HYDRO
THE POWER OF COMMITMENT

THE Lower Churchill PROJECT

April 2008

DC1010 - Voltage and Conductor Optimization

prepared by

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in association with

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Introduction

The objective of WTO DC1010 was to determine the optimum operating voltage and conductor size for the HVdc overhead lines from a converter station at Gull Island in Labrador, to Converter Stations at Soldiers Pond in Newfoundland and Salisbury in New Brunswick. This Final Report discusses the methodology and results of WTO DC1010 and incorporates the Hydro comments and suggestions on the February 5, 2008 Draft Report.

Basic System Parameters

Two transmission scenarios were evaluated to determine if there would be any impact on the selection of voltage and conductors:

- Scenario 1 — 800 MW transmission from Gull Island
  800 MW to Soldiers Pond
- Scenario 2 — 1,600 MW transmission from Gull Island
  800 MW to Soldiers Pond
  800 MW to Salisbury

In monopolar operation, each converter station pole and its associated overhead line conductors and submarine cables between Gull Island and Soldiers Pond must be capable of transmitting 200% (800 MW) of single pole power for 10-minutes, and 150% (600 MW) of single pole power continuously. These criteria are not required for the Salisbury HVdc converter station, or for the submarine cables between Newfoundland and New Brunswick.

The HVdc transmission system will be a single, bi-directional bipole (multi-terminal for Scenario 2) with the following sections of overhead (O/H) line and submarine cables (see Figure 1-1):

- Gull Island to Strait of Belle Isle (O/H) — 407 km
- Strait of Belle Isle Crossing Submarine cable — 30 km
- Strait of Belle Isle to Taylor's Brook (O/H) — 238 km
- Taylor's Brook to Soldiers Pond (O/H) — 450 km
- Taylor's Brook to Cape Ray (O/H) — 288 km
- Cabot Strait Crossing Submarine cable — 480 km
- New Brunswick coast to Salisbury (O/H) — 100 km

Technologies and HVdc Operating Voltage

HVdc Converter Stations and overhead transmission lines, operating at voltages of ±400, ±450 and ±500 kVdc, are well-proven technologies, and HVdc transmission systems have been in service, worldwide, for more than 40-years. A number of manufacturers and contractors would be pre-qualified to bid on the HVdc Converter Stations and on the HVdc overhead lines.

However, if ±400 kVdc is chosen for Scenario 2, an operating restriction may be required for the Salisbury Converter Station to permit the 100% overload at Soldiers Pond while limiting the Gull Island converter current to 3 000 A.

Self Contained Oil Filled (SCOF) submarine cables could be used at ±400, ±450, or ±500 kVdc for the Strait of Belle Isle crossing, but are limited by oil-pumping requirements to maximum route lengths of approximately 50 km. Therefore, SCOF cable could not be used for the Cabot Strait crossing. Also, although the insulating oil has a low viscosity and would evaporate from the surface of the sea, the possibility of long-term oil discharge while waiting for cable repairs may cause environmental concerns.

Mass Impregnated (MI) submarine cables could be used at ±400, ±450, or ±500 kVdc for both the Strait of Belle Isle crossing and the Cabot Strait crossing.

From a technical viewpoint the review it was concluded that:

1,600 MW could be efficiently transmitted from Gull Island to Soldiers Pond and to Salisbury at ±400, ±450 or ±500 kVdc.

Overhead Transmission Lines

The HVdc overhead line will pass through regions of extreme icing, so it would be an advantage if a single conductor per pole is used in place of a twin bundle conductor.

For the LCP project, the limiting corona and field effect parameter in the selection of conductor configuration is the recommended maximum Radio Interference Level of 65 dB (at 1 MHz) at the edge of the Right-of-Way (ROW). (Note: Similar values have been recommended for the HVac transmission systems associated with the Gull Island Project.)

Conductor manufacturers have advised that the largest conductor that has been commercially installed had a diameter of 58.7 mm.

The corona analysis showed that a single, 58 mm diameter conductor per pole could be used for ±450 kVdc and ±400 kVdc.

The analysis showed that for ±500 kVdc, a 70 mm diameter conductor would be required for a single conductor configuration (beyond manufacturing capabilities) and therefore a twin conductor configuration would be required. The minimum conductor diameter would be 39.5 mm, although this would not be the optimal conductor, as is discussed later.

Generic tower designs were used to estimate the tower weights (and costs) for each operating voltage, with a range of conductors that would meet meteorological loading and corona requirements. The analysis showed that tower weights would be most affected by the Rated Tensile Strength of the conductors, which determines the sag and therefore the tower height and spans, not the HVdc operating voltage nor the size of the conductor.

A comparison of total transmission line costs, based on the preliminary tower designs, is given below for the optimal conductor configuration for each operating voltage. The total costs include the construction cost plus the present values of the costs of transmission losses for the different conductor configurations, but exclude operation and maintenance which would be the same for each voltage and conductor option.

		Total Comparative Cost Estimates For Overhead Transmission Lines ($Million)		
		±400 kVdc	±450 kVdc	±500 kVdc
Scenario 1	Conductor	(Single 50.4 mm)	(Single 58.0 mm)	(Twin 41.9 mm)
	Total Cost	$861	$897	$988
	Diffferential	Least Cost	$35	$126
			4%	15%
Scenario 2	Conductor	(Single 51.4 mm)	(Single 58.0 mm)	(Twin 41.9 mm)
	Total Cost	$1,298	$1,297	$1,414
	Diffferential	$1	Least cost	$117
		0%		9%

A detailed estimate of the HVdc transmission line costs in their final configuration can be found in the Final Report on WTO DC1200 "HVdc Overland Transmission Re-estimate".

Costs for HVdc Converter Stations and Submarine Cables

The analysis showed that when the supply costs for the converter stations and submarine cables are added to the overhead line transmission costs, the choice of optimal operating voltage and conductor configuration is unchanged, but the overall differences in costs between the different options are reduced.

As an example, when considering only the overhead lines for Scenario 2, the ±450 kVdc option is 10% less than the ±500 kVdc option. When the costs of supply of the converter stations and submarine cables are included, this cost difference is reduced to 5%.

Conclusions and Recommendations

The least cost options for the HVdc overhead lines at the three operating voltages would be:

Scenario 1

- ±400 kVdc Single, 50.4 mm diameter conductor.
- ±450 kVdc Single, 58.0 mm diameter conductor.
- ±500 kVdc Twin, 41.9 mm diameter conductor.

Scenario 2

- ±400 kVdc Single, 51.4 mm diameter conductor.
- ±450 kVdc Single, 58.0 mm diameter conductor.
- ±500 kVdc Twin, 41.9 mm diameter conductor.

The differences in estimated costs are less than the level of accuracy of the WTO DC1010 comparative cost estimates so it is concluded that, if the Lower Churchill Project were staged with Scenario 2 to Salisbury constructed some time after Scenario 1 to Soldiers Pond, there would be no significant difference in the comparative cost estimates whichever operating voltage is selected for Scenario 1.

If there is a reasonable probability that Scenario 2 will proceed, the Gull Island Converter Station and the Strait of Belle Isle submarine cables should be installed with the full 1,600 MW rated capacity during Scenario 1 construction, and the Taylor's Brook switching station should be constructed with isolation capabilities to minimize power disruptions to Soldiers Pond when the line to Cape Ray is constructed and commissioned.

Operating at ±400 kVdc or ±450 kVdc gives the option of using a single conductor per pole, which would be beneficial in regions of heavy ice loads. This single conductor per pole option is not possible for ±500 kVdc because of corona limitations.

Although there would be a relatively small difference between the total project costs for the three operating voltages, within the accuracy limits of the comparative cost estimates, the least cost option for the HVdc overhead lines would be:

- Scenario 1 ±400 kVdc with a single, 50.4 mm diameter conductor.
- Scenario 2 ±450 kVdc with a single, 58.0 mm diameter conductor.

However, because each operating voltage is technically acceptable, and there is a small comparative cost difference between the three operating voltages, it may be beneficial to retain all three voltage options to maximize the competition in the tendering phase.

1. Introduction

1.1 Background and Purpose

Newfoundland and Labrador Hydro (Hydro) is undertaking preliminary engineering studies of the development of the hydroelectric potential of the Lower Churchill River at Gull Island and Muskrat Falls. These sites are located downstream 225 km and 285 km respectively from the Upper Churchill hydroelectric facility that was developed in the early 1970's. The total potential capacity at the two sites is approximately 2,800 megawatts (MW), the Gull Island site being the larger at 2,000 MW.

In addition to the development of these sites, the overall concept includes various potential alternative power transmission arrangements involving combinations of HVac and HVdc lines of various capacities.

In April 2007, NLH contracted Hatch Ltd of St. John's to undertake a program of studies to address aspects of this development, relating primarily but not exclusively, to hydrology/hydraulics and transmission components. Approximately thirty such studies have been carried out by Hatch and its associated sub-consultants, RSW of Montreal, Statnett of Oslo, and TransGrid Solutions of Winnipeg. The program has been managed from Hatch's office in St. John's using the company's project management tools and a project services team that has liaised throughout with a similar group in Hydro.

The Lower Churchill Project (LCP) transmission system will comprise double circuit 230 kVac lines, single circuit 735 kV lines, and bipolar HVdc lines (Figure 1-1).

The HVdc line will connect the Gull Island Converter Station to those at Soldiers Pond and Salisbury, and the objectives of WTO DC1010, "Voltage and Conductor Optimization" are

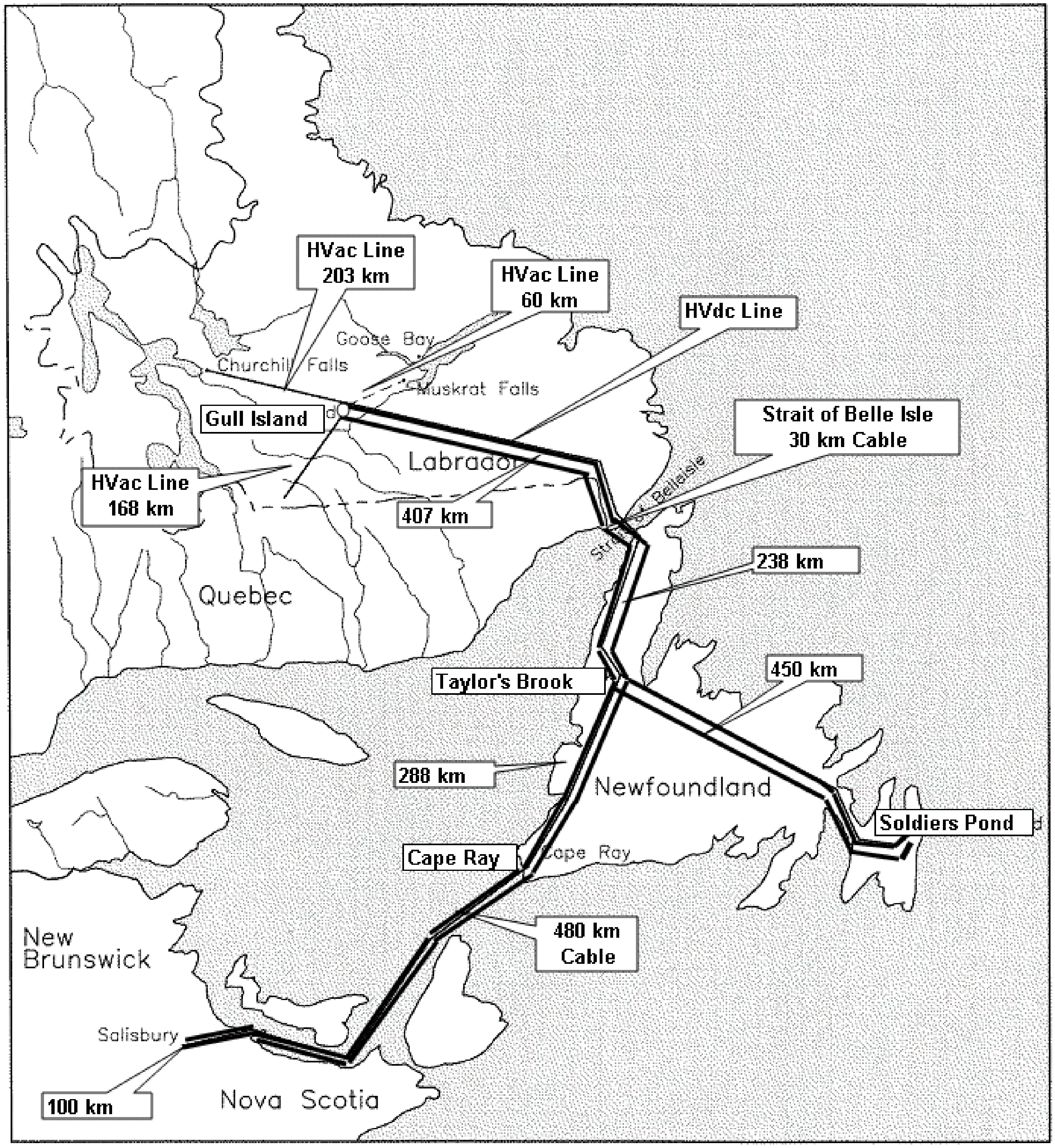
- to recommend the preferred HVdc operating voltage; and
- to recommend the optimal HVdc conductor(s) for overhead lines.

1.2 Interrelation with other Work Tasks

This task was carried out in conjunction with the following work tasks within the LC project:

- System Integration (WTO DC1020)
- Meteorological Load Review (WTO DC1070)
- Electrode Review (WTO DC1110)
- Submarine Cables (WTO's DC 1130 and DC1140)
- Assess Cable De-icing (WTO AC1090)

Figure 1-1
Lower Churchill Project Transmission Systems
(New Brunswick Option Shown)



2. Approach to the Work

2.1 Overview

Two, separate, transmission scenarios were evaluated to determine if there would be any impact on the selection of optimal HVdc voltage and conductor configuration:

- Scenario 1 — 800 MW transmission from Gull Island
  800 MW to Soldiers Pond
- Scenario 2 — 1,600 MW transmission from Gull Island
  800 MW to Soldiers Pond
  800 MW to Salisbury

Hydro has defined the measured points of power delivery to be the Soldiers Pond and Salisbury Converter stations. Therefore, the output from the Gull Island Converter Station will be the DC power delivered to Soldiers Pond and to Salisbury plus the HVdc transmission losses

The existing thermal generation at Holyrood will be retired and, without the HVdc link, there may be insufficient spinning reserve in the NLH system to allow for the loss of one pole's transmission capability (400 MW). Therefore, in monopolar operation each pole and its associated conductors and submarine cables between Gull Island and Soldiers Pond must be capable of transmitting 200% of single pole power (800 MW) for 10-minutes, and 150% of single pole power (600 MW) continuously. The Salisbury HVdc Converter Station poles will have a 10% overload capacity (440 MW).

The HVdc link is required to be capable of power flow in any direction. Therefore, the Soldiers Pond and Salisbury Converter Stations, although normally operating as Inverters, will also be capable of Rectifier operation, rated at 800 MW.

The HVdc transmission system will comprise a single bipole line with the following sections of overhead line and submarine cables (see Figure 1-1):

- Gull Island to Strait of Belle Isle (O/H) — 407 km
- Strait of Belle Isle Crossing Submarine cable — 30 km
- Strait of Belle Isle to Taylor's Brook (O/H) — 238 km
- Taylor's Brook to Soldiers Pond (O/H) — 450 km
- Taylor's Brook to Cape Ray (O/H) — 288 km
- Cabot Strait Crossing Submarine cable — 480 km
- New Brunswick coast to Salisbury (O/H) — 100 km

2.2 Selection of Optimal HVDC Operating Voltage

The principal study activities related to selection of HVdc operating voltage were:

- Development of a list of HVdc projects, worldwide operating at 400, 450 and 500 kVdc, that have similar characteristics to the proposed LCP transmission system.
- Review of the impact of operating voltages on:
  - Conductor configuration and tower design, based on corona levels
  - Impacts of submarine cable designs for the Strait of Belle Isle and Cabot Strait crossings
  - Impacts of HVdc Converter Station designs at Gull Island, Soldiers Pond and Salisbury

(Note: The submarine cables and Converter Stations are not a part of WTO DC1010, except where they may have an impact on the selection of operating voltage and the total project costs. Therefore, only a brief overview is included on the choice of submarine cables and converter stations).

2.3 Selection of Optimal Overhead Line Conductor(s)

The principal study activities related to selection of HVdc Overhead Line Conductors were:

- Definition of the main evaluation parameters and criteria
- Calculation of the present value of cost of losses for each conductor, at each operating voltage
- Calculation of transmission line costs for each conductor configuration at each operating voltage
- Recommendations for conductor type(s)
- Review of impacts of installing overhead electrode lines for ground return in monopolar operation (interaction with WTO DC1110)

This Final Report incorporates the Hydro comments and suggestions on the February 5, 2008 Draft Report.

3. Details of the Work/Analysis

3.1 Selection of Optimal HVdc Transmission Voltage

The LCP HVdc transmission project will include:

- Overhead HVdc transmission lines
- Submarine cables for the Strait of Belle Isle and Cabot Strait Crossings
- HVdc Converter Stations at Gull Island, Soldiers Pond and Salisbury

There will be a total of 1,083 km of HVdc overhead lines between Gull Island, and Soldiers Pond for Scenario 1, with an additional 400 km of HVdc overhead lines from Taylor's Brook to Salisbury for Scenario 2, so the selection of the optimal operating voltage and conductor configuration will have a significant impact on the total project costs.

The selection of submarine cable parameters is considered in detail in WTO DC1130 and WTO DC1140. Except for a brief overview of the technology, the review of submarine cables is limited to the impact of operating voltage on the comparative total cost estimates (including costs of losses, but excluding costs of installation and burial).

The review of converter stations is limited to the impact of operating voltage on the comparative cost estimates.

The main study activities for the evaluation of ±400, ±450 and ±500 kVdc transmission systems are described below.

3.1.1 List of HVDC Projects, World-Wide Operating at 400, 450 and 500 kV

The principal source of data listing the operating and planned HVdc systems is a 2006 IEEE Report[1]. This is reproduced as Table B-1 in Appendix B.

Table 3-1 extracts from Table B-1 a total of thirty projects with operating voltages between 400 kV and 500 kV that are in service or under construction. This includes a number of projects with submarine cables or a combination of overhead line and submarine cables. Two ±500 kVdc projects using submarine cables are planned, Sardinia to Italy (under construction) and Finland to Sweden (under tendering process).

Table 3-2 lists HVdc overhead line projects with similar power transmission levels and line lengths to the LCP project.

Table 3-3 lists submarine cable projects that are in operation, under construction or in the design phase, with operating voltages between 400 kVdc and 500 kVdc.

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[1] Prepared by the Working Group on HVdc and FACTS Bibliography and Records

The review of the information on existing and planned HVdc operating systems showed that 1,600 MW could be efficiently transmitted from Gull Island to Soldiers Pond and to Salisbury at ±400 kVdc, ±450 kVdc or ±500 kVdc.

3.1.2 *Impacts of System Voltage on Overhead Line Tower Design*

The selection of transmission voltage will have an impact on tower design, conductor selection (voltage drop and power losses) and corona (audible noise, radio interference, field effects and corona losses).

Usually, the HVdc pole conductors are designed to limit corona effects and voltage drop, rather than for thermal considerations. This is evidenced by the Pacific Intertie project for which the conductor current increased from 900 A in 1970 to 1 550 A in 1989, using the same twin, 45.8 mm ACSR, conductor configuration.

Preliminary tower geometry (based on insulation clearances) was used to determine the special conductor configuration and to calculate the minimum conductor diameter that would be required to give acceptable corona levels at ±400 kVdc, ±450 kVdc and ±500 kVdc.

The following sections provide a definition of corona effects and a review of the principal differences between corona and field effects for HVac and HVdc overhead transmission lines.

3.1.2.1 *Description of Corona and Other Field Effects*

<u>Corona</u>

Corona is observed as a faint glow, by audible noise and by radio interference, and is the result of electrical discharges caused when the electric field intensities at the conductor or insulator exceed the electrical breakdown withstand capacity of the air.

The calculations of the impacts of corona are based on the determination of "conductor surface gradient" at the transmission conductor, which in turn is determined by operating voltage and the tower and conductor geometries.

<u>Conductor Surface Gradient</u>

The conductor surface gradient is defined as the electric field at the surface of a transmission line conductor and is usually calculated on the assumption that the conductor is smooth. The calculations assume that, for a single conductor, the gradient is determined by the outside diameter of the stranded conductor and, for a bundled conductor configuration, the gradient is determined by the *"equivalent overall diameter"* of the bundle.

Maximum or average maximum gradients are used for bundled conductors, but for most practical cases, the difference is relatively small so the "*average maximum gradient*" is used. This is the average for all conductors in a bundle, rather than the largest value of any conductor in the bundle.

For a bipolar transmission line, the voltage gradient is affected by the following design parameters:

- Voltage
- Pole spacing
- Mean conductor height

- Sub-conductor diameter
- Number and spacing of conductors in a multi-conductor bundle

Differences Between HVac and HVdc Corona

The following main parameters are considered in the design of HVac and HVdc transmission lines:

- Audible Noise
- Radio Interference
- Corona Losses
- Field Effects

The basic nature of corona for HVac and HVdc transmission lines is the same, but there are substantial differences in the measured responses under different ambient conditions. These differences are summarized below.

Parameters	HVac	HVdc
Polarity	Not applicable	Only Positive pole is considered
Audible Noise	Worse in Wet weather	Worse in Fair weather
Radio Interference	Worse in Wet weather	Worse in Fair weather
Losses	Worse in Wet weather	Worse in Fair weather
Field Effects	No Effect	Changes with weather

Audible Noise

For HVdc, the negative pole generates little or no audible noise, so calculations are usually made for the positive pole only.

In contrast to HVac, the worst case conditions occur during fair-weather in the summer when the presence of insects "glued" to the conductors causes surface irregularities which increases the conductor surface gradients and the levels of audible noise . Conductor surface gradients, (hence the audible noise) are reduced during wet weather because rain washes the insects off the conductors, thereby reducing the surface irregularities. The transition period between fair and foul weather conditions, when rain first begins to wash-off the pollution, may also be of concern.

Audible noise from HVdc transmission lines is often barely distinguishable from general industrial noise background, and is difficult to measure under such ambient conditions. However, it has been observed that HVdc lines have maximum generated audible noise in fine weather when people would be outdoors, whereas HVac lines generate maximum audible noise during wet weather when the people are less likely to be outdoors, and when the sound of the rain masks, to some extent, the generated audible noise.

Studies[2] show that HVac and HVdc audible noise causes the same level of annoyance at 50 dBA[3], but above that level, HVdc is perceived to be more annoying.

Operating experience with HVdc lines indicates that audible noise from transmission line insulators is not of significant concern, so only the noise generation from the conductors is considered in this study.

The Audible Noise level is usually specified at the edge of the Right-of-Way (ROW) and, because of the variability of audible noise with ambient conditions, it is usually specified by a median value, and "L_{50}", is the specified value that would be exceeded 50% of the time.

Since audible noise is worse during fair weather conditions, common practice is to use "$L_{50\text{-fair}}$" for the evaluation criteria for an HVdc transmission line configuration.

The literature[4] indicates that most operating HVdc transmission lines produce less than 50 dBA outside the ROW so, for the LCP transmission line study, it is recommended that the

$L_{50\text{-fair}}$ at the edge of the ROW should be limited to 50 dBA.

Radio Interference (RI)

For HVdc, the negative pole is assumed to generate little or no radio interference, so calculations are made for the positive pole only.

RI is usually measured as a signal to noise ratio (S/N) given in dB above 1micro-volt/metre, and in this study it was calculated at 1 MHz.

Originally, RI limits were considered mainly because of the impact on AM broadcast frequencies, and there is now some discussion that the specified limits should be changed because of the change to FM or digital broadcasts. However, in this study, the existing evaluation criteria were retained.

The highest levels of conductor surface gradients, and hence RI, are experienced during fair weather, and may increase with increasing temperature and decrease with increasing humidity.

RI also decreases with decreasing relative air density, so RI decreases with altitude.

RI levels decrease with increasing earth resistivities, and there would typically be a change of –2dB if the earth resistivity increases from 100 ohm-metres to 1 000 ohm-metres[5].

RI from the line insulators is greatest during wet weather (in contrast to the conductor generated RI) but is considered to be negligible in comparison with conductor-generated RI, and was not included in the calculations.

Although research has shown that higher levels of RI are acceptable for HVdc transmission, the International Special Committee on Radio Interference recommends that new HVdc transmission lines should be evaluated with the same RI levels as HVac transmission[6].

[2] EPRI HVdc Transmission Line Reference Book (page 3-43)
[3] dBA is the audible noise level above 1 Watt/metre, measured with a logarithmic scale
[4] EPRI HVdc Transmission Line Reference Book
[5] EPRI HVdc Transmission Line Reference Book (Figure 3-49)
[6] EPRI HVdc Transmission Line Reference Book (page 3-69)

For HVac transmission systems, the CSA Standard CAN3-C108.3.1-M84 specifies a maximum RI level of 49 dB at 15 metres from the outer phase conductor for fair-weather conditions. Taking into account that RI for HVac lines increases by approximately 20 dB in foul-weather conditions, this would give a target level of 69dB for an HVac line in foul- weather conditions.

Therefore, applying equivalent HVac limits to an HVdc transmission lines, it is recommended that the fair weather RI at the edge of the ROW should be limited to 65dB.

(Note: The same RI level has been recommended for the HVac lines associated with the Gull Island Project.)

<u>Corona Losses</u>

HVdc corona losses are much higher during fair weather than foul weather, and increase during transition between the two. However, corona losses are a small fraction of the conductor full-load resistive losses, and would only play a significant role in tower geometry and conductor selection if the transmission system were operated normally in “hot-standby” mode, transmitting little or no power for most of the time.

Since the LCP transmission lines will normally be transmitting close to rated power, the corona losses will be a negligible component of the total losses and are not included in the overall loss calculation.

<u>Field Effects</u>

The electric field effects at ground level have different properties for HVdc than for HVac overhead transmission lines.

One important difference is that HVdc fields depend on climatic conditions, whereas HVac fields depend only on tower/conductor configuration and voltage.

HVdc fields have the same polarity as the nearest conductor but, in contrast to HVac fields, depend on aerosol movement through space by climatic conditions, particularly wind, after the space charges have been released by corona at the conductor surfaces. HVdc generates “air-ions” which collide with neutral air molecules as they are moved through space, and by transfer of charge may produce concentrations of charges that are higher than background levels. This movement of space charges means that the electric field at ground level may be much higher than they would be if the space charges were confined to the conductor. Because of this, the electric field from HVdc overhead conductors may be significantly higher than those produced by HVac systems with the same operating voltage.

HVdc fields may vary slowly with time as the space charges are moved by winds, for example. Therefore, HVdc electric fields can only be described in broad, statistical terms, such as values that may be exceeded 5% or 50% of the time, as is the case for Audible Noise.

HVdc overhead lines generate unidirectional magnetic fields, which are less than the values of the earth’s magnetic field and therefore have no safety or biological effects.

From considerations of nuisance and safety, the most significant difference between HVdc and HVac fields is that HVdc cannot induce currents in conductive objects such as metallic skins of vehicles, or animal and plant tissues. HVac can generate induced currents, which has raised concerns about the biological impacts of small AC current densities in human, animal and plant tissues. This is not a concern for HVdc overhead lines.

Overall, electric fields generated by overhead HVdc transmission lines are less than many other typically occurring electric fields. For example the electric field due to static charge at a typical viewing distance in front of a television set is 5 kV/cm, which is significantly less than the design values used in this study for the electric field at the edge of the HVdc transmission line ROW.

Electric Power Research Institute (EPRI) tests[7] have shown that voltages and currents induced on vehicles near HVdc transmission lines are of practically negligible concern, that there is very low probability of gasoline ignition from an overhead HVdc line, and that such probabilities are much less than for an equivalent HVac line.[8]

3.1.2.2 Insulation Clearances

The aspects of insulation clearances considered were *Insulator Lengths* and *Clearances* (to tower and to ground).

The LCP line will have significant design differences to other HVdc schemes in North America because of the ice and wind loading criteria.

Previous LCP study reports have classified the HVdc line route into regions of different contamination levels, especially from salt pollution where the line passes close to the coast with onshore winds.

In WTO DC1010 studies, an average leakage distance of 26.7 mm/kV was used to determine the numbers and lengths of the insulator strings for a typical tower. Suspension “I-type” insulators were used in the preliminary tower designs. Detailed considerations of insulation requirements are reviewed in WTO DC1080 (Tower Type Selection).

3.1.2.3 Tower Design Criteria

As noted above, detailed tower design is a part of WTO DC1080 that will detail the complete tower family for the HVdc line.

For the WTO DC1010 study, the conductors were selected with the minimum conductor diameter required to satisfy corona and field effect limits, and with similar tensile strengths (nominally 400 kN) to withstand ice/wind loadings.

Preliminary tower clearances were based on the required insulator leakage distances and line to ground clearances given in CSA guidelines (ref. CSA document C22.3 Tables 3 and 4). The calculations also assumed that there would be 0.9 m of snow under the conductors in the ROW.

Table 3-5 compares the clearances defined for the LCP HVdc lines with those of North American HVdc transmission lines operating at the same voltages.

Sketches of the tower geometries used in the field effect calculations for ±400, ±450 and ±500 kVdc are shown in Figures 3-1 through 3-3.

[7] The referenced EPRI report was produced by the High Voltage Transmission Centre at Lenox, Massachusetts
[8] EPRI HVdc Transmission Line Reference Book (page 4-164)

Sketches of typical HVdc tower configurations used for estimating tower weights and costs are shown in Figure 3-4.

The preliminary analyses showed that the tower weights (hence costs) were more affected by the rated tensile strength of the conductors than by any other parameter, including different operating voltage clearances or conductor sizes.

The HVdc transmission line will pass through many different climatic loading zones with radial ice loadings varying from 45 mm to more than 150 mm, and reference-winds exceeding 200 km/hour.

For the tower analyses, the conductor sag and tension were determined by maximum ice loadings, whereas tower designs and weights were determined by combined ice and wind loadings. Median loading conditions were selected from the MRI loading tables given in the 1999 Teshmont report, including:

- 110 mm of radial ice
- 100 mm of rime ice with 125 km/hour winds

The following transmission parameters were used in the preliminary tower designs:

- Ruling Span 300 m
- Wind span 330 m
- Weight span 380 m

Sag / tension criteria aims to limit cable tension under various conditions. Under non-loaded conditions at -5° C, the initial tension (before creep) is limited to a tension (weight per metre) value of 2200 m, with vibration dampers installed. The maximum tension is limited to 75% of the cable's rated tensile strength under maximum loads.

Overhead wires and optical ground wires (OPGW) protect the pole conductors from lightning strikes, with a protection angle of 30°. The overhead wires and OPGW must maintain their angle of protection over the full span under normal conditions and must not encroach upon the pole conductors under adverse conditions that could cause flashover. Typical sag/tension calculations are included in Appendix E, and these calculations will be further refined during the detailed tower design phase where the coordination of sag and tensions between the various cables is optimized.

The following tower family was assumed:

- 0° – 2° Tangent (guyed-suspension)
- 0° – 10° Angle (guyed-suspension)
- 0° – 60° Angle (self-supporting: tension)
- 0° – 90° Angle and Terminal (self-supporting: tension)
- Anti-cascade Self-supporting: tension

Typical tower configurations are shown in Figure 3-4.

The comparative capital cost estimates for the transmission lines use 2007 supply and installation costs and include all main elements, as appropriate, such as towers, foundations, guys and anchors, insulators and hardware, conductors, OPGW, electrode line conductors and grounding. Typical calculation charts are included in Appendix D.

3.1.2.4 Calculation of Corona and Field Effects

Comparative methods of calculation use theoretical and empirical formulae to compare the geometry of a proposed new line with a reference line for which measured data is available.

The EPRI HVdc report[9] presents "base-case" transmission line geometries for a number of HVdc transmission line voltages, and then gives a number of empirical formulae and graphs showing the impacts of changing conductor parameters and tower geometries. These calculation methods were applied to the LCP HVdc transmission lines to determine the audible noise, radio interference and field strengths of different tower and conductor configurations.

Based on the HVdc system design parameters given in Table 3-6, a number of conductors were selected (from Table D.9 in CSA/40) which had sufficient mechanical strength to meet the ice/wind loading conditions (nominal tensile strength of 400 kN). Each of these conductors was evaluated to see if it would satisfy the minimum corona requirements.

Table 3-7 gives the formulae and sample results for the LCP HVdc transmission systems, and compares these with calculated results for some North American HVdc systems operating at similar voltages.

±500 kVdc

Table 3-8 summarizes the calculated corona and field effect parameters for different conductor configurations, and compares these values with calculated values for a typical, 500 kVdc North American transmission line, namely the BPA system in California.

The limiting factor for the LCP ±500 kVdc line will be the 65 dB Radio Interference limit. A single conductor per pole is not permissible at ±500 kV because the analysis showed that a minimum conductor diameter of 70 mm would be required and the existing manufacturing capability is limited to conductors with a maximum conductor diameter of 58.7 mm. (The 70 mm diameter single conductor is included in Table 3-8 as a "fictitious conductor".)

The minimum conductor diameter for a twin conductor bundle is 39.5 mm.

Table 3-8 shows that the calculated corona and field effects for the twin, 41.9 mm diameter conductor configuration are similar to those calculated for the existing BPA 45.8 mm diameter twin conductor configuration.

±450 kVdc

Table 3-9 summarizes the calculated corona and field effect parameters for different conductor configurations, and compares these values with calculated values for the Nelson River Bipole in Manitoba, which was originally designed and operated at ±450 kVdc.

[9] EPRI HVdc Transmission Line Reference Book (pages 3-67-3-60)

The limiting corona factor for the LCP ±450 kVdc line option will be the 65 dB Radio Interference limit, which determines that the minimum a single conductor diameter required would be 58 mm. All twin conductor bundles give acceptable performance.

Table 3-9 shows that the calculated corona and field effects for the 58 mm diameter single conductor configuration, although within the specified maximum limits, are higher than those calculated for the Nelson River twin, 40.6 mm diameter conductor configuration. However, the Nelson River Bipoles are now being operated at ±500 kVdc, with the same tower and conductor configurations, and (Table 3-7 shows that the calculated Audible Noise and Radio Interference levels at ±500 kVdc are almost identical with those for the LCP single, 58 mm conductor configuration at ±450 kVdc.

±400 kVdc

Table 3-10 summarizes the calculated corona and field effect parameters for different conductor configurations, and compares these values with calculated values for the ±400 kVdc Coal Creek line in North Dakota.

At ±400 kVdc, neither Audible Noise nor the Radio Interference levels are close to the recommended limits, so a single conductor per pole could be used, and all twin conductor configurations also give acceptable corona performance.

Acceptable Conductor Configurations

Table 3-11 lists the conductor configurations which satisfy the Corona, Field Effects and Mechanical Strength requirements of the LCP HVdc transmission line.

3.1.2.5 Electrode Line Conductors

WTO DC1110 "Electrode Review" studies show that the installation of sea electrodes would be an environmentally acceptable, less expensive alternative to installing a metallic return along the whole HVdc overhead transmission line. Electrode line conductors will therefore be required between the Gull Island converter station and the sea electrode location (assumed for purposes of this report to be in the Strait of Belle Isle).Electrode line conductors will not be installed from the Newfoundland side of the SOBI to Taylor's Brook, nor from Taylor's Brook to Soldiers Pond, nor from Taylor's Brook to Cape Ray.

Electrode Line Current Ratings

The electrode lines must carry unbalance currents between the two poles during normal, bipole operation, but these long-term unbalance currents will be relatively small and will not determine the electrode line current rating. The electrode lines must also carry monopolar current for:

- Loss of converter station pole equipment (e.g. converter transformer)
- Loss of one pole conductor

Loss of converter station pole equipment would not, necessarily, require current flow in the electrode line because the pole conductor from the faulted converter pole could itself be used as a metallic return. However, in Scenario 2 operation, the HVdc system between Gull Island, Soldiers Pond and Salisbury will be multi-terminal, so if one converter pole equipment is lost (say the positive pole at Soldiers Pond) then the other two positive poles at Gull Island and at Salisbury must also be switched out to permit the positive pole conductor to be used as a metallic return for the negative pole. This would be a restrictive operating mode so it is probable that the electrode lines will be required for loss of converter pole equipment in Scenario 2 multi-terminal operation.

Loss of one pole conductor would require the electrode line to carry full monopole overload current because the station electrodes at Gull Island and at Salisbury will not be capable of carrying long-term monopole currents.

During monopolar overload operation (600 MW) to Soldiers Pond and 440 MW to Salisbury (Scenario 2), the maximum Gull Island to SOBI electrode line currents will be:

Gull Island to SOBI Electrode Line Currents (A)

	400 kV	450 kV	500 kV
Scenario 1	1,500	1,333	1,200
Scenario 2	2,600	2,311	2,080

The bipole cannot operate without the electrode line because the station electrodes at Gull Island and at Salisbury will not be capable of carrying long-term current unbalances during bipole operation. Therefore, the electrode line conductors should be duplicated to insure that loss of a single conductor during normal operation (n-1 contingency) would not cause a bipole shutdown.

Each of the two electrode line conductors would be rated for half the pole overload current and would be sized accordingly. Tables C-6 and C-7 (Appendix C) give the cost estimates for twin and single conductors on a separate electrode line. The additional cost for two electrode line conductors (compared with a single conductor) is estimated to be $ per km, so the two conductor option would cost million more for the 407 km line between Gull Island and the SOBI sea electrode.

Electrode Line Contingencies

During normal bipolar operation, if one of the two electrode line conductors were lost, the remaining conductor would be able to carry the small bipole unbalance currents that exist during normal, bipole operation.

If one of the two electrode lines is lost when the system is in monopolar operation, the power transmission would be limited by the current carrying capability of the remaining electrode line conductor which would, in turn, depend on ambient temperature conditions. If each of the two electrode line conductors is rated at half the monopolar overload capacity, the maximum monopolar power transfer would be reduced to 50%, but this would be an acceptable limitation for this n-2 contingency.

The preliminary selection for electrode line conductors is an 800-A2/S3-54/19 ACSR conductor that has an overall diameter of 41.9 mm, a rated tensile strength (RTS) of 445 kN and a DC resistance of 0.03615 ohms/km. This RTS is greater than, or equal to, that of most of the pole conductors so that the sag of the electrode line conductor will be less than that of the pole conductors, to maintain clearances, if the electrode line conductors are installed on the HVdc line towers.

Location of Electrode Line Conductors

The electrode line conductors from the Gull Island converter station to the sea electrode could be installed on the HVdc line towers (Option-A) or on separate, low voltage (25 kV) towers (Option-B).

Comparative cost estimates were made for these two options (Tables C-4 through C-6) and the results are summarized below.

COMPARISON OF ELECTRODE LINE OPTIONS FOR SOBI SEA ELECTRODES		
Construction Option	**Construction Costs per km ($million)**	**Construction Cost for 407 km Line ($million)**
Option-A. Gull Island to SOBI With Two Electrode Lines on the ±450 kVdc Towers		
HVdc Towers With 2-Electrode Conductors & Optical Fibre	$	**$**
Option-B. Gull Island to SOBI With Separate Electrode Line		
HVdc Towers With Single OPGW	$	**$**
Separate LV Electrode Line With 2-Electrode Conductors	$	**$**
Total Cost for Option-B		**$**
Cost Benefit for Option-A		**$93**

The analysis shows that a separate electrode line (Option B) would cost an additional $93 million, would also require a considerably larger ROW for the separate electrode line and HVdc line, and would have increased maintenance costs.

Therefore, it was assumed that the electrode line conductors between Gull Island and the SOBI marine electrode would be mounted on the HVdc towers.

The recommended electrodes configuration can be found in the Final Report on WTO DC1110 “Electrode Review”.

Optical Ground Wires

An optical fibre link, for primary control and protection signalling, would be installed on the HVdc towers for all sections of the HVdc transmission line. The preliminary tower designs assume that optical fibre would be installed in one of the electrode line conductors for the section between Gull Island and the SOBI electrode, and that an OPGW will be installed on the HVdc lines from SOBI to Taylor’s Brook, and to Soldiers Pond and to Cape Ray. The recommended configuration can be found in the Final Report on WTO DC1080 “Tower Type Selection”.

3.1.2.6 Preliminary Tower Designs

Preliminary tower designs were prepared for the overhead lines, based on the minimum conductor configurations that meet the specified mechanical strength and corona conditions. The conductors are listed in Table 3-11.

The tower designs were most affected by the strength of the pole conductors, the overhead shield wires and the electrode lines, that must withstand the ice and wind loads. Higher strength cables will have reduced sag, which will increases the tower spans and reduces the total cost for the alignment towers. However, stronger conductors result in higher tensions, which will increase the loads on angle towers and increases their costs.

With these assumptions, generic designs were developed for the overhead transmission lines for the three operating voltages (see Figure 3-4).

The optimization of the tower parameters is treated in WTO DC1080 "Tower Type Selection".

3.1.3 Selection of Optimal Conductors at Each Operating Voltage

3.1.3.1 System Design Parameters

As noted earlier, Hydro has specified that the measured points of power delivery will be the Soldiers Pond and Salisbury Converter Stations. Therefore, the HVdc power transmitted from the Gull Island Converter Station will be the rated power at Soldiers Pond and Salisbury, plus the HVdc transmission losses. Table 3-4 gives the pole conductor ratings for full load and monopolar overload operation.

3.1.3.2 Main Evaluation Parameters and Criteria

Hydro provided the nominal values of the parameters to be used in calculating and comparing the costs of losses for the different overhead line conductor configurations. These are given below.

- Cost of Losses — 6.5 ¢/kWh
- Load factor (LF) — 0.6
- Loss factor[10] ($= 0.15 \times LF + 0.85 \times LF^2$) — 0.4
- Discount rate — 8%
- Operating life — 50 years

[10] Formula provided by Hydro

Each voltage/conductor configuration was analyzed, based on the above parameters, and sensitivity analyses were carried out with load factors of 0.6 through 0.8, and with discount rates between 4% and 10%.

3.1.3.3 Preliminary List of Conductors

The conductors listed in Table 3-11 meet the corona and tensile strength requirements, for the HVdc overhead lines.

3.1.3.4 Costs of Losses

Table 3-12 gives the Annual Cost of Losses, for each conductor at the different operating voltages, calculated at a conductor temperature of 55^{O}C.

Table 3-13 shows the Present Values of these Annual Costs of Losses with an 8% Discount rate and a 50-year operating life.

Some conductors were precluded because they exceeded the corona limits. The minimum diameter of single conductor for ±400 kV was 50.4 mm and for ±450 kV was 58 mm, based on the maximum radio interference measured at the edge of the ROW.

The minimum sizes of single conductor for ±500 kV would be 70 mm, which is greater than the present conductor fabrication capabilities. The minimum conductor diameter for the twin conductor configuration was 39.5 mm, and the optimal conductor, taking into account construction costs and costs of losses, has a diameter of 41.9 mm.

3.1.3.5 Results

Tower Design and Weight

It was concluded that the LCP overhead HVdc transmission lines could be operated at ±400, ±450 or ±500 kVdc and that the choice of optimal voltage would be determined by total line costs, including the costs of losses.

With the same conductor configuration, tower weights and costs would be very similar for ±400, ±450 or ±500 kVdc.

The total weight of the towers was shown to be significantly effected by the tensile strength of the conductors which determine the sag and hence the tower spacing.

Conductor Configuration

The choice of optimal conductor size was again determined by the total cost of construction and costs of losses.

The analysis shows that the costs of losses continue to decrease as the conductor size increases, up to the reasonable limit for conductor size. These benefits must be balanced against the additional construction costs for larger conductors and the resulting increase in wind and ice loading.

Corona and Field Effects

For the ±400 and ±450 kVdc options, it would be possible to satisfy corona limits with a single, 58 mm diameter conductor, and manufacturers have advised that that would be close to the largest conductor that has been commercially supplied. However, it should be noted that such large conductors would require specialized conductor fittings, installation and maintenance equipment, and would need a greater number of cable reels.

The analyses showed that the least cost options for the HVdc overhead lines at the three operating voltages would be:

Scenario 1

- ±400 kVdc Single, 50.4 mm diameter conductor.
- ±450 kVdc Single, 58.0 mm diameter conductor.
- ±500 kVdc Twin, 41.9 mm diameter conductor.

Scenario 2

- ±400 kVdc Single, 51.4 mm diameter conductor.
- ±450 kVdc Single, 58.0 mm diameter conductor.
- ±500 kVdc Twin, 41.9 mm diameter conductor.

3.1.4 Impact of Operating Voltage on Submarine Cable Designs

3.1.4.1 Design Considerations

The evaluation of submarine cable design is given in WTO DC1130 and WTO DC1140. In this report, a brief overview is given in the context of selecting the optimal HVdc voltage.

Two types of HVdc submarine cable could be considered for the LCP transmission system:

- Self Contained Oil-Filled (SCOF) Cable
- Mass Impregnated (MI) Cable

A brief review of the cable technologies with their possible application to the LCP is given in Appendix D.

The advantage of SCOF cables is that they can be designed for a higher conductor temperature and higher electrical gradient because the insulation is pressurised under all operating conditions. The disadvantage is that the oil has to be transported along the cable length to/from the pressure tanks or pumping plants at both ends of the cable, and the dynamic pressure drop in oil flow along the cable limits the maximum length of SCOF submarine cable to approximately 50 km. Therefore, SCOF cable could be used for the SOBI crossing but not for the Cabot Strait crossing. Also, although the insulating oil has a low viscosity and would evaporate from the surface of the sea, the possibility of long-term oil discharge while waiting for cable repairs may cause environmental concerns.

The MI cable does not have this maximum length limitation and could be used for both crossings.

The key parameter for the cable design will be the continuous overload current requirements, which determine the maximum operating temperature. The preliminary submarine cable design parameters for Scenarios 1 and 2 are given in Table 3-14. These initial design parameters will be refined when more details are available regarding transient requirements and ambient conditions for the two cable crossings.

For the SOBI crossing, the preliminary designs indicate that a single SCOF cable per pole would be sufficient, for Scenario 1 and Scenario 2, whereas two MI cables per pole would be required for Scenario 2. This would mean that a total of three (3) SCOF cables would be installed for Scenario 2 (one per pole plus a spare cable) compared with five (5) MI cables. This would have a significant impact on the time and costs of cable installation.

There is a possibility that a single MI cable per pole could be manufactured for the SOBI crossing, and the preliminary designs indicate that the ±450 kVdc cable would have a conductor size of 3,000 mm^2 and the ±500 kVdc cable conductor would be 2,800 mm^2. Although the supply costs for these larger cables would be greater, the installation costs would be significantly reduced because only 3-cables would be required for the SOBI crossing instead of 5- cables.

However, the largest MI cable produced to date has a 2,100 mm^2 conductor, so significant prototype testing would be required for both the ±450 and ±500 kVdc single cable per pole options.

Therefore the 2-cables per pole options (with smaller conductor) were retained for the purposes of WT0 DC1010 comparative cost estimates.

3.1.4.2 Costs of Losses

The parameters used in comparing costs of losses for the different submarine cables are summarized in Section 3.1.3.2.

Table 3-15 gives losses for each cable, the Annual Cost of Losses and the Present Values of the Annual Costs of Losses, at a Discount Rate of 8% and a 50-year operating life.

3.1.4.3 Conclusions

For the Strait of Belle Isle crossing, the choice of either SCOF or MI cables would be determined, not by the technology or operating voltage, but by total costs of manufacture, laying and burial, and the costs of losses.

For the Cabot Strait crossing, only MI cables could be considered (because of the route length) and the choice would again be determined by the total costs, not by operating voltage.

The conclusions for submarine cable are:

- Both routes — ±400, ±450 or ±500 kVdc cables could be used
- Strait of Belle Isle — SCOF or MI cables could be used
- Cabot Strait — MI cables would be used

The total costs for the submarine cable options are discussed in Section 3.2.2.

3.1.5 Impact of System Voltage on Converter Stations

3.1.5.1 Overview

Consideration of the converter stations is limited to the impact of operating voltages.

3.1.5.2 Converter Station Pole and Bipole Ratings

The Gull Island and Soldiers Pond Converter Stations will be rated at twice their monopole 50% continuous overload capacity because, even though only one pole would be operating in overload at any one time, each pole equipment must have the full overload rating. Therefore the principal items of HVdc equipment would have the 50% continuous overload rating, although the HVac equipment may be rated at nominal capacity (except for the converter transformers).

The converter station ratings, based on the Soldiers Pond and Gull Island continuous monopolar overload operation, are given below.

Converter Station	**Scenario 1** Transmission From Gull Island **To Soldiers Pond Only**	**Scenario 2** Transmission From Gull Island **To Soldiers Pond & Salisbury**
Gull Island	**1,200 MW**	**2 080 MW**
Soldiers Pond	**1,200 MW**	**1 200 MW**
Salisbury	**-**	**880 MW**

In WTO DC1020, a simple PSCAD model of the HVdc system with 100% monopole overload at Soldiers Pond and 10% overload at Salisbury was used. The Soldiers Pond monopole load was set at twice the initial bipole load so that the delivered power remained unchanged at Soldiers Pond for the monopole 100% overload case. The Gull Island converter must provide for the increased HVdc transmission line losses associated with the monopolar operation. The Salisbury monopole load of 110% also must be taken into account of the Gull Island Converter Station.

With these assumptions, the following Gull Island converter valve currents were determined in the system studies:

- $\pm$500 kVdc 2 700 A
- $\pm$450 kVdc 3 000 A
- $\pm$400 kVdc 3 400 A

It is understood from the DC1020 studies that the 3 400 A requirement at $\pm$400 kVdc may not be possible, since conventional converter valves are limited, by the current carrying capabilities of the thyristors, to 3 000 A,

Therefore, if $\pm$400 kVdc is chosen for Scenario 2, an operating restriction may be required for the Salisbury Converter Station to permit the 100% overload at Soldiers Pond while limiting the Gull Island converter current to 3 000 A.

3.1.6 Conclusions on HVdc Operating Voltage

It is concluded that the choice of operating voltage will be made on the basis of cost, not from technical considerations, except, possibly, for the Gull Island thyristor valve rating for ±400 kVdc overload operation in Scenario 2.

3.2 Comparative Cost Estimates

The total costs of the transmission system for the different operating voltages would be the determining factor in selecting operating voltage and conductor configurations, so the objective of the comparative cost estimates was to determine the cost differentials between the various voltage/conductor options.

The costs include the supply and construction of the overhead transmission lines (plus the present value of cost of losses) plus the supply of the submarine cables (excluding the costs of laying and protection) and the supply of the HVdc Converter Stations.

Operating and maintenance costs are excluded from the comparative cost comparisons because they would be the same for the different overhead line configurations.

3.2.1 Overhead Transmission Lines

Comparative cost estimates were prepared with generic tower designs and different conductor configurations. The generic tower designs represent the average requirements for all line sections. For example, the line from Gull Island to the Strait of Belle Isle has two electrode line conductors, which are not used for the remainder of the line to Soldiers Pond, but this would be offset by the increased ice/wind loading for the Strait of Belle Isle to Soldiers Pond section and, for example, the route through the Long Range Mountains where the loads are considerably greater.

With the generic tower configuration, one metallic return conductor also contains the optical fibre, whereas in the final configuration studied in WTO DC1080, "Tower Type Selection", a separate optical ground-wire (OPGW) will be included, so five cables will be supported from Gull Island to the Strait of Belle Isle (2 pole conductors, two electrode lines and one OPGW). For the HVdc line in Newfoundland, three cables will be supported (2 pole conductors and one OPGW). These changes do not the selection of optimal voltage and conductor configurations.

Table 3-16 summarizes the estimated construction costs per 100 km for each of the conductor configurations at each operating voltage, with further details given in Appendix D.

The table shows that, with the same conductor configuration, the differential cost for construction between ±400 kVdc and ±500 kVdc overhead lines would be approximately 3%.

In contrast, as noted earlier, the RTS of the pole conductors has a more significant impact on construction costs because it determines the tower spacing required to give the same clearance to ground at mid-span. One example of this is the lower construction costs for a 1250-A2/S3A-72/19 conductor with an RTS of 526.9 kN, compared with an 1120-A2/S3A-72/19 conductor, which has an RTS of 472.1 kN. In this example, the larger 1250-A2/S3A-72/19 conductor has a lower total construction cost.

Sag and tension tables for the selected conductor, metallic return and optical ground wire with various spans and ice loadings are included in Appendix E. The sags of the metallic return (800-A2/S3A-54/19) are considerably less than those of the conductor (2126-A1/A4-91) under most conditions. This would indicate that the metallic return could be sagged with lower tension, or a lower strength cable could be used. The optical ground wire (OPGW), however, shows sags that are greater than the conductor under heavy loads and long spans, indicating that a stronger OPGW may be required under these conditions.

WTO DC1080 will coordinate the cable strengths for these final arrangements considering the full spectrum of loading conditions and appropriate spans.

Table 3-17 gives the total costs for the overhead transmission lines, including costs of losses, for each conductor configuration at each operating voltage. A comparison of total costs with the optimal conductor configuration for each operating voltage is given below.

		Total Comparative Cost Estimates For Overhead Transmission Lines ($Million)		
		±400 kVdc	**±450 kVdc**	**±500 kVdc**
Scenario 1	**Conductor**	**(Single 50.4 mm)**	**(Single 58.0 mm)**	**(Twin 41.9 mm)**
	Total Cost	**$861**	**$897**	**$988**
	Diffferential	**Least Cost**	**$35**	**$126**
			4%	**15%**
Scenario 2	**Conductor**	**(Single 51.4 mm)**	**(Single 58.0 mm)**	**(Twin 41.9 mm)**
	Total Cost	**$1,298**	**$1,297**	**$1,414**
	Diffferential	**$1**	**Least cost**	**$117**
		0%		**9%**

A detailed estimate of the HVdc transmission line costs in their final configuration can be found in the Final Report on WTO DC1200 "HVdc Overland Transmission Re-estimate".

Figure 3-5 shows the effects of varying the conductor size on the total comparative cost estimates (including costs of losses) for ±400, ±450 and ±500 kVdc operation. The curves show that the total costs for twin conductor configurations decrease slightly with increasing conductor size because of the impact of the reduction in costs of losses.

(The "cost-spike" for conductor 1439-A1/S3A-84/19 is due to the higher line construction cost because this conductor has a lower RTS than other conductors. This results in increased sag, which increases the number of towers and the overall construction costs, that is not offset by reduced costs of losses.)

It should be noted that all single conductor configurations are precluded by corona considerations for ±500 kVdc and that two of the single conductor configurations (50.4 mm and 51.4 mm) are precluded for ±450 kVdc and ±500 kVdc.

Figures 3-6 through 3-8 show the effects on total comparative cost estimates of varying the Load Factor between 0.60 and 0.80, for each operating voltage. The curves show that Load Factor has no impact on the selection of the optimal conductor.

3.2.2 Submarine Cables

In this initial assessment, without marine survey results, the estimated costs for installation and burial are excluded from the comparison of costs.

The comparative cost estimates for supply of submarine cables, plus the recent values of the costs of Losses (8% over 50 years) are given in Table 3-18.

For Scenario 1, there is a $2 million (5%) cost difference between operating voltages,

For Scenario 2, the ±500 kVdc option would cost $51 million (15%) less than the ±450 kVdc option.

Preliminary cost estimates for the single cable per pole options (total of 3 cables) for the SOBI crossing indicate similar levels of differential costs at ±450 kVdc or ±500 kVdc, so the comparative cost estimates for submarine cables would not affect the choice of operating voltage).

3.2.3 HVdc Converter Station

The comparative cost estimates for the converter stations were based on the installed MW capacity required for the continuous monopolar overload operation.

For Scenario1, each converter pole at Gull Island and Soldiers Pond is rated at 600 MW for continuous monopole overload operation, so the Gull Island and Soldiers Pond Converter Station cost estimates are based on a 1,200 MW rating.

For Scenario 2, each converter pole at Soldiers Pond is rated at 600 MW and each Salisbury converter pole is rated at 440 MW, so each Gull Island pole is rated at 1,040 MW. For cost estimating, the Gull Island Converter Station is rated at 2,080 MW, the Soldiers Pond Converter Station at 1,200 MW and the Salisbury Converter Station at 880 MW.

Converter Stations costs are approximately $Can150/kW for a nominal 1000 MW link.

However, because higher converter station voltages are more economical for higher levels of power transmission, the ±450 kV converter station would cost approximately 5% more than a ±400 kV station, and a ±500 kV converter station would also cost approximately 5% more than a ±450 kV station.

The comparative cost estimates for the three converter stations at different HVdc operating voltages are given in Table 3-19, which show that for Scenario 2, the ±500 kVdc option would cost $17 million more than the ±450 kVdc option.

3.2.4 Total Comparative Costs for HVdc Transmission Systems

The comparative cost estimates for the supply of the submarine cables and the HVdc converter stations are added to the cost estimates for the overhead lines to determine if there would be any impact on the voltage selection. These cost estimates exclude the costs for operating and maintaining the transmission system, and also exclude the costs for laying and protecting the submarine cables, which will have a significant impact on the total project costs.

The total comparative cost estimates for the HVdc overhead lines assume a 60% Load actor, a Discount Rate of 8% and a 50-year operating life. Changing these parameters has no impact on the comparative costs for the converter stations, which include only the costs of supply.

The total project costs are shown below (for MI cables), with the optimal conductor configuration for each operating voltage. Similar cost comparisons are observed for SCOF cables.

Voltage	Diffential Total Cost Estimates ($Million)		
	±400 kVdc	±450 kVdc	±500 kVdc
Scenario 1	(Single 50.4 mm)	(Single 58 mm)	(Twin 41.9 mm)
	$1,085	$1,127	$1,226
	Least Cost	$43	$141
		3.9%	13.0%
Scenario 2	(Single 51.4 mm)	(Single 58 mm)	(Twin 41.9 mm)
	$2,072	$2,073	$2,156
	-$1	Least Cost	$83
	-0.1%		4.0%

The analysis shows that when the supply costs for the converter stations and submarine cables are added to the overhead line transmission costs, the choice of optimal operating voltage and conductor configuration is not changed, but the cost differences for the different operating voltages are reduced.

As an example, when considering costs for the overhead lines only for Scenario 2, the ±450 kVdc option is 9% less than the ±500 kVdc option. When the costs of supply for the converter stations and submarine cables are included, this cost difference is reduced to 4%.

It should be noted that these differences are less than the levels of accuracy of the WTO DC1010 comparative cost estimates.

3.2.5 Conclusions

For both Scenario 1 and Scenario 2, the differences between the total project costs for ±400, ±450 or ±500 kVdc transmission are less than the level of accuracy of the comparative cost estimates.

However, within the accuracy limits of the comparative cost estimates, the least cost options for the HVdc overhead lines would be:

Scenario 1 ±400 kVdc with a single, 50.4 mm diameter conductor.

Scenario 2 ±450 kVdc with a single, 58.0 mm diameter conductor.

Table 3-1
HVdc Transmission Projects at Operating Voltages Between 400 and 500 kVdc

Project & (Country)	Year	HVdc Voltage (kVdc)	Power Rating (MW)	Length (km)	Overhead Line/Cables
Lower Churchill Project			**1 600 MW**	**1 800 km**	**Lines/Cables**
400 kVdc Projects					
Kontek (Denmark-Germany)	1995	±400	600	171	Cables
Fenno-Skan (Finland-Sweden)	1989	±400	500	233	Cables
GRITA (Greece-Italy)	2001	±400	500	316	Cables
Volvograd-Donbrass (Russia)	1965	±400	720	473	OH Lines
Pacific Intertie (USA)	1970/ 1982	±400	1 440/ 1 600	1 362	OH Lines
CU Project (USA)	1979	±400	1 000	701	OH Lines
Basslink (Australia)	2006	±400	600	360	Lines/Cables
450 kVdc Projects					
Baltic Cable (Sweden-Germany)	1994	±450	600	261	Cables
SWEPOL Link (Sweden-Poland)	2 000	±450	600	254	Cables
Long Island Cable Project (USA)	2007	±450	600	40	Cables
Nelson River Bipole 1 (Canada)	1973	±450	1 854	890	OH Lines
Des Cantons (Canada-USA)	1986	±450	690	172	OH Lines
Radisson-New England (Canada)	1992	±450	2 250	1 500	OH Lines
NorNed (Norway-Netherlands)	**Under Construction (2007)**	±450	700/790	580	Cables

Table 3-1
HVdc Transmission Projects at Operating Voltages Between 400 and 500 kVdc

Project & (Country)	Year	HVdc Voltage (kVdc)	Power Rating (MW)	Length (km)	Overhead Line/Cables
500 kVdc Projects					
Inga Shaba (Zaire)	1983	± 500	560	1 700	OH Lines
Pacific Intertie Upgrade(USA)	1985	± 500	2 000	1 362	OH Lines
Nelson River Bipole 2 (Canada)	1985	± 500	2 000	940	OH Lines
Intermountain Power Project (USA)	1986	± 500	1 920	785	OH Lines
Gesha (China)	1989	± 500	1 200	1 046	OH Lines
Pacific Intertie Expansion (USA)	1989	± 500	3 100	1 362	OH Lines
Rihand-Delhi (India)	1992	± 500	1 500	814	OH Lines
Chandrapur-Padghe (India)	1998	± 500	1 500	736	OH Lines
South-East Interconnector (India)	2003	± 500	2 000	1 400	OH Lines
Three Gorges - Changzhou(China)	2003	± 500	3 000	860	OH Lines
Gui-Guang (China)	2004	± 500	3 000	936	OH Lines
Three Gorges - Guangdong (China)	2004	± 500	3 000	940	OH Lines
KII Channel (Japan)	2006	± 500	660	50	Cables
Neptune Project, (USA)	2007	± 500	660	82 Submarine 20 Land	Cables
Three Gorges-Shanghai (China)	2006	± 500	3 000	1060	OH Lines
SAPEI (Sardinia–Italy)	2008/09	± 500	500/1000	420	Cables
Fenno-Skan-2 (Finland-Sweden)	Planned (2010)	± 500	800	233	Cables

Table 3-2
HVdc Overhead Line Transmission Projects Similar to the Lower Churchill Project

Project & (Country)	Year	HVdc Voltage (kVdc)	Power Rating (MW)	Length (km)
Lower Churchill Project Canada)			**1 600 MW**	**1 400 km**
Pacific Intertie (USA)	1970	± 400	1 440	1 362
Pacific Intertie Upgrade (USA)	1985	± 500	2 000	1 362
Radisson-New England (Canada)	1992	± 450	2 250	1 500
Inga Shaba (Zaire)	1983	± 500	560	1 700
Nelson River Bipole 2 (Canada)	1985	± 500	2 000	940
Intermountain Power Project (USA)	1986	± 500	1 920	785
Gesha (China)	1989	± 500	1 200	1 046
Pacific Intertie Expansion (USA)	1989	± 500	3 100	1 362
Rihand-Delhi (India)	1992	± 500	1 500	814
Chandrapur-Padghe (India)	1998	± 500	1 500	736
South-East Interconnector (India)	2003	± 500	2 000	1 400

Table 3-3
List of HVdc Submarine Cable Projects (In Service, Under Construction or Proposed)

HVdc link	Year	Type of Cable	Voltage (kV)	System	Length (km)	Capacity (MW)	Conductor size (mm2 Cu)	Current Per Cable (A)
Kontek	1995	MI	±400	Monopole	171	600		
Fenno Skan		MI	±400	Monopole		500	1200	1250
Storebælt	2010	MI	±400	Monopole Metallic Return	58	600		
Italy -Greece	2001	MI	±400	Mono-pole	316	500	1250	1250
Basslink	2006	MI	±400	Metallic return	360	500	1500	1250
Baltic Cable	1994	MI	±450	Mono- pole	261	600	1600	1350
SwePol	2000	MI	±450	Metallic return	254	600	2100	1350
NorNed *	2007	MI	±450	Simplified Bipole	580	700	790 700	780
BritNed	2010	MI	±450		260	1000		
KII Channel	1999	SCOF	±500	Bipole	50	2800	3000	2800
Neptune Project		MI	+500	Monopole Metallic Return	102	660 MW	2100	1 320
SAPEI Cable**	2008/ 2009	MI	±500	Bipole	420	1 000 MW	1150	1 000 A
FennoSkan 2	2010	MI	±500	Bipole	233	800		
Viking Cable ***		MI	±500	Metallic return	600	600	1375/2100	1260
Bakun ****		MI	±500	Mono- pole		600	2100	1200

*) Under construction with planned commissioning Fall, 2007. Two cable suppliers.

**) Under construction with planned commissioning for in Fall, 2008/2009.

***) Complete type tests performed prior to project termination

****) Some suppliers performed more or less complete type tests for this project prior to its termination

Table 3-4
Nominal Pole Currents for Full Load and Continuous Monopole Overload Operation

Scenario 1. Transmission From Gull Island to Soldiers Pond Only							
Section	Length (km)	Full Load Pole Current (A)			Continuous Monopole Overload Current (A)		
		400 kV	450 kV	500 kV	400 kV	450 kV	500 kV
Strait of Belle Isle	30	1,000	889	800	1,500	1,333	1,200
Scenario 2. Transmission From Gull Island to Soldiers Pond & Salisbury							
Strait of Belle Isle	30	2,000	1,778	1,600	2,600	2,311	2,080
Cabot Strait	480	1,000	889	800	1,100	978	880

Note: Nominal Currents calculated at receiving end assuming rated voltage and neglects transmission losses.

Table 3-5
Clearances for HVdc Overhead Line Transmission Projects

Project/Location	Voltage (kVDC)	Altitude (m)	Minimum Clearances (m.)							Leakage Distance (mm.)			
			Pole to Tower	Pole to Pole	Pole Conductor Height At Tower	Final Sag (@ 20Oc	Minimum Conductor Height (Bottom of Sag)	Pole to Ground (Mean)	ROW	Suspension			
										Number	Type	Unit Leakage Distance	Total Leakage
Coal Creek (USA) (Twin)	400	610	2.7	12.2	29.3	19.5	9.8	16.3	49	20	I	508	10,160
Walker County (USA)	400	77	4.0	12.2	24.9	10.1	14.8	18.2	46	39	V	406	15,850
400 kVDC LCP Lines	**400**	**800**	**5.9**	**13.8**	**27.0**	**15.4**	**9.4**	**14.5**	**60**	**20**	**I**	**508**	**10,160**
Des Cantons (Canada)	450	620	3.3	11.0	21.2	17.7	3.4	9.4	61	27	V	540	14,580
Radisson Phase 1 (Canada)	450	693	3.7	13.7	24.1	7.7	16.4	18.9	61	25	V	527	13,176
Nelson River (Canada) (Twin)	450	247	3.5	13.4	37.5	23.4	14.1	21.9	96	21	I	508	10,668
450 kVDC LCP Lines	**450**	**800**	**6.2**	**14.4**	**28.0**	**15.4**	**9.7**	**14.8**	**60**	**22**	**I**	**550**	**12,100**
Nelson River (Canada) (Twin)	500	693	3.5	13.4	37.5	23.4	14.1	21.9	96	21	I	508	10,668
LAD Pacific Intertie (USA	500	2,591	2.4	12.2	24.4	13.4	11.0	15.4	61	27	I	470	12,687
BPA Pacific Intertie (USA) (Twin)	500	1,981	2.3	11.6	24.4	10.7	13.7	17.3	91	20	I	508	9,906
Intermountain Power (USA)	500	1,875	4.0	12.8	29.5	15.2	14.2	19.3	61	27	V	546	14,745
Salt River (USA)	500	1,524	4.6	12.2	29.5	12.5	17.0	21.1	61	29	V	546	15,837
500 kVDC LCP Lines	**500**	**800**	**6.7**	**15.4**	**29.0**	**15.4**	**10.0**	**15.1**	**60**	**24**	**I**	**550**	**13,200**

Table 3-6
Nominal Design Parameters for the LCP HVdc Transmission Systems

Parameter	HVDC Operating Voltage:		
	+/- 400	**+/- 450**	**+/- 500**
Full Load Pole Current (Scenario 2)			
Gull Island to Taylor's Brook	2,000 A	1,780 A	1,600 A
Taylor's Brook to Soldiers Pond	1,000 A	890 A	800 A
Taylor's Brook to Salisbury	1,000 A	890 A	800 A
Overhead Transmission Line Lengths			
Gull Island to Taylor's Brook	682 km	682 km	682 km
Taylor's Brook to Soldiers Pond	406 km	406 km	406 km
Taylor's Brook to Salisbury	400 km	400 km	400 km
Maximum ice loading:	100 mm	100 mm	100 mm
Wind Span	330 m	330 m	330 m
Mean Conductor Height	14.5	14.8	15.1

Table 3-7
Sample calculations of Voltage Gradients and Field Strengths With Optimal LCP Conductors

FORMULAE	PARAMETERS	LCP	BPA Pacific Intertie (USA) (Twin)	LCP	Nelson River Manitoba	Nelson River Manitoba	LCP	Coal Creek Dakota
	Voltage kVdc V =	**500**	**500**	**450**	**450**	**500**	**400**	**400**
	Conductor Spacing (m) S =	0.4572	0.4572		0.4572	0.4572		0.4572
	Mean height of conductor (m) H =	15.1	17.2720	14.8	21.9	21.9	14.53	16.3
	Pole to pole spacing (m) P =	15.4	11.5824	14.4	13.4	13.4	13.8	12.2
	Conductor Type	800-A2/S3A-54/19		COMPACT 2455-A1F			1250-A2/S3A-72/19	
	Number of Conductors (n) =	**2**	2	**1**	**2**	**2**	**1**	**2**
	Conductor Diameter (mm) d =	**41.9**	**45.8**	**57.9**	**40.6**	**40.6**	**50.4**	**38.2**
D = S/Sin(pi/n)	Bundle Diameter (m) D=	0.457	0.457	0.058	0.457	0.457	0.050	0.457
deq = D(nd/D)1/n	Equivalent bundle dia. (m) d_{eq} =	0.196	0.205	0.058	0.193	0.193	0.050	0.187
F = (1+(2H/P)2)1/n	F=	2.2051	3.1456	2.2901	3.4134	3.4134	2.3316	2.8480
T = 4H/deq	T=	309	338	1025	454	454	1153	348
Gav = 2V/(nd ln(T/F))	**Average** conductor gradient (kV/cm) G_{av} =	24.1	23.4	25.5	22.7	25.2	25.6	21.8
Eo = 30m(1+0.301/SQRT (r))	**Corona Onset Gradient (kV/cm) E_0**	**31.53**	**31.29**	**30.72**	**31.61**	**31.61**	**31.05**	**31.78**
Gmax = Gav(1+d(n-1)/D)	**Maximum conductor gradient (kV/cm) G_{max} =**	**26.4**	**25.7**	**25.5**	**24.7**	**27.4**	**25.6**	**23.6**
						26.6		
(Gav/go)	**Corona Inception Ratio**	**0.836**	**0.821**	**0.829**	**0.781**	**0.867**	**0.824**	**0.743**
E =2*V*H/(LN(4H/deq)-0.5*LN(4h2+P2)/P2)) *(1/(H2+(X-P32)^2)-(1/(H2+(X+P/2)^2)	**Field Strength at Ground Level (kV/cm) E =**	**2.36**	**0.70**	**1.59**	**1.74**	**1.93**	**1.32**	**2.25**
						-39.47		
	m (rougness factor) =	0.87	0.87	0.87	0.87	0.87	0.87	0.87
	Distance to edge of ROW (m)	30	46	30	30	30	30	24
Rp = SQRT(H^2+(ROW-P/2)^2)	Distance from Pole to Measuring point	27	44	27	32	32	27	24
A50 = 56.9+124*log(Gmax/25)+25*log(d/4.45)+18*log(n/2)-10*log Rp-0.02*Rp+Kn	**Audible Noise (dBA) Limit = 50 dBA**	**46.8**	**44.0**	**47.9**	**42.1**	**47.8**	**46.7**	**40.4**
RI = 86 x log (Gmax/25) + 10 x log(n/3) + 40 x log(d/4.57) +20 x log((1 + fo2)/(1 + f2)) + 40 log(D0/Dr) + 3.3 x ALT + 0.375*Wp +Earth Resistivity factor + Seasonal factor	**Radio Interference (dB) Limit = 65 dB**	**61.7**	**62.3**	**63.0**	**58.7**	**62.6**	**60.8**	**56.0**

Kn = 2.6 for Twin conductors and 7.5 for Single conductor
Wp = Wind factor = 0.0.
Earth Resistivity Factor = 0.0 (= 0.0 for 100 Ohm-m = -1.5 for 1,000 Ohm-m).
Seasonal factor = 0.0 (=0.0 for Spring & Fall = +3.0 for Summer = -3.0 for Winter)

Table 3-8
Calculated Field effects, $L_{50\ Fair}$ and RI Levels for $\pm$500 kVdc Overhead Lines

CONDUCTOR		HVDC FIELD EFFECTS			
Type	Conductor Diameter (mm)	Maximum Conductor Gradient (kV/cm)	Field Strength at Ground Level (kV/cm)	Audible Noise L50 FAIR (dBA)	Radio Interference S/N @ 100 Ohm-m (dB)
BPA Pacific Intertie (USA) (Twin)	**45.77**	**25.70**	**0.70**	**44.0**	**62.3**
710-A2/S3A-54/19 39.5 mm (Twin)	39.50	27.7	2.35	48.8	62.5
800-A2/S3A-54/19 41.9 mm (Twin)	**41.90**	**26.4**	**2.36**	**46.8**	**61.7**
900-A2/S3A-84/7 43.6 mm (Twin)	43.60	25.5	2.37	45.5	61.2
1000-A2/S3A-72/7 45.1 mm (Twin)	45.10	24.8	2.38	44.4	60.7
1120-A2/S3A-72/19 47.7 mm (Twin)	47.70	23.7	2.39	42.6	60.0
1250-A2/S3A-72/19 50.4 mm (Twin)	50.40	22.7	2.40	40.8	59.3
1439-A1/S3A-84/19 51.4 mm (Twin)	51.40	22.4	2.41	40.2	59.1
1250-A2/S3A-72/19 50.4 mm (Single)	50.40	31.5	1.85	58.8	68.6
1439-A1/S3A-84/19 51.4 mm (Single)	51.40	31.0	1.86	57.2	68.3
1871-A4-91 (58 mm) Single	57.9	28.6	1.59	53.6	67.3
COMPACT 2455-A1F 58.0 mm (Single)	57.9	28.6	1.59	53.6	67.3
Fictitious 70 mm Conductor (Single	70.00	24.1	1.95	46.9	64.1

Note: The last conductor in the table (70 mm diameter) is a fictitious conductor which satisfies the Audible Noise Limit but cannot be manufactured at this time.

Table 3-9
Calculated Field effects, $L_{50\ Fair}$ and RI Levels for ±450 kVdc Overhead Lines

CONDUCTOR		HVDC FIELD EFFECTS			
Type	Conductor Diameter (mm)	Maximum Conductor Gradient (kV/cm)	Field Strength at Ground Level (kV/cm)	Audible Noise L50 FAIR (dBA)	Radio Interference S/N @ 100 Ohm-m (dB)
Nelson River (Canada) (Twin)	**40.6**	**24.68**	**1.74**	**42.1**	**58.7**
710-A2/S3A-54/19 39.5 mm (Twin)	39.50	25.2	1.98	43.7	59.0
800-A2/S3A-54/19 41.9 mm (Twin)	41.90	24.0	1.99	41.8	58.2
900-A2/S3A-84/7 43.6 mm (Twin)	43.60	23.2	2.00	40.4	57.7
1000-A2/S3A-72/7 45.1 mm (Twin)	45.10	22.6	2.00	39.3	57.3
1120-A2/S3A-72/19 47.7 mm (Twin)	47.70	21.6	2.02	37.5	56.5
1250-A2/S3A-72/19 50.4 mm (Twin)	50.40	20.7	2.03	35.7	55.9
1439-A1/S3A-84/19 51.4 mm (Twin)	51.40	20.4	2.03	35.1	55.6
1250-A2/S3A-72/19 50.4 mm (Single)	50.40	28.6	1.56	52.7	65.0
1439-A1/S3A-84/19 51.4 mm (Single)	51.40	28.1	1.56	52.0	64.7
1871-A4-91 (58 mm) Single	57.9	25.5	1.59	47.9	**63.0**
COMPACT 2455-A1F 58.0 mm (Single)	**57.9**	**25.5**	**1.59**	**47.9**	**63.0**

Table 3-10
Calculated Field effects, $L_{50\ Fair}$ and RI Levels for ±400 kVdc Overhead Lines

CONDUCTOR		HVDC FIELD EFFECTS			
Type	Conductor Diameter (mm)	Maximum Conductor Gradient (kV/cm)	Field Strength at Ground Level (kV/cm)	Audible Noise L50 FAIR (dBA)	Radio Interference S/N @ 100 Ohm-m (dB)
Coal Creek (USA) (Twin)	**38.20**	**23.61**	**2.25**	**40.4**	**56.0**
710-A2/S3A-54/19 39.5 mm (Twin)	39.50	22.6	1.69	28.3	54.9
800-A2/S3A-54/19 41.9 mm (Twin)	41.90	21.5	1.70	35.8	54.1
900-A2/S3A-84/7 43.6 mm (Twin)	43.60	20.8	1.70	34.5	53.6
1000-A2/S3A-72/7 45.1 mm (Twin)	45.10	20.3	1.71	33.4	53.2
1120-A2/S3A-72/19 47.7 mm (Twin)	47.70	19.4	1.72	31.6	52.4
1250-A2/S3A-72/19 50.4 mm (Twin)	50.40	18.5	1.73	29.8	51.8
1439-A1/S3A-84/19 51.4 mm (Twin)	51.40	18.2	1.73	29.2	51.5
1250-A2/S3A-72/19 50.4 mm (Single)	**50.40**	**25.6**	**1.32**	**46.7**	**60.8**
1439-A1/S3A-84/19 51.4 mm (Single)	51.40	25.2	1.33	46.0	60.5
1871-A4-91 (58 mm) Single	57.9	23.2	1.20	42.6	59.5
COMPACT 2455-A1F 58.0 mm (Single)	57.9	30.7	1.20	42.6	59.5

Table 3-11
LCP Conductor Configurations that Satisfy Corona and Mechanical Strength Requirements

ID.	400 kVDC	450 kVDC	500 kVDC	Stranding	Diameter (mm)	Weight of Conductor Bundle (kg/m)	Nominal Breaking Load (kN)	DC Resistance of Conductor Bundle @55^{0}C (ohms/km)
710-A2/S3A-54/19 39.5 mm (Twin)	X	X		54/19	**39.5**	6.134	395.2	**0.02324**
800-A2/S3A-54/19 41.9 mm (Twin)	X	X	X	54/19	**41.9**	6.912	445.3	**0.02062**
900-A2/S3A-84/7 43.6 mm (Twin)	X	X	X	84/7	**43.6**	7.07	431.6	**0.01835**
1000-A2/S3A-72/7 45.1 mm (Twin)	X	X	X	72/7	**45.1**	7.126	421.2	**0.01650**
1120-A2/S3A-72/19 47.7 mm (Twin)	X	X	X	72/19	**47.7**	7.964	472.1	**0.01474**
1250-A2/S3A-72/19 50.4 mm (Twin)	X	X	X	72/19	**50.4**	8.89	526.9	**0.01320**
1439-A1/S3A-84/19 51.4 mm (Twin)	X	X	X	84/19	**51.4**	8.89	407.2	**0.01147**
1250-A2/S3A-72/19 50.4 mm (Single)	X			72/19	**50.4**	4.445	526.9	**0.02640**
1439-A1/S3A-84/19 51.4 mm (Single)	X			84/19	**51.4**	4.445	407.2	**0.02295**
1871-A4-91 (58 mm) Single	X	X		91	**57.9**	5.366	496	**0.01763**
COMPACT 2455-A1F 58.0 mm (Single)	X	X		Trapaziodal	**57.9**	6.636	405	**0.01344**

Table 3-12
Annual Costs of Losses (@ 55^{O}C Conductor Temperature) for Different Overhead Line Conductor Configurations

CONDUCTOR		ANNUAL OF COST OF LOSSES (@$0.065/kWh)		
ID & Diameter (mm)	Configuration	400 kVDC ($million)	450 kVDC ($million)	500 kVDC ($million)
Scenario 1. Gull Island to Soldiers Pond Only				
710-A2/S3A-54/19 39.5 mm (Twin)	(Twin)	$5.7	$4.5	$3.7
800-A2/S3A-54/19 41.9 mm (Twin)	**(Twin)**	$5.1	$4.0	**$3.3**
900-A2/S3A-84/7 43.6 mm (Twin)	(Twin)	$4.5	$3.6	$2.9
1000-A2/S3A-72/7 45.1 mm (Twin)	(Twin)	$4.1	$3.2	$2.6
1120-A2/S3A-72/19 47.7 mm (Twin)	(Twin)	$3.6	$2.9	$2.3
1250-A2/S3A-72/19 50.4 mm (Twin)	**(Twin)**	**$3.3**	$2.6	$2.1
1439-A1/S3A-84/19 51.4 mm (Twin)	(Twin)	$2.8	$2.2	$1.8
1250-A2/S3A-72/19 50.4 mm (Single)	(Single)	$6.5	$5.2	$4.2
1439-A1/S3A-84/19 51.4 mm (Single)	(Single)	$5.7	$4.5	$3.6
1871-A4-91 (58 mm) Single	(Single)	$4.4	$3.4	$2.8
COMPACT 2455-A1F 58.0 mm (Single)	**(Single)**	$3.3	**$2.6**	$2.1
Scenario 2. Gull Island to Soldiers Pond $ Salisbury				
710-A2/S3A-54/19 39.5 mm (Twin)	(Twin)	$17.9	$14.2	$11.5
800-A2/S3A-54/19 41.9 mm (Twin)	**(Twin)**	$15.9	$12.6	**$10.2**
900-A2/S3A-84/7 43.6 mm (Twin)	(Twin)	$14.1	$11.2	$9.1
1000-A2/S3A-72/7 45.1 mm (Twin)	(Twin)	$12.7	$10.0	$8.1
1120-A2/S3A-72/19 47.7 mm (Twin)	(Twin)	$11.4	$9.0	$7.3
1250-A2/S3A-72/19 50.4 mm (Twin)	(Twin)	$10.2	$8.0	$6.5
1439-A1/S3A-84/19 51.4 mm (Twin)	(Twin)	$8.8	$7.0	$5.7
1250-A2/S3A-72/19 50.4 mm (Single)	(Single)	$20.3	$16.1	$13.0
1439-A1/S3A-84/19 51.4 mm (Single)	(Single)	$17.7	$14.0	$11.3
1871-A4-91 (58 mm) Single	(Single)	$13.6	$10.7	$8.7
COMPACT 2455-A1F 58.0 mm (Single)	**(Single)**	**$10.4**	**$8.2**	$6.6

(Notes: Options highlighted are precluded by Field Effect limitations.)

Table 3-13
Present Value of Annual Costs of Losses (@ 55°C Conductor Temperature) for Different Overhead Line Conductor Configurations (Discount rate = 8%. Operating Life 50 Years)

CONDUCTOR		PRESENT VALUE OF ANNUAL OF COST OF LOSSES (@$0.065/kWh)		
ID & Diameter (mm)	**Configuration**	**400 kVDC ($million)**	**450 kVDC ($million)**	**500 kVDC ($million)**
Scenario 1. Gull Island to Soldiers Pond Only				
710-A2/S3A-54/19 39.5 mm (Twin)	(Twin)	76 $	60 $	49 $
800-A2/S3A-54/19 41.9 mm (Twin)	**(Twin)**	67 $	53 $	**43 $**
900-A2/S3A-84/7 43.6 mm (Twin)	(Twin)	60 $	47 $	38 $
1000-A2/S3A-72/7 45.1 mm (Twin)	(Twin)	54 $	43 $	34 $
1120-A2/S3A-72/19 47.7 mm (Twin)	(Twin)	48 $	38 $	31 $
1250-A2/S3A-72/19 50.4 mm (Twin)	(Twin)	43 $	34 $	28 $
1439-A1/S3A-84/19 51.4 mm (Twin)	(Twin)	37 $	30 $	24 $
1250-A2/S3A-72/19 50.4 mm (Single)	**(Single)**	**86 $**	68 $	55 $
1439-A1/S3A-84/19 51.4 mm (Single)	(Single)	75 $	59 $	48 $
1871-A4-91 (58 mm) Single	(Single)	58 $	45 $	37 $
COMPACT 2455-A1F 58.0 mm (Single)	**(Single)**	44 $	**35 $**	28 $
Scenario 2. Gull Island to Soldiers Pond $ Salisbury				
710-A2/S3A-54/19 39.5 mm (Twin)	(Twin)	237 $	187 $	151 $
800-A2/S3A-54/19 41.9 mm (Twin)	**(Twin)**	210 $	166 $	**134 $**
900-A2/S3A-84/7 43.6 mm (Twin)	(Twin)	187 $	148 $	120 $
1000-A2/S3A-72/7 45.1 mm (Twin)	(Twin)	168 $	133 $	108 $
1120-A2/S3A-72/19 47.7 mm (Twin)	(Twin)	150 $	119 $	96 $
1250-A2/S3A-72/19 50.4 mm (Twin)	(Twin)	134 $	106 $	86 $
1439-A1/S3A-84/19 51.4 mm (Twin)	(Twin)	117 $	92 $	75 $
1250-A2/S3A-72/19 50.4 mm (Single)	(Single)	269 $	212 $	172 $
1439-A1/S3A-84/19 51.4 mm (Single)	(Single)	234 $	185 $	150 $
1871-A4-91 (58 mm) Single	(Single)	180 $	142 $	115 $
COMPACT 2455-A1F 58.0 mm (Single)	**(Single)**	**137 $**	**108 $**	88 $

(Notes: Options highlighted are precluded by Field Effect limitations.)

Table 3-14
Preliminary Submarine Cable Parameters

Scenario 1. Transmission From Gull Island to Soldiers Pond Only							
Section	Length (km)	Self Contained Oil Filled Number & Size (mm^2) of Cable Conductors/Pole			Mass Impregnated Number & Size (mm^2) of Cable Conductors/Pole		
		400 kV	450 kV	500 kV	400 kV	450 kV	500 kV
Strait of Belle Isle	30	1 x 1 600	1 x 1 500	1 x 1 300	1 x 1 800	1 x 1 600	1 x 1 500
Scenario 2. Transmission From Gull Island to Soldiers Pond & Salisbury							
Strait of Belle Isle	30		1 x 2 500	1 x 2 200		2 x 1 900	2 x 1 600
Cabot Strait	480		1 x 1 100 (MI)	1 x 1 000 (MI)		1 x 1 000	1 x 1 000

Table 3-15
Present Value of the Annual Costs of Losses for Submarine Cables

			SELD CONTAINED OIL FILLED SUBMARINE CABLES				MASS IMPREGNATED SUBMARINE CABLES			
Operating Voltage	ROUTE LENGTH (km)	FULL LOAD CURRENT (A)	Number and Conductor Size (mm2)	DC Resistance @55°C (ohms/km)	ANNUAL COST OF LOSSES @$0,065 Can/kWh $Can million)	PRESENT VALUE OF ANNUAL COST OF LOSSES @ 8% FOR 50 YEARS $Can million)	Number and Conductor Size (mm2)	DC Resistance @55°C (ohms/km)	ANNUAL COST OF LOSSES @$0,065 Can/kWh $Can million)	PRESENT VALUE OF ANNUAL COST OF LOSSES @ 8% FOR 50 YEARS $Can million)
Scenario 1. Gull Island to Soldiers Pond Only.										
SOBI CABLES										
400 kVDC	30	1000	1 x 1 600	0.01246	$0.04	$0.56	1 x 1 800	0.01114	$0.04	$0.50
450 kVDC	30	890	1 x 1 500	0.01334	$0.04	$0.47	1 x 1 600	0.01246	$0.03	$0.44
500 kVDC	30	800	1 x 1 300	0.01566	$0.03	$0.45	1 x 1 500	0.01334	$0.03	$0.38
Scenario 2. Gull Island to Soldiers Pond & to Salisbury										
SOBI CABLES										
400 kVDC										
450 kVDC	30	1800	1 x 2 500	0.00794	$0.17	$2.30	2 x 1 900	0.00524	$0.11	$1.52
500 kVDC	30	1600	1 x 2 200	0.00902	$0.16	$2.06	2 x 1 600	0.00623	$0.11	$1.43
CABOT STRAIT CABLES										
400 kVDC										
450 kVDC	480	900	1 x 1 100 (MI)	0.01797	$0.79	$10.41	1 x 1 100	0.01797	$0.79	$10.41
500 kVDC	480	800	1 x 1 000 (MI)	0.01940	$0.67	$8.88	1 x 1 000	0.01940	$0.67	$8.88
				TOTALS FOR SCENARIO 2				TOTALS FOR SCENARIO 2		
				400 kVDC				400 kVDC		
				450 kVDC	$0.96	$12.7		450 kVDC	$0.90	$11.92
				500 kVDC	$0.83	$10.9		500 kVDC	$0.78	$10.30

Table 3-16
Comparative Costs for Construction of Overhead Lines
(With Different Conductor Configurations)

Conductor	Type	Diameter (mm)	RTS (kN)	Configuration	Voltage (kV)	Total Line cost $/100 km
710-A2/S3A-54/19 39.5 mm (Twin)	ACSR	39.5	395.2	Twin	400	
					450	
					500	
800-A2/S3A-54/19 41.9 mm (Twin)	ACSR	41.9	445.3	Twin	400	
					450	
					500	
900-A2/S3A-84/7 43.6 mm (Twin)	ACSR	43.6	431.6	Twin	400	
					450	
					500	
1000-A2/S3A-72/7 45.1 mm (Twin)	ACSR	45.1	421.2	Twin	400	
					450	
					500	
1120-A2/S3A-72/19 47.7 mm (Twin)	ACSR	47.7	472.1	Twin	400	
					450	
					500	
1250-A2/S3A-72/19 50.4 mm (Twin)	ACSR	50.4	526.9	Twin	400	
					450	
					500	
1439-A1/S3A-84/19 51.4 mm (Twin)	ACSR	51.4	407.2	Twin	400	
					450	
					500	
1250-A2/S3A-72/19 50.4 mm (Single)	ACSR	50.4	526.9	Single	400	
					450	
					500	
1439-A1/S3A-84/19 51.4 mm (Single)	ACSR	51.4	407.2	Single	400	
					450	
					500	
1871-A4-91 (58 mm) Single	AAC	57.9	496	Single	400	
					450	
					500	
COMPACT 2455-A1F 58.0 mm (Single)	AAC	57.9	405	Single	400	
					450	
					500	

Details given in Appendix C. Table C-1

Details given in Appendix C Table C-3

Details given in AppendixC. Table C-2

Table 3-17
Comparative Total Cost Estimates for Overhead Transmission Lines

CONDUCTOR	CONSTRUCTION COSTS			Conductor Resistance (ohms/km @55°C	ANNUAL LOSSES (MWh)			ANNUAL COST OF LOSSES (@$0.065/kWh)			PRESENT VALUE OF ANNUAL COST OF LOSSES (Discount Rate = 8% & 50 years)			TOTAL COSTS INCLUDING PRESENT VALUE OF COST OF LOSSES		
ID & Diameter (mm)	400 kVDC ($million)	450 kVDC ($million)	500 kVDC ($million)		400 kVDC ($million)	450 kVDC ($million)	500 kVDC ($million)	400 kVDC ($million)	450 kVDC ($million)	500 kVDC ($million)	400 kVDC ($million)	450 kVDC ($million)	500 kVDC ($million)	400 kVDC ($million)	450 kVDC ($million)	500 kVDC ($million)
Scenario 1. Gull Island to Soldiers Pond Only																
710-A2/S3A-54/19 39.5 mm (Twin)														$1,001	$998	$997
800-A2/S3A-54/19 41.9 mm (Twin)														$987	$985	**$988**
900-A2/S3A-84/7 43.6 mm (Twin)														$1,022	$1,022	$1,025
1000-A2/S3A-72/7 45.1 mm (Twin)														$1,017	$1,018	$1,022
1120-A2/S3A-72/19 47.7 mm (Twin)														$1,012	$1,014	$1,018
1250-A2/S3A-72/19 50.4 mm (Twin)														$1,003	$1,006	$1,012
1439-A1/S3A-84/19 51.4 mm (Twin)														$1,026	$1,031	$1,037
1250-A2/S3A-72/19 50.4 mm (Single)														**$861**	$849	$847
1439-A1/S3A-84/19 51.4 mm (Single)														$861	$856	$855
1871-A4-91 (58 mm) Single														$897	**$897**	$899
COMPACT 2455-A1F 58.0 mm (Single)														$910	$913	$918
Scenario 2. Gull Island to Soldiers Por																
710-A2/S3A-54/19 39.5 mm (Twin)														$1,490	$1,457	$1,436
800-A2/S3A-54/19 41.9 mm (Twin)														$1,456	$1,428	**$1,414**
900-A2/S3A-84/7 43.6 mm (Twin)														$1,491	$1,468	$1,456
1000-A2/S3A-72/7 45.1 mm (Twin)														$1,473	$1,454	$1,445
1120-A2/S3A-72/19 47.7 mm (Twin)														$1,455	$1,440	$1,434
1250-A2/S3A-72/19 50.4 mm (Twin)														$1,434	$1,423	$1,419
1439-A1/S3A-84/19 51.4 mm (Twin)														$1,456	$1,448	$1,447
1250-A2/S3A-72/19 50.4 mm (Single)														$1,319	$1,270	$1,244
1439-A1/S3A-84/19 51.4 mm (Single)														**$1,298**	$1,263	$1,243
1871-A4-91 (58 mm) Single														$1,317	$1,295	$1,283
COMPACT 2455-A1F 58.0 mm (Single)														$1,310	**$1,297**	$1,293

Optimal Conductors

Optimal

Notes: Comparative Cost estimates do ***not*** include costs for operation and maintenance

Options highlighted are precluded by Field Effect limitations.

Table 3-18
Comparative Total Cost Estimates for Submarine Cables

	SELF CONTAINED OIL-FILLED CABLES					MASS IMPREGNATED CABLES				
Operating Voltage (kVDC)	Number of Cables & Conductor Size (mm^2)	Cable SUPPLY Costs ($Can Million)	Present Value of Costs of Losses ($Can Million)	TOTAL COST ($Can Million)	Incremental Cost ($Can Million)	Number of Cables & Conductor Size (mm^2)	Cable SUPPLY Costs ($Can Million)	Present Value of Costs of Losses ($Can Million)	TOTAL COST ($Can Million)	Incremental Cost ($Can Million)
Scenario 1. Gull Island to Soldiers Pond Only										
Strait of Belle Isle (30 km)										
+/- 400 kV	3 x 1 600 mm^2									
+/- 450 kV	3 x 1 500 mm2									
+/- 500 kV	3 x 1 300 mm2									
Strait of Belle Isle (30 km)										
+/- 400 kV										
+/- 450 kV	3 x 2 500 mm2									
+/- 500 kV	3 x 2 200 mm2									
Cabot Strait 460 km										
+/- 400 kV										
+/- 450 kV	2 x 1100									
+/- 500 kV	2 x 1000									
+/- 400 kV										
+/- 450 kV										
+/- 500 kV										

Notes: Comparative Cost estimates do ***not*** include costs for cable laying and protection, nor costs for operation and maintenance.

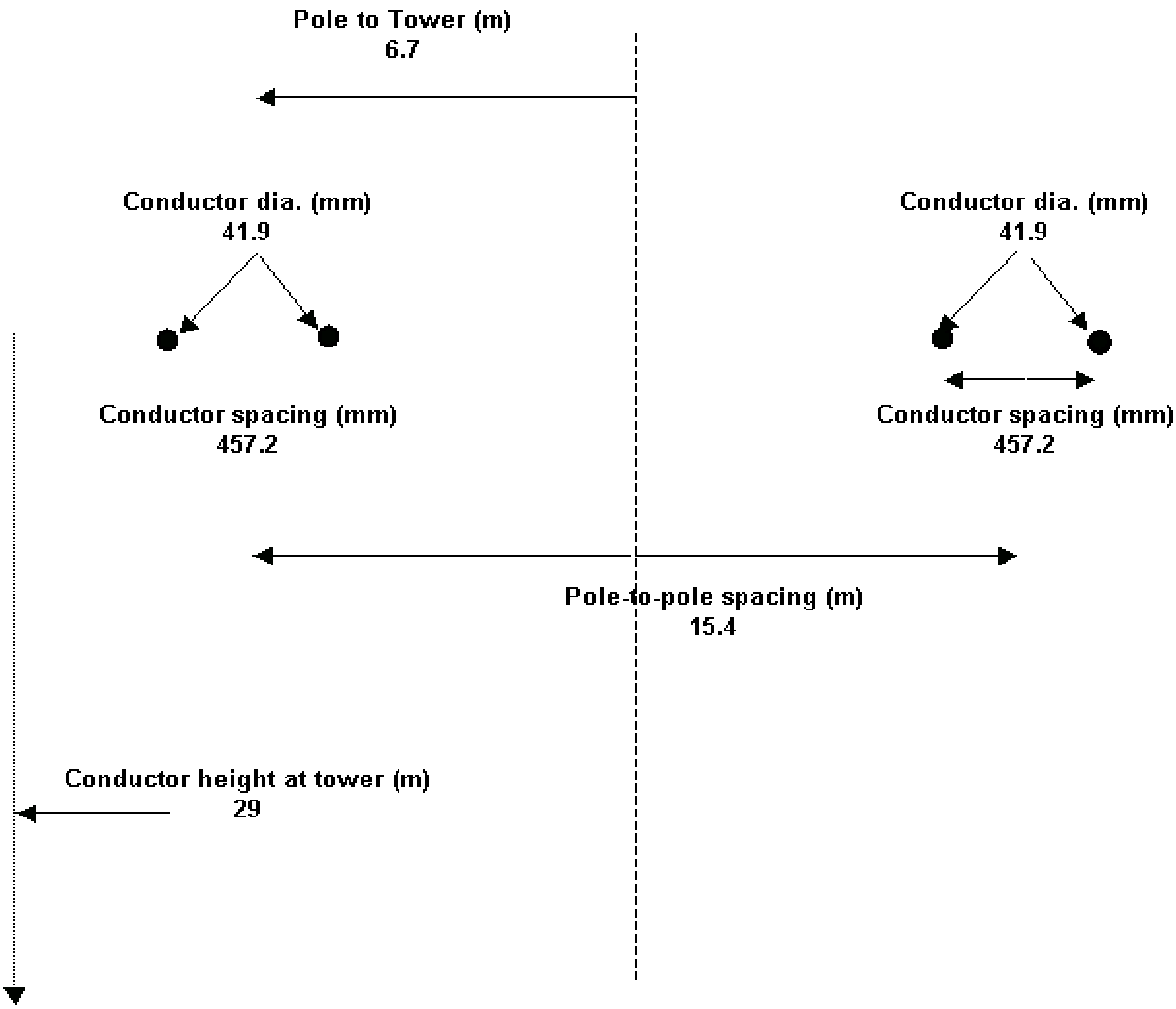
The SCOF option in Scenario 2 uses MI cables for the Cabot Strait Crossing.

Table 3-19
Comparative Cost Estimates for HVdc Converter Station Construction

Comparative Costs for HVDC Converter Stations					
Scenario 1. Gull Island to Soldiers Pond Only					
Operating Voltage (kVDC)	Gull Island **1 200 MW** ($Can million)	Soldiers Pond **1 200 MW** ($Can million)	Salisbury **800 MW** ($Can million)	Total Converter Station Costs ($Can Million)	**Incremental Cost ($Can Million)**
+/- 400 kV					
+/- 450 kV					
+/- 500 kV					
Scenario 2. Gull Island to Soldiers Pond & Salisbury					
Operating Voltage (kVDC)	Gull Island **2 080 MW**	Soldiers Pond **1 200 MW**	Salisbury **880 MW**	Total Converter Station Costs	**Incremental Cost**
+/- 400 kV					
+/- 450 kV					
+/- 500 kV					

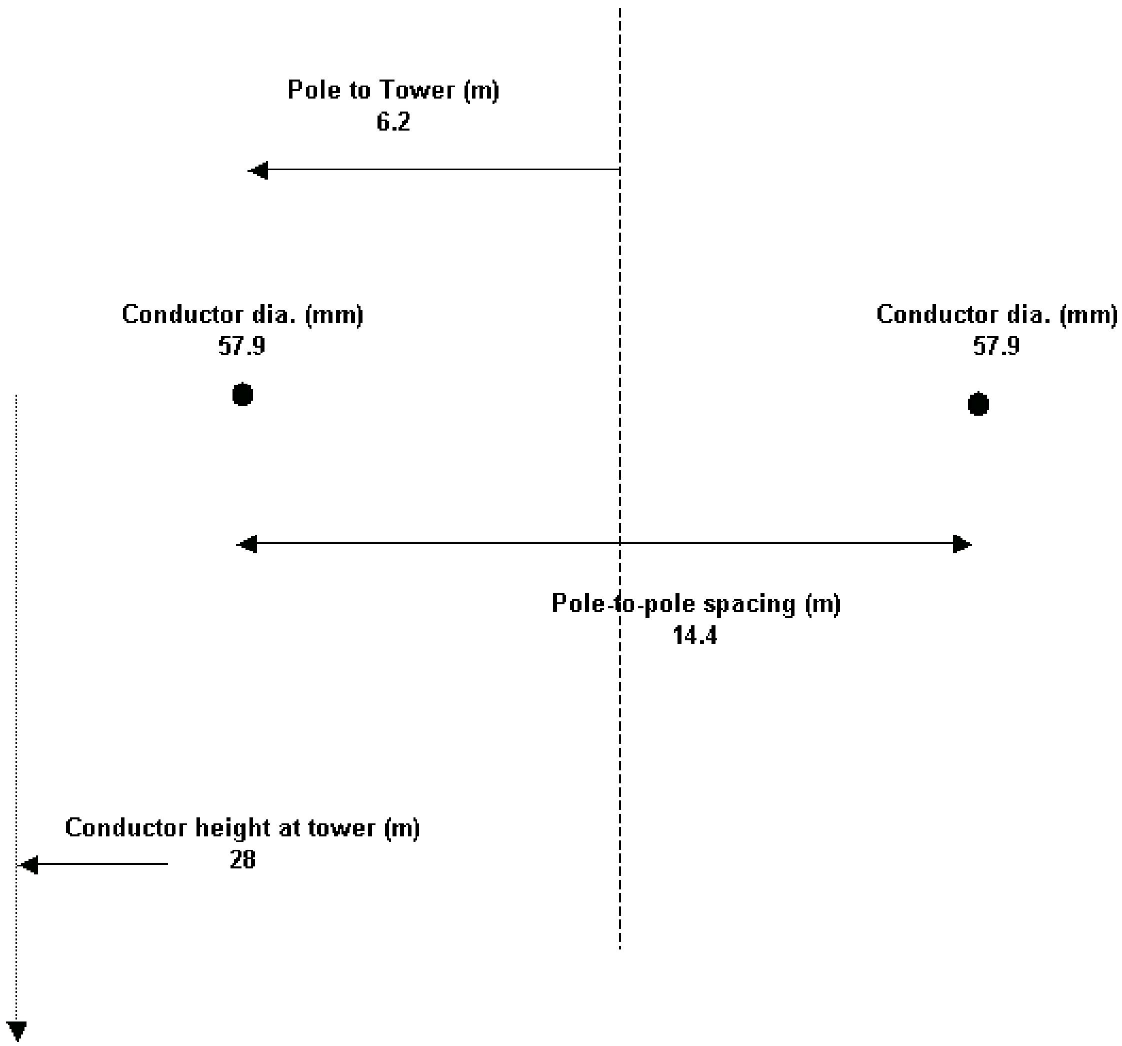
Notes: Comparative Cost estimates do ***not*** include costs for operation and maintenance.

Figure 3-1
Sketch of Preliminary ±500 kVdc Tower Configuration for Corona and Field Effect Analysis



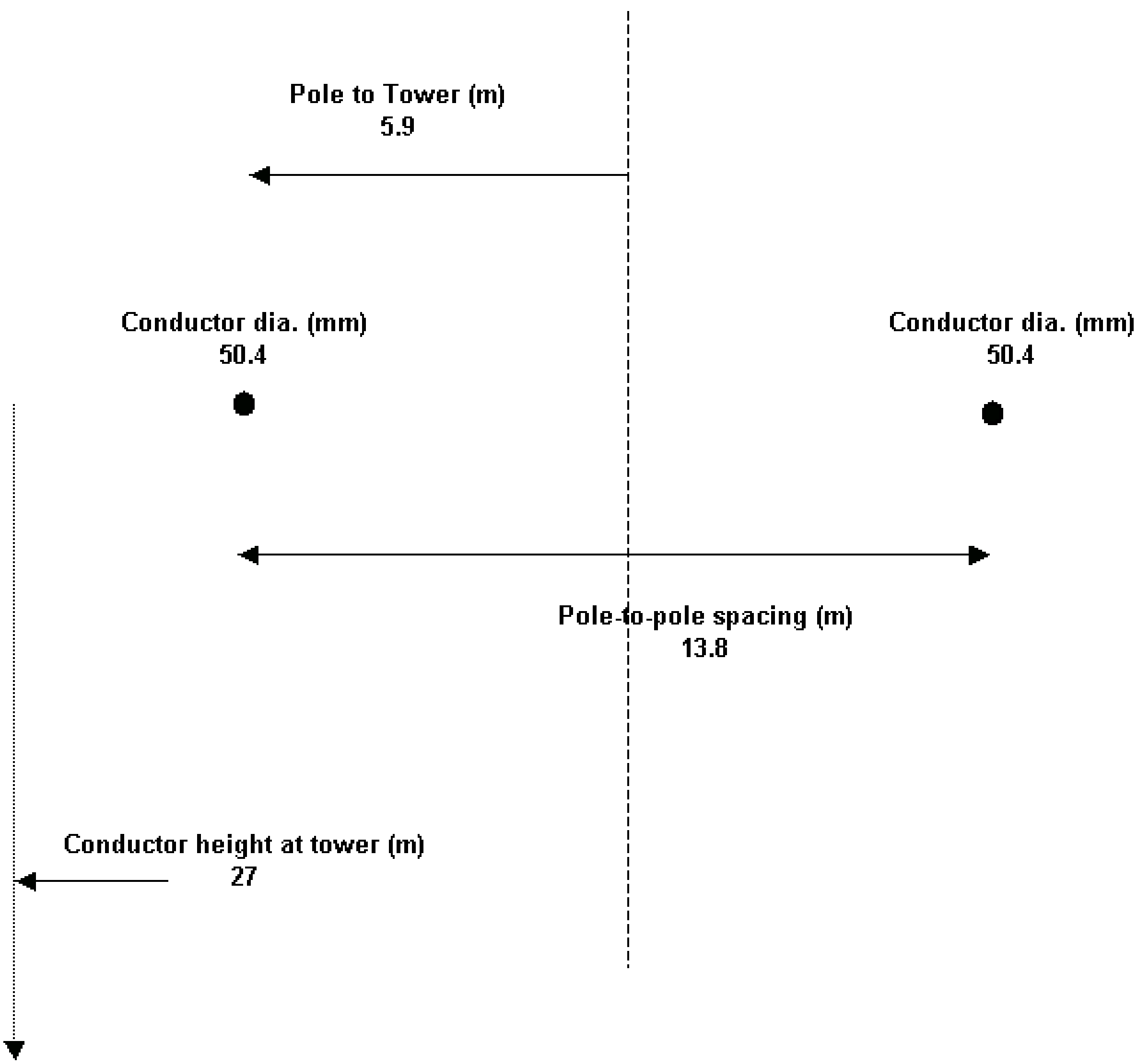
Conductor height at bottom of sag (m)	10
Conductor sag @ 20^0 C(m)	15.4
Conductor mean height (m)	15.1
Right of Way (m)	60
Distance to measurement point (m)	27.0

Figure 3-2
Sketch of Preliminary ±450 kVdc Tower Configuration for Corona and Field Effect Analysis



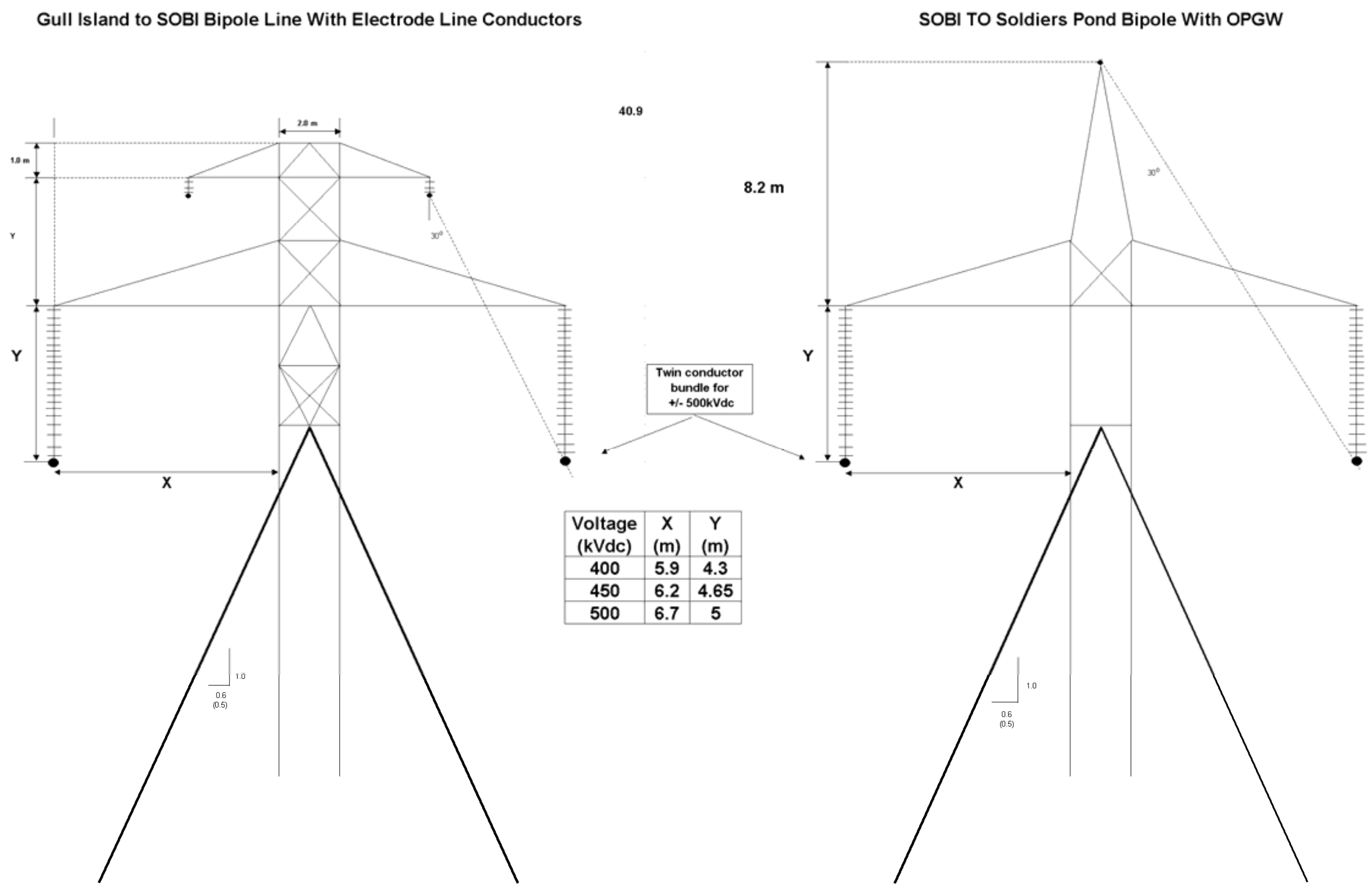
Conductor height at bottom of sag (m)	9.7
Conductor sag @ 20^0 C(m)	15.4
Conductor mean height (m)	14.8
Right of Way (m)	60
Distance to measurement point (m)	27.2

Figure 3-3
Sketch of Preliminary ±400 kVdc Tower Configuration for Corona and Field Effect Analysis



Conductor height at bottom of sag (m)	9.4
Conductor sag @ 20^0 C(m)	15.4
Conductor mean height (m)	14.5
Right of Way (m)	60
Distance to measurement point (m)	27.3

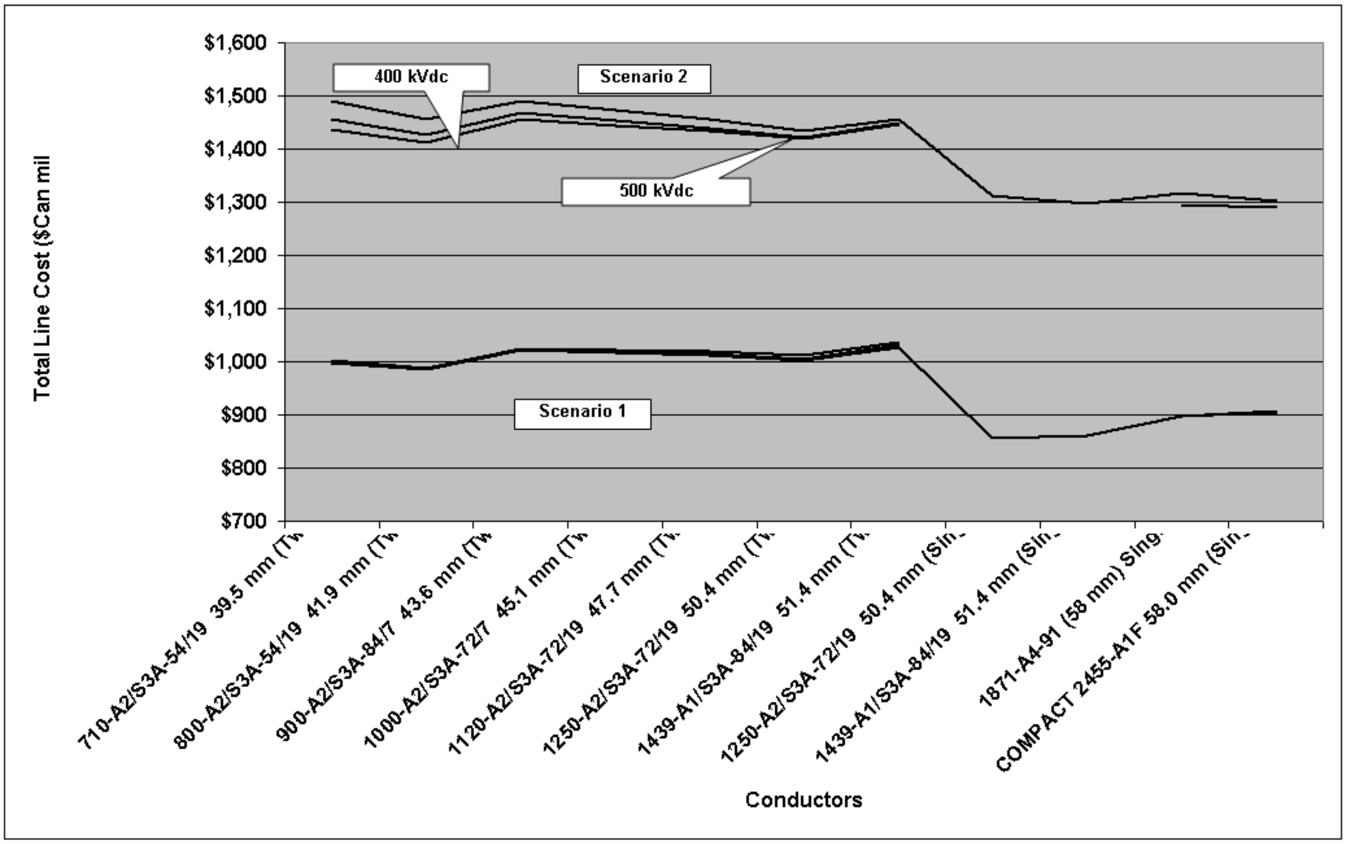
Figure 3-4
Typical HVdcTower Configurations for Weight & Cost Estimates



Voltage (kVdc)	X (m)	Y (m)
400	5.9	4.3
450	6.2	4.65
500	6.7	5

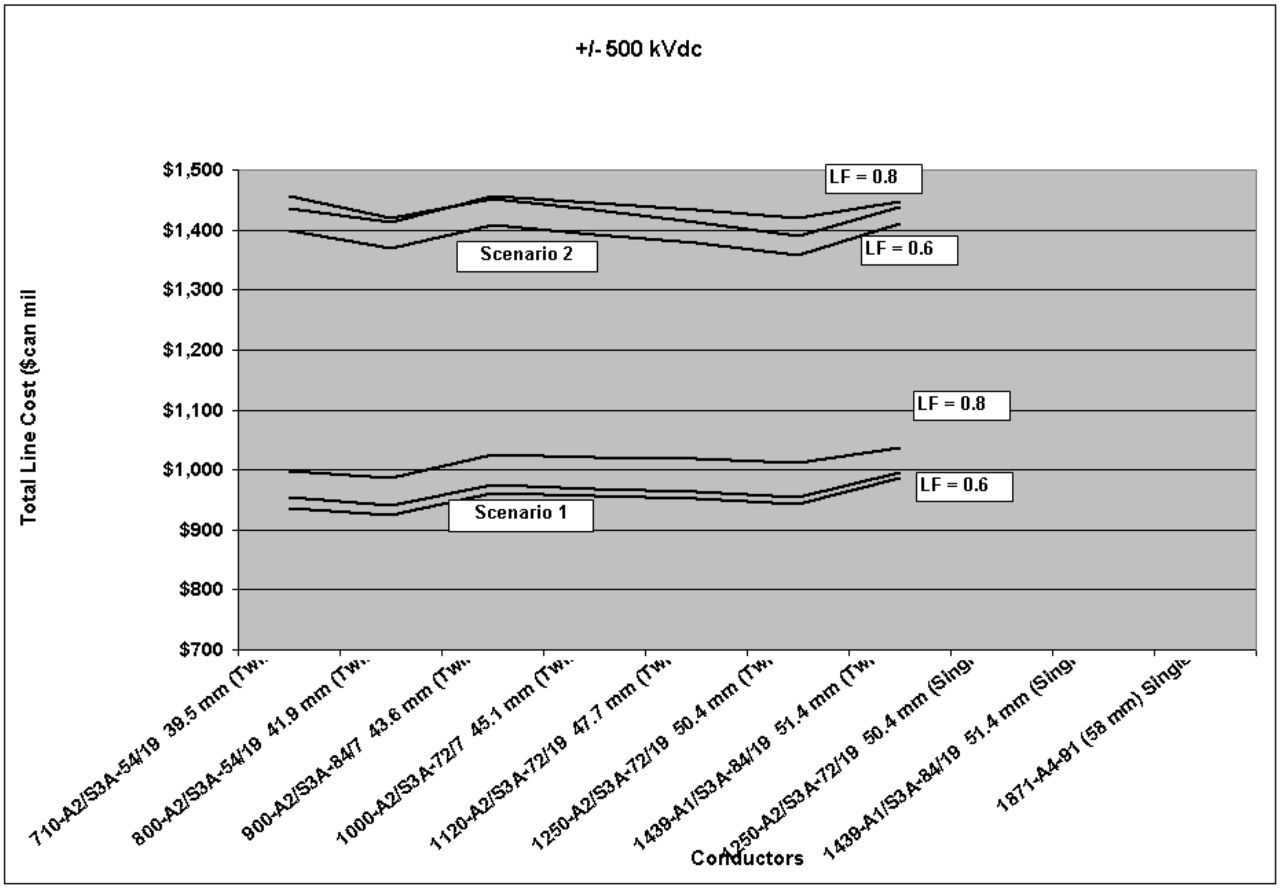
Note: The final configurations for towers and accessories are found in the report on WTO DC1080 “Tower Type Selection”.

Figure 3-5
Comparative Cost Estimates For Overhead Transmission Lines
As Functions of Conductor Size and Voltages



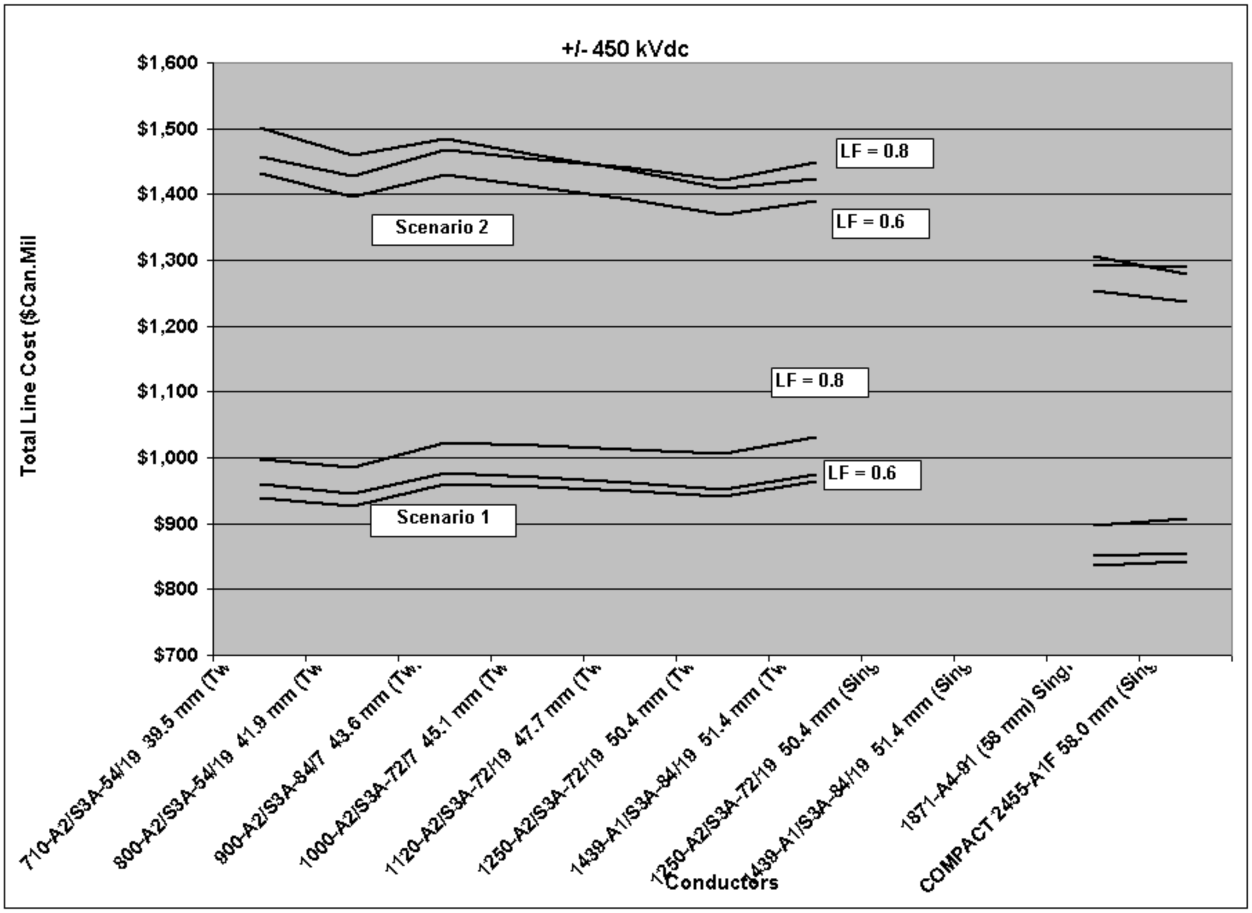
Notes: All single conductor options are precluded for ±500 kVdc because of Field Effects
50.4 mm and 51.4 mm diameter single conductor options are precluded for ±450 kVdc because of Field Effects

Figure 3-6
Comparative Cost Estimates for ±500 kVdc Overhead Transmission Lines
As Functions of Load Factors (0.6, 0.7 & 0.8)



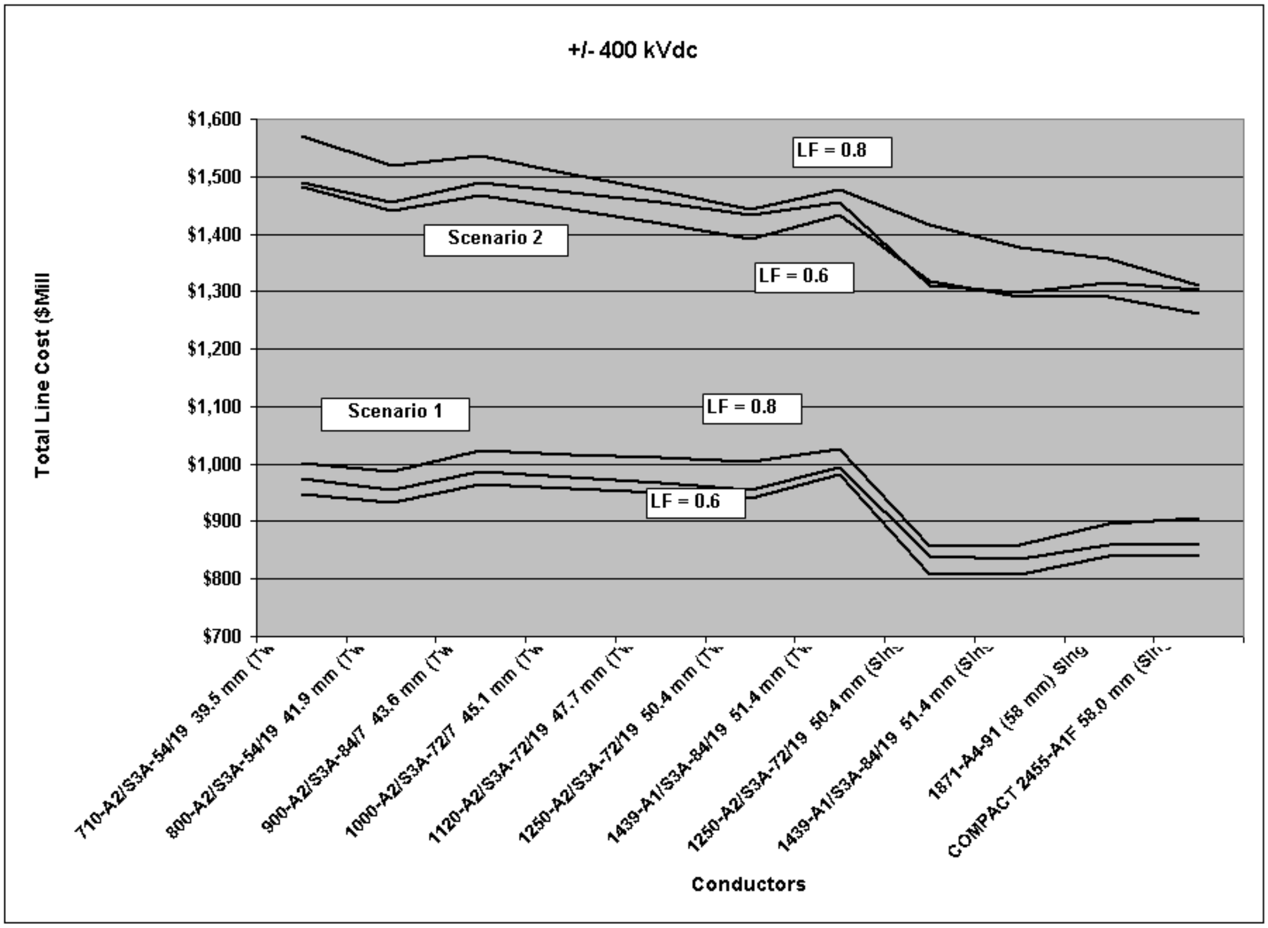
Notes: All single conductor options are precluded for ±500 kVdc because of Field Effects

Figure 3-7
Comparative Cost Estimates for ±450 kVdc Overhead Transmission Lines
As Functions of Load Factors (0.6, 0.7 & 0.8)



Notes: 50.4 mm and 51.4 mm diameter single conductor options are precluded for ±450 kVdc because of Field Effects

Figure 3-8
Comparative Cost Estimates for ± 400 kVdc Overhead Transmission Lines
As Functions of Load Factors (0.6, 0.7 & 0.8)



4. Discussion of Results

4.1 Technologies

The Lower Churchill Project HVdc transmission system will comprise converter stations, submarine cables and HVdc overhead transmission lines. All are well-proven technologies at operating voltages of ±400, ±450, ±500 kVdc, and HVdc transmission systems have been in operation, worldwide, for more than 40 years.

A number of manufacturers and contractors would be pre-qualified to bid on the HVdc converter stations and the HVdc overhead lines, at voltages between ±400 and ±500 kVdc.

Self Contained Oil Filled (SCOF) or Mass Impregnated (MI) submarine cables could be used at ±400, ±450 or ±500 kVdc, and either could be used for the Strait of Belle Isle crossing

The advantage of SCOF cables is that they can be designed for a higher conductor temperature and higher electrical gradient because the insulation is pressurised under all operating conditions. The disadvantage is that the oil has to be transported along the cable length to/from the pressure tanks or pumping plants at both ends of the cable, and the dynamic pressure drop in oil flow along the cable limits the maximum length of SCOF submarine cable to approximately 50 km so SCOF cable could be used for the SOBI crossing but not for the Cabot Strait crossing. Also, although the insulating oil has a low viscosity and would evaporate from the surface of the sea, the possibility of long-term oil discharge while waiting for cable repairs may cause environmental concerns.

MI cable could be used for the SOBI or the Cabot Strait crossing.

Several manufacturers, world-wide, would be pre-qualified to bid on SCOF cables up to ±500 kVdc and on MI cables up to ±450 kVdc, but when the LCP project is in the bidding phase, only European manufacturers may be able to submit operating experience for MI cables at ±500 kVdc.

4.2 HVdc Overhead Transmission Lines

The limiting parameter in the selection of conductor configuration is the Radio Interference Level at the edge of the Right-of-Way, which is recommended to be 65 dB at 1 MHz.

The HVdc overhead line will pass through regions of extreme icing, and there may be a benefit if a single pole conductor is used instead of a twin bundle conductor.

The conductor manufacturers have advised that the largest conductor that has been manufactured and delivered had a diameter of 58.7 mm. The corona and field effect analysis showed that a single 58 mm diameter conductor per pole could be used for ±450 kVdc and ±400 kVdc.

For ±500 kVdc transmission, the analysis showed that a 70 mm diameter conductor would be required for a single conductor configuration, which would be beyond present manufacturing capabilities. The optimal configuration for ±500 kVdc would be a twin conductor bundle with a conductor diameter of 41.9 mm.

4.3 Comparative Cost Estimates

Generic tower designs were used to estimate the tower weights (and costs) for each operating voltage, with a range of conductors that would meet the mechanical loading and corona requirements. The analysis showed that tower weights would be most affected by the Rated Tensile Strength of the conductors, which determines the sag and therefore the tower height and spans, not by the operating voltage or the size of the conductor.

A comparison of total transmission line costs (including present values of the costs of losses) with the optimal conductor configuration for each operating voltage is given below.

		Total Comparative Cost Estimates For Overhead Transmission Lines ($Million)		
		±400 kVdc	±450 kVdc	±500 kVdc
Scenario 1	Conductor	(Single 50.4 mm)	(Single 58.0 mm)	(Twin 41.9 mm)
	Total Cost	$861	$897	$988
	Diffferential	Least Cost	$35	$126
			4%	15%
Scenario 2	Conductor	(Single 51.4 mm)	(Single 58.0 mm)	(Twin 41.9 mm)
	Total Cost	$1,298	$1,297	$1,414
	Diffferential	$1	Least cost	$117
		0%		9%

The same size optimal conductor diameters are selected for both scenarios for ±450 kVdc (58 mm) and ±500 kVdc (41.9 mm).

For the ±400 kVdc option, although different optimal conductor diameters are selected for Scenario 1 (50.4 mm) and Scenario 2 (51.4 mm), the differential total line costs between the two are less than 1%. Further optimization will be required in collaboration with fabricators to determine the optimal conductor diameter and strength.

For Scenario 2, the differential total line costs for ±400 kVdc, ±450 kVdc and ±500 kVdc is 10%, which is less than the accuracy of comparative cost estimates. The percentage differences are further reduced when the supply costs for submarine cables and converter stations are included

The analysis shows that, within the level of accuracy of comparative cost estimates, the total transmission system costs are substantially the same for all operating voltages.

However, within these accuracy limits, the least cost options for the HVdc overhead lines would be:

Scenario 1

- ±400 kVdc with a single, 50.4 mm diameter conductor.
- ±450 kVdc with a single, 58.0 mm diameter conductor.
- ±500 kVdc with a twin 41.9 mm diameter conductor.

Scenario 2

- ±400 kVdc with a single, 51.4 mm diameter conductor.
- ±450 kVdc with a single, 58.0 mm diameter conductor.
- ±500 kVdc with a twin 41.9 mm diameter conductor.

A detailed estimate of the HVdc transmission line costs in their recommended configuration can be found in the Final Report on WTO DC1200 “HVdc Overland Transmission Re-estimate”. The differences between the final recommended configurations and those used in the comparative estimates do not effect the selection of optimal voltage or conductor configurations.

4.4 Comments and Conclusions

The comparative cost estimates for the submarine cables and HVdc converter stations at the three operating voltages do not affect the choice of optimal operating voltage. Therefore it is concluded that, if the Lower Churchill Project is staged with Scenario 2 to Salisbury constructed some time after Scenario 1 to Soldiers Pond, there would be no significant difference in the comparative cost estimates whichever operating voltage is selected for Scenario 1.

If there is a reasonable probability that Scenario 2 will proceed, the Gull Island Converter Station and the Strait of Belle Isle submarine cables should be installed with the full 1,600 MW rated capacity during Scenario 1 construction. Also, the Taylor’s Brook switching station should be constructed with isolation capabilities to minimize power disruptions to Soldiers Pond when the line to Cape Ray is constructed and commissioned.

Operating at ±400 kVdc or ±450 kVdc gives the option of using a single pole conductor, which would be beneficial in regions of heavy ice loads. Single pole conductors are not possible for ±500 kVdc because of Radio Interference limitations.

If ±400 kVdc is chosen for Scenario 2, an operating restriction may be required for the Salisbury Converter Station to permit the 100% overload at Soldiers Pond while limiting the Gull Island converter current to 3 000 A.

Although there would be a relatively small difference between the total project costs for the three operating voltages, within the accuracy limits of the comparative cost estimates the least cost option for the HVdc overhead lines would be:

- Scenario 1 ±400 kVdc with a single, 50.4 mm diameter conductor.
- Scenario 2 ±450 kVdc with a single, 58.0 mm diameter conductor.

However, because each operating voltage is technically acceptable, and there is a small comparative cost difference between the three operating voltages, it may be beneficial to retain all three options to maximize the competition during the tendering phase

Appendix A

Referenced Technical Documents

Technical Publications on Voltage and Conductor Selection for HVdc Transmission

Published by IEEE

- IEEE, "HVdc Projects Listing Prepared For The DC And Flexible AC Transmission Subcommittee Of The IEEE Transmission And Distribution Committee By The Working Group On HVdc And FACTS", Bibliography And Records, January 2006.
- Optimized Conductor And Conductor Bundle Solutions For Long Distance HVdc Transmission
- Environmental Characteristics Of HVdc Overhead Transmission Lines
- Third Workshop on Power Grid Interconnection in Northeast Asia, Vladivostok 2003
- A New Approach to Calculate the Ionized Field of HVdc Transmission Lines in the Space and on the Earth Surface. Ref: International Conference on Power System Technology (POWERCON2006), Chongqing, China, October 22-26, 2006.
- HVdc transmission and the environment
- Power Engineering Journal [see also Power Engineer] Volume 10, Issue 5, Oct. 1996 Page(s):204 - 210
- EM Environmental Evaluation of HVdc Transmission Lines.
- Environmental Electromagnetics, The 2006 4th Asia-Pacific Conference on Aug. 2006 Page(s):260 - 262 Digital Object Identifier 10.1109/CEEM.2006.257948
- A New Approach to Calculate the Ionized Field of HVdc Transmission Lines in the Space and on the Earth Surface. Power System Technology, 2006. PowerCon 2006. International Conference on Oct. 2006 Page(s):1 - 7
- Degree of corona saturation for HVdc transmission lines
  Power Delivery, IEEE Transactions on Volume 5, Issue 2, April 1990 Page(s):695 - 707 Digital Object Identifier 10.1109/61.53072

Published by CIGRE

- Tian Guang HVdc power transmission project - Design aspects and realization experience. Ref: 14-110_2002
- Ge-Nan ±500 kV HVdc transmission system operation analysis
- Ref: 14-115_1998
- Economic assessment of HVdc links. 2002 Ref: 186
- IMPACTS OF HVdc LINES ON ECONOMICS OF HVdc PROJECTS: Electric and mechanical performance of HVdc system (Transmission Lines + Converter Stations) with economical cost evaluation). Ref: B2-17 JWG-B2-B4-C1
- AG B4.04 Compendium of HVdc Schemes Throughout the World 2005

Published by EPRI

- HVdc Transmission Line Reference Book. September 1993

Appendix B

HVDC Projects Listing

HVDC PROJECTS LISTING

Prepared for the
DC and Flexible AC Transmission Subcommittee
of the
IEEE Transmission and Distribution Committee
by the
Working Group on HVDC and FACTS Bibliography and Records

SYSTEM / PROJECT	HVDC SUPPLIER	YEAR COMMISSIONED	POWER RATING (MW)	DC VOLTAGE (kV)	LINE/ CABLE (km)	MERCURY/ THYRISTOR/ TRANSISTOR	LOCATION
MOSOW-KASHIRA (retired from service)	RUSSIAN	1951 (____)	30	±100	100	MERC	RUSSIA
GOTLAND I (retired from service)	ASEA	1954 (1986)	20	±100	96	MERC	SWEDEN
GOTLAND EXTENSION (retired from service)	ASEA	1970 (1986)	30	±150	96	THY	SWEDEN
GOTLAND II	ASEA	1983	130	150	100	THY	SWEDEN
GOTLAND III	ASEA	1987	260	±150	103	THY	SWEDEN
GOTLAND HVDC LIGHT	ABB	1999	50	±60	70	TRA	SWEDEN
ENGLISH CHANNEL (retired from service)	ASEA	1961 (____)	160	±100	64	MERC	ENGLAND-FRANCE
VOLGOGRAD-DONBASS	MINISTRY FOR ELECTROTECHNICAL INDUSTRY OF USSR	1962/65	720	±400	473	MERC/THY	RUSSIA
NEW ZEALAND HYBRID INTER ISLAND LINK	ASEA	1965	600	±250	609	MERC	NEW ZEALAND
NEW ZEALAND HYBRID INTER ISLAND LINK	ABB	1992	1240	+270/-350	612	THY	NEW ZEALAND
NEW ZEALAND HYBRID INTER ISLAND LINK		PLANNED				THY	NEW ZEALAND
KONTI-SKAN 1	ASEA	1965	250	±250	180	MERC	DENMARK-SWEDEN
KONTI-SKAN 1	AREVA	2005	250	±250	180	THY	DENMARK-SWEDEN
KONTI-SKAN 2	ASEA	1988	300	285	150	THY	DENMARK-SWEDEN
SAKUMA (retired from service)	ASEA	1965 (____)	300	2x125	B-B	MERC	JAPAN
SARDINIA (retired from service)	ENGLISH ELECTRIC	1967 (____)	200	200	413	MERC	ITALY
VANCOUVER I	ASEA	1968/69	312	±260	74	MERC	CANADA
VANCOUVER II	GENERAL ELECTRIC	1977/79	370	±280	74	THY	CANADA
PACIFIC INTERTIE	ASEA/GE	1970	1440	±400	1362	MERC	U.S.A
PACIFIC INTERTIE	ASEA/GE	1982	1600	±400	1362	MERC	U.S.A
PAC INTERTIE UPGRADE	ASEA	1985	2000	±500	1362	THY	U.S.A
PACIFIC INTERTIE EXPANSION	BROWN BOVERI	1989	3100	±500	1362	THY	U.S.A
KINGSNORTH (retired from service)	ENGLISH ELECTRIC	1972 (1987)	640	±266	82	THY	UNITED KINGDOM
EEL RIVER	GENERAL ELECTRIC	1972	320	±80	B-B	THY	CANADA
NELSON RIVER 1	ENGLISH ELECTRIC/GEC ALSTHOM	1973	1854	±463	890	MERC	CANADA
NELSON RIVER 1	GEC ALSTHOM	1992/93	1854	±463	890	MERC/THY	CANADA
NELSON RIVER 1	SIEMENS	2001/02	1854	±463	890	THY	CANADA
NELSON RIVER 2	AEG/BBC/SIEMENS	1978	900	±250	940	THY	CANADA
NELSON RIVER 2	AEG/BBC/SIEMENS	1985	2000	±500	940	THY	CANADA
SKAGERRAK I	ASEA	1976	275	±250	240	THY	NORWAY-DENMARK
SKAGERRAK II	ASEA	1977	275	±250	240	THY	NORWAY-DENMARK
SKAGERRAK III	ABB	1993	500	±350	240	THY	NORWAY-DENMARK
SHIN-SHINANO 1	HITACHI/TOSHIBA/NISSHIN	1977	300	125	B-B	THY	JAPAN
SHIN-SHINANO 2	HITACHI/TOSHIBA/NISSHIN	1992	300	125	B-B	THY	JAPAN
SQUARE BUTTE	GENERAL ELECTRIC	1977	500	±250	749	THY	U.S.A.
DAVID A. HAMIL	GENERAL ELECTRIC	1977	100	±50	B-B	THY	U.S.A
CAHORA-BASSA	AEG/BBC/SIEMENS	1977/78/79	1920	±533	1420	THY	SOUTH AFRICA
C.U.	ASEA	1979	1000	±400	701	THY	U.S.A
HOKKAIDO-HONSHU	ASEA	1979	150	125	167	THY	JAPAN
HOKKAIDO-HONSHU	HITACHI/TOSHIBA	1980	300	250	167	THY	JAPAN
HOKKAIDO-HONSHU	HITACHI/TOSHIBA	1993	600	±250	167	THY	JAPAN
ACARAY	SIEMENS	1981	50	±25.6	B-B	THY	PARAGUAY-BRAZIL
VYBORG	MINISTRY FOR ELECTROTECHNICAL INDUSTRY OF USSR	1981	355	1X170(±85)	B-B	THY	RUSSIA-FINLAND
VYBORG	MINISTRY FOR ELECTROTECHNICAL INDUSTRY OF USSR	1982	710	2x170	B-B	THY	RUSSIA-FINLAND
VYBORG	MINISTRY FOR ELECTROTECHNICAL INDUSTRY OF USSR	1984	1065	3x170	B-B	THY	RUSSIA-FINLAND
VYBORG	MINISTRY FOR ELECTROTECHNICAL INDUSTRY OF USSR	1999	4x405	±85	B-B	THY	RUSSIA-FINLAND
ZHOU SHAN PROJECT		1982	50	100	42	THY	CHINA
INGA-SHABA	ASEA/GE	1982/83	560	±500	1700	THY	ZAIRE
DUERNROHR 1 (retired from service)	AEG/BBC/SIEMENS	1983 (1997)	550	145	B-B	THY	AUSTRIA
EDDY COUNTY	GENERAL ELECTRIC	1983	200	82	B-B	THY	U.S.A.
CHATEAUGUAY	BBC/SIEMENS	1984	2x500	2x140.6	B-B	THY	CANADA-U.S.A.
OKLAUNION	GENERAL ELECTRIC	1984	200	82	B-B	THY	U.S.A
ITAIPU 1	ASEA	1984	1575	±300	807	THY	BRAZIL
ITAIPU 1	ASEA	1985	2383	±300	807	THY	BRAZIL
ITAIPU 1	ASEA	1986	3150	±600	807	THY	BRAZIL
ITAIPU 2	ASEA	1987	3150	±600	818	THY	BRAZIL
BLACKWATER	BBC	1985	200	57	B-B	THY	U.S.A.
SACOI	CGEE/ALSTHOM	1985	200	200	415	THY	ITALY-CORSICA-SARDINIA
SACOI THREE TERMINAL	CGEE/ALSTHOM	1993	300	±200	385	THY	ITALY-CORSICA-SARDINIA
HIGHGATE	ASEA	1985	200	±56	B-B	THY	U.S.A.
MADAWASKA	GENERAL ELECTRIC	1985	350	130.5	B-B	THY	CANADA
MILES CITY HVDC SYSTEM (MCCS)	GENERAL ELECTRIC	1985	200	82	B-B	THY	U.S.A
BROKEN HILL	ASEA	1986	40	2x17 (±8.33)	B-B	THY	AUSTRALIA
INTERMOUNTAIN POWER PROJECT (I.P.P.)	ASEA	1986	1920	±500	785	THY	U.S.A.
CROSS CHANNEL BP 1+2	CGEE-ALSTHOM/GEC-ALSTHOM	1985/86	2000	±270	70	THY	FRANCE-U.K.
DES CANTONS-COMFERFORD	GENERAL ELECTRIC	1986	690	±450	172	THY	CANADA-U.S.A.
QUEBEC-NEW ENGLAND	GE/ABB	1986/92	2250	±450	1500	THY	CANADA-U.S.A.
VIRGINIA SMITH	SIEMENS	1987	200	50	B-B	THY	U.S.A
GESHA (GEZHOUBA-SHANGHAI)	ABB/SIEMENS	1989	600	500	1000	THY	CHINA
GESHA (GEZHOUBA-SHANGHAI)	ABB/SIEMENS	1990	1200	±500	1046	THY	CHINA
VINDHYACHAL	ASEA	1989	500	2x69.7	B-B	THY	INDIA
McNEILL	GEC ALSTHOM	1989	150	42	B-B	THY	CANADA
FENNO-SKAN	ABB/ALCATEL	1989/98	572	±400	233	THY	FINLAND-SWEDEN
FENNO-SKAN 2		PLANNED 2010	800	500	233	THY	FINLAND-SWEDEN
BARSOOR LOWER SILERU	BHEL	1989/91	100	±200	196	THY	INDIA
BARSOOR LOWER SILERU	BHEL	FUTURE	400			THY	INDIA
RIHAND-DELHI	ABB/BHEL	1991	750	500	814	THY	INDIA
RIHAND-DELHI	ABB/BHEL	1992	1500	±500	814	THY	INDIA
NICOLET TAP	ASEA	1992	2000				CANADA
SAKUMA	HITACHI/TOSHIBA/MITSUBISHI/NISSHIN	1993	300	±125	B-B	THY	JAPAN
ETZENRICHT (retired from service)	SIEMENS	1993 (1997)	600	160	B-B	THY	GERMANY-CZECH REPUBLIC
VIENNA SOUTH-EAST (retired from service)	SIEMENS	1993 (1997)	600	145	B-B	THY	AUSTRIA-HUNGARY
URUGUAIANA	TOSHIBA	1994	50	15	B-B	THY	BRAZIL-ARGENTINA
BALTIC CABLE	ABB	1994	600	±450	261	THY	SWEDEN-GERMANY
WELSH	SIEMENS	1995	600	162	B-B	THY	U.S.A
KONTEK	ABB/NKT CABLES	1995	600	400	171	THY	DENMARK-GERMANY
HAENAM-CHEJU	GEC ALSTHOM	1997	300	±180	101	THY	SOUTH KOREA
CHANDRAPUR-RAMAGUNDUM	GEC ALSTHOM	1997/98	1000	2x205	B-B	THY	INDIA
CHANDRAPUR-PADGHE	ABB	1998	1500	±500	736	THY	INDIA
LEYTE-LUZON	ABB/MARUBENI	1998	440	350	455	THY	PHILIPPINES
VISAKHAPATNAM	GEC ALSTHOM	1998	500	205	B-B	THY	INDIA
MINAMI-FUKUMITZU	HITACHI/TOSHIBA	1999	300	125	B-B	THY	JAPAN
VIZAG 1	GEC ALSTHOM	1999	500	205	B-B	THY	INDIA
VIZAG 2	ABB	2005	500	±88	B-B	THY	INDIA
KAALAMO		PLANNED 1999	40	20	B-B	THY	FINLAND
NORTH-SOUTHEAST		PLANNED 1999	1000			THY	BRAZIL
SWEPOL LINK	ABB	2000	600	±450	254	THY	SWEDEN-POLAND
DIRECTLINK	ABB	2000	3 x 60	±80	59	TRA	AUSTRALIA
KII CHANNEL	HITACHI/TOSHIBA/MITSUBISHI	2000	1400	±250	102	THY	JAPAN
KII CHANNEL		FUTURE	2800	±500	102	THY	JAPAN
GARABI 1	ABB	2000	1100	±70	B-B	THY	ARGENTINA-BRAZIL
GARABI 2	ABB	2002	2000	±70	B-B	THY	ARGENTINA-BRAZIL
RIVERA	GEC ALSTHOM	2000	70	20	B-B	THY	URUGUAY-BRAZIL
GRITA	PIRELLI/ABB	2001	500	400	316	THY	GREECE-ITALY
TIAN-GUANG	SIEMENS	2001	1800	±500	960	THY	CHINA
HIGASHI-SHIMIZU	HITACHI/TOSHIBA	2001	300	125	B-B	THY	JAPAN
MOYLE INTERCONNECTOR	SIEMENS	2001	2x250	2x250	64	THY	UNITED KINGDOM
THAILAND-MALAYSIA	SIEMENS	2001	300	±300	110	THY	THAILAND-MALAYSIA
MANTARO-SOCABAYA		PLANNED 2001	300	±190	640	THY	PERU
CROSS SOUND	ABB	2002	330	±150	40	TRA	U.S.A
MURRAYLINK	ABB	2002	200	±150	176	TRA	AUSTRALIA
SASARAM	GEC ALSTHOM	2002	500	205	B-B	THY	INDIA
IB VALLEY-JAIPUR		PLANNED 2002	3000			THY	INDIA
EUROCABLE		PLANNED 2002	600	500	600	THY	NORWAY-GERMANY
RAPID CITY TIE	ABB	2003	2 x 100	±13	B-B	THY	U.S.A.
EAST-SOUTH INTERCONNECTOR	SIEMENS	2003	2000	±500	1400	THY	INDIA
BAKUN			2130	3x±500	1335	THY	MALAYSIA
THREE GORGES-CHANGZHOU	ABB/SIEMENS	2003	3000	±500	860	THY	CHINA
THREE GORGES-GUANGDONG	ABB	2004	3000	±500	940	THY	CHINA

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HVDC PROJECTS LISTING
Prepared for the
DC and Flexible AC Transmission Subcommittee
of the
IEEE Transmission and Distribution Committee
by the
Working Group on HVDC and FACTS Bibliography and Records

SYSTEM / PROJECT	HVDC SUPPLIER	YEAR COMMISSIONED	POWER RATING (MW)	DC VOLTAGE (kV)	LINE/ CABLE (km)	MERCURY/ THYRISTOR/ TRANSISTOR	LOCATION
GUI-GUANG	SIEMENS	2004	3000	±500	936	THY	CHINA
TROLL A	ABB	2004	2x40	±60	70	TRA	NORWAY
LEYTE-MINDANAO		PLANNED 2004	400			THY	PHILIPPINES
VIKING CABLE		PLANNED 2004	600	450	600	THY	NORWAY-GERMANY
LAMAR	SIEMENS	2005	211	±63	B-B	THY	U.S.A
EAST-WEST ENERGY BRIDGE		PLANNED 2005	500	600	1800	THY	GERMANY-POLAND-RUSSIA
EAST-WEST ENERGY BRIDGE		PLANNED 2010	1000			THY	GERMANY-POLAND-RUSSIA
ICELAND-SCOTLAND LINK		PLANNED 2005	550	400	950	THY	ICELAND-SCOTLAND
ICELAND-SCOTLAND LINK		FUTURE	1100	±400	950	THY	ICELAND-SCOTLAND
NORWAY-UK		PLANNED 2005	800		700	THY	NORWAY-UK
MEPANDA UNCUA		PLANNED 2006	500			THY	MOZAMBIQUE
BASSLINK	SIEMENS	2006	500	400	360	THY	AUSTRALIA
ESTLINK	ABB	UNDER CONSTRUCTION 2006	350	150	106	TRA	ESTONIA-FINLAND
LEWIS DE-ICER	AREVA	UNDER CONSTRUCTION 2006	250	±17.4	242	THY	CANADA
LONG ISLAND CABLE PROJECT		2007	600	±450	40	THY	USA
RUSSIA-CHINA		PLANNED 2007	2500		2000	THY	RUSSIA-CHINA
NORNED		UNDER CONSTRUCTION 2007	600	500	580	THY	NORWAY-NETHERLANDS
THREE GORGES-SHANGHAI		UNDER CONSTRUCTION 2007	3000	±500	900	THY	CHINA
NEPTUNE	SIEMENS	UNDER CONSTRUCTION		±500		THY	CANADA-U.S.A.
SAPEI		PLANNED 2008	500	±500	440	THY	ITALY MAINLAND-SARDINIA
CHINA-RUSSIA (HEIHE)		PLANNED 2008	750		B-B	THY	CHINA-RUSSIA
NORTHEAST-NORTH (GOALING)		PLANNED 2008	1500		B-B	THY	CHINA
OUTAOUAIS	ABB	2009	2x625	315	B-B	THY	CANADA
YUNNAN-GUANGDONG		PLANNED 2009	5000	800		THY	CHINA
LINGBAO EXPANSION		PLANNED 2009	750		B-B	THY	CHINA
AL FADHILI	AREVA	UNDER CONSTRUCTION 2009	3 x 600	3 x 222	B-B	THY	SAUDI ARABIA
STOREBAELT		PLANNED 2010	600	400	58	THY	DENMARK
FAREAST (RUSSIA) - NE CHINA		PLANNED 2010	3000			THY	CHINA-RUSSIA
HULUNBEIR (INNER MONGOLIA) - SHENYANG		PLANNED 2010	3000			THY	CHINA
NINGXIA-TIANJING		PLANNED 2010	3000			THY	CHINA
NW-SICHUAN (BAOJI-DEYANG)		PLANNED 2011	3000			THY	CHINA
NORTH SHAANXI-SHANDONG		PLANNED 2011	3000			THY	CHINA
SHANDONG-EAST		PLANNED 2011	1200		B-B	THY	CHINA
GEZHOUBA-SHANGHAI EXPANSION		PLANNED 2011	3000			THY	CHINA
XIANJIABA-SHANGHAI		PLANNED 2011	6400	800		THY	CHINA
JINGPING-EAST CHINA		PLANNED 2012	6400	800		THY	CHINA
NORTH-CENTRAL		PLANNED 2012	1000		B-B	THY	CHINA
JINGHONG-THAILAND		PLANNED 2013	3000		900	THY	CHINA-THAILAND
XILUODU-HUNAN		PLANNED 2014	6400	800		THY	CHINA
LABRADOR-NEWFOUNDLAND (LOWER CHURCHILL PROJECT)		PLANNED 2015				THY	
IRKUTSK (RUSSIA) - BEIJING		PLANNED 2015	6400	800		THY	RUSSIA-CHINA
XILUODU-HANZHOU		PLANNED 2015	6400	800		THY	CHINA
NUOZHADU-GUANGDONG		PLANNED 2015	6400	800		THY	CHINA
HUMENG-SHANDONG		PLANNED 2015	6400	800		THY	CHINA
JINSHA RIVER II - EAST CHINA		PLANNED 2016	6400	800		THY	CHINA
HUMENG-TIANJING		PLANNED 2016	6400	800		THY	CHINA
GOUPITAN-GUANGDONG		PLANNED 2016	3000			THY	CHINA
HUMENG-LIAONING		PLANNED 2018	6400	800		THY	CHINA
JINSHA RIVER II - FUJIAN		PLANNED 2018	6400	800		THY	CHINA
HAMI-C.CHINA		PLANNED 2018	6400	800		THY	CHINA
JINSHA RIVER II - EAST CHINA		PLANNED 2019	6400	800		THY	CHINA
TALCHER-BANGALORE	SIEMENS	FUTURE	2000	±500	1400	THY	INDIA
CEPA (RASPIER-RAJASTHAN)		FUTURE	2000	500		THY	INDIA
ISACCEA		FUTURE	600		B-B	THY	RUMANIA
POLAND-LITHUANIA		FUTURE			B-B	THY	
UK-NETHERLANDS		FUTURE				THY	UK-NETHERLANDS

The above HVDC List was based on the 2005 version of the CIGRE Compendium of HVDC Schemes Throughout the World.
Initial changes to the CIGRE list were made by incorporating changes from:
- Mike Barhman, ABB - January 2006
- Neil Kirby, AREVA - April 2006
- Robyn Taylor, Teshmont - modifications based on the detailed descriptions from the 2005 version of CIGRE AG B4.04, COMPENDIUM OF HVDC SCHEMES THROUGHOUT THE WORLD text
- Robyn Taylor, Teshmont - modifications based on the IEEE HVDC Projects Listing, January 2000 Issue

Further changes have been made by persons listed in the "comments" column

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Appendix C

Cost Estimates for Overhead Line Transmission Towers

Capital cost estimates not filed in public version

Appendix D

Overview of Submarine Cable Designs

Aspects of HVdc Cable Design

The design of DC transmission cables is different from that of comparable AC cables, with one example being the electrical stress distribution. In HVac cables, the electrical stress distribution is capacitive and therefore will be same at full load as at no load. In contrast, in an HVdc cable the stress distribution within the insulation is dependent, amongst other factors, on the electrical resistivity of the insulation. This insulation resistivity is dependent on temperature and to some extent on applied stress and, as a result, the electrical stress distribution is influenced by the thermal characteristics of the insulation and by the heat generated by load current in the conductor.

At no load, the electrical stress distribution will be the same for DC and AC cables, but with load current flowing in the DC cable, the temperature in the inner part of the insulation will be higher than in the outer part and this cause a “stress inversion” as the electrical stress near the conductor decreases while the electrical stress in the outer part of the insulation increases. Therefore, at full load the stress in the outer part of the insulation may be higher than in the inner part and this physical behaviour has to be taken into account in designing the cable for steady state operation, for load variations and for transient voltages.

Two types of HVdc submarine cable could be considered for the route lengths and power transmission levels required for the Strait of Belle Isle and Cabot Strait crossings:

- Self Contained Oil-Filled (SCOF) Cable
- Mass Impregnated (MI) Cable

A brief overview of the design principles of each type of cable is given below.

Self Contained Oil Filled Cables

In Self Contained Oil Filled *Cables* the paper insulation is pressurized by low viscosity oil to avoid the formation of voids during the thermal expansion and contraction of the cable, and this oil is supplied via a central oil-channel in the conductor (Figure D-1). In the event of severe mechanical damage which ruptures the cable sheathing, the hydraulic oil-feeding system is designed to prevent water intrusion, and must maintain a sufficient oil pressure and oil-flow at the cable break until a repair or preliminary sealing of the cable is carried out, which may take many months because of weather conditions and the availability of a cable repair vessel. Therefore, oil storage tanks are required at each end of the cable to provide an oil feed from both sides of the cable break. This oil leakage aspect is an additional complication and a negative feature with environmental implications.

The advantage of SCOF cables is that they can be designed for a higher conductor temperature and higher electrical gradient because the insulation is pressurised under all operating conditions.

The disadvantage is that the oil has to be transported along the cable length to/from the pressure tanks or pumping plants at both ends of the cable, and the dynamic pressure drop in oil flow along the cable limits the maximum length of SCOF submarine cable. Also, although the insulating oil has a low viscosity and would evaporate from the surface of the sea, the possibility of long-term oil discharge while waiting for cable repairs may cause environmental concerns.

The oil pumping requirements limit the maximum length of SCOF submarine cable to approximately 50 km, so SCOF cables would not be a feasible option for the 480 km Cabot Strait Crossing.

The most recent SCOF type HVdc submarine cable project is the 500 kVdc, KII Channel interconnection in Japan, which is a 50 km, 2 800 MW bipole project comprising two, 3 000 mm^2 cables carrying pole current of 2

800 A. This is presently operating at 250 kVdc and will be upgraded to 500 kVdc in the next stage of development.

Mass Impregnated Cables

Mass Impregnated MI cables (Figure D-2) are impregnated with very high viscosity oil/compound and are not subject to leaks or significant water ingress in case of external mechanical damage to the cable. Thermal volume change is handled as a radial expansion, rather than longitudinal transport of oil (as in the case for SCOF cables) and it is this radial expansion that contributes to a limitation of the maximum conductor temperature.

As may be seen from the table, the majority of long submarine HVdc cables are of the MI type, with lengths varying between 160 km and 580 km, and with operating voltages between 400 kVdc and 500 kVdc.

The most recent MI type HVdc submarine cable project are the recently commissioned 82 km Neptune project between New Jersey and Long Island, New York, and the 400 km SAPEI project between Italy and Sardinia which is under construction.

Design Criteria

The principal design criteria for HVdc submarine cables are:

- Maximum conductor temperature
- Electrical stress in the insulation
- Mechanical forces during cable laying

These parameters are discussed below.

<u>Maximum conductor temperature</u>

For many years the maximum conductor temperature limit was generally 50 °C, but, in the last 10 years, some cable manufacturers have increased this limit to 55 °C C. The maximum conductor temperature, which will determine the conductor size, will be a function of the transmission current and the ambient thermal conditions, including thermal resistivity of ambient soil, burial depth, backfill material and thermal details of any protection pipes.

<u>Electrical stress of insulation</u>

The electric stress in the insulation will vary with the load on the cable and will also be affected by any overvoltages transferred from the overhead line. In existing HVdc systems, the maximum electrical stress during normal DC operation has been in the range of 25-30 kV/mm, but this stress could be increased up to 85 kV/mm by a transient of opposite polarity during fault conditions in the "other pole" when operating at full load. These superimposed gradients of opposite or same polarity will determine the maximum stress at the conductor.

The transient overvoltages may also be caused by lightning or by switching surges. CIGRE has recommended that the lightning impulse design level should be 1.15 x the cable-arrester protective level, and system studies are required to determine the overvoltages caused by switching surges.

As noted earlier, the "stress inversion" with increasing load currents depends on the temperature variation across the insulation, so this temperature may be used to represent the limitation in electrical stress. Most cable manufacturers specify maximum temperature drop across the insulation to be between 12 and15 °C.

Mechanical forces acting on the cable

During installation, the submarine cable is exposed to mechanical forces including tension under bending corresponding to the weight of cable in water plus a certain bottom tension needed to control the cable laying, and when laying with steep sea-bottom slopes, this bottom tension must be higher than for laying on flat seabed.

The mechanical stress will be distributed between the cable armour and conductor, so mechanical stress has an influence on design of most elements of the cable. Knowing that there will be some steep, sea-bottom slopes for laying in Strait of Belle Isle, these factors should be addressed in the engineering phase, prior to type tests.

The CIGRE recommendations for mechanical testing during type testing also include an allowance to cover the dynamic behaviour of the vessel.

Technology and Operating Experience

The design and fabrication of Self Contained Oil-Filled HVdc submarine cables is a well-proven technology, and SCOF submarine cables have been in operation for many years at voltages up to 500 kVdc.

Mass Impregnated HVdc cables is also a well-proven technology, and MI submarine cables have been in operation for voltages up to 450 kVdc for several years and, by the time that a definitive decision is required on the operating voltage for the Gull Island HVdc system, there will be a few years of operating experience with ±500 kVdc MI submarine cables, of similar design to the LCP cables.

Maximum Route Lengths

The practical maximum length for SCOF submarine cables is approximately 50 km, which means that they would be a practical chose for the SOBI crossing but not the Cabot Strait crossing.

MI submarine cables have been designed for routes in excess of 600 km so could be used for both of the LCP submarine crossings.

Cable Installation

For shorter cable routes, which can be installed without on-site cable splicing, there is very little difference in the installation methods for SCOF or MI submarine cables. If on-site splicing is required, then the SCOF cables requires a special environment on-board the cable laying vessel where oil continuously flows over the splice to avoid ingress of moisture. Although a well-established technique, this does introduce more difficulties than would be the case for MI cable.

The preliminary designs indicate that the greater transmission capability of the SCOF cable, compared to the MI cable, means that a single cable per pole would be sufficient for the SOBI crossing, for Scenario 1 and Scenario 2. This would mean that a total of three (3) SCOF cables would be installed, compared with five (5) MI cables. This would significantly reduce the time and costs of cable installation for the SCOF cables.

Environment

Although the use of low viscosity oil in the SCOF cables means that the potential oil pollution is minimal, its use will most likely be questioned in the licensing process. This can delay the project approvals process and, because some of the suppliers are using synthetic oil, the environmental assessment would be more complex.

Reparability

SCOF submarine cables have been repaired with good results, but the complexity before, during and after the repair operation is greater than for MI cables, and therefore implies higher risk.

In contrast, MI cables have been repaired offshore several times and the operation is relatively predictable, which would be especially favourable in the difficult environment of Strait of Belle Isle, and MI cables have no environmental concerns from the possibility of oil leakage from mechanical damage to the cables.

Operating Voltages and Costs of Losses

The analysis shows that, there is relatively little difference in the costs of losses because the lower transmission voltages require larger conductor sizes, which have lower resistances to offset the increased currents.

Figure D-1
Cross Section of Typical Self-Contained Oil Filled Cable

(Picture shows a HVac cable. DC cable would typically have steel wire armour instead of copper armour)

(Prysmian)

Figure D-2
Cross Section of Typical Mass Impregnated Submarine Cable

(Prysmian)

Appendix E

Typical Sag / Tension Charts

Figure E-1 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Conductor 2126-A1/A4-91 (60.0 mm Diameter)
(50 mm Ice)

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DATE: 01-10-2008


PROBLEM TITLE       :       LOWER CHURCHILL 450KV
CABLE DESIGNATION   :       2126-A1-A4-91
TITLE FOR SAG TABLE :       60CONDUCTOR

CABLE DATA :
------------
            DIA               (MM) =  60
            AREA             (MM2) =  2126
            MASS            (KG/M) =  5.747
            TEMPERATURE COEFF  (C) =  .00023
            RTS               (KN) =  404.5
            EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1        45.00           91.00
       2        31.00          300.00

FINAL AND CREEP MODULUS (GPA) :  56        32


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT   SAG TYPE
                                                       1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    30.00    1
       2      55.0    0.90    0.00       -5.0    75.00    2
       3      50.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00



    CRITICAL LOAD NUMBER    =  1   INITIAL UNSTRESSED LENGTH (M) =   250.11143
    BIFURCATION LOAD NUMBER =  4   FINAL   UNSTRESSED LENGTH (M) =   250.30873


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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 250.00 DATE : 01-10-2008

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LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	5.747	-5.0	121350 *	121145	3.64	96475	96217	4.58
2	23.623	-5.0	252897	251227	7.21	253203	251534	7.20
3	20.323	-5.0	233458	232120	6.71	228638	227271	6.86
4	16.168	-10.0	251339	250555	4.95	251339	250555	4.95
5	5.747	-40.0	638704	638665	0.69	950740	950713	0.46
6	5.747	-35.0	563316	563272	0.78	814120	814089	0.54
7	5.747	-30.0	488059	488008	0.90	677631	677594	0.65
8	5.747	-25.0	413138	413078	1.07	541752	541707	0.81
9	5.747	-20.0	338878	338804	1.30	407247	407186	1.08
10	5.747	-15.0	266026	265933	1.66	277049	276959	1.59
11	5.747	-10.0	196617	196491	2.24	163901	163749	2.69
12	5.747	-5.0	121350	121145	3.64	96475	96217	4.58
13	5.747	0.0	80490	80180	5.49	68051	67684	6.51
14	5.747	5.0	61245	60836	7.25	54422	53962	8.17
15	5.747	10.0	50758	50264	8.77	46458	45917	9.61
16	5.747	15.0	44162	43592	10.12	41175	40562	10.88
17	5.747	20.0	39585	38946	11.34	37372	36694	12.04
18	5.747	25.0	36201	35500	12.44	34479	33741	13.10
19	5.747	30.0	33573	32814	13.47	32187	31394	14.08
20	5.747	35.0	31463	30650	14.43	30319	29473	15.01
21	5.747	40.0	29725	28861	15.33	28759	27864	15.89
22	5.747	45.0	28261	27349	16.19	27432	26490	16.72
23	5.747	50.0	27009	26050	17.01	26289	25302	17.51
24	5.747	55.0	25923	24920	17.79	25290	24260	18.28
25	5.747	60.0	24970	23925	18.54	24408	23337	19.01
26	5.747	65.0	24126	23040	19.26	23623	22511	19.72
27	5.747	70.0	23372	22247	19.96	22918	21768	20.40
28	5.747	75.0	22693	21530	20.63	22281	21094	21.07
29	5.747	80.0	22078	20878	21.29	21702	20479	21.71
30	5.747	85.0	21518	20282	21.93	21174	19915	22.34
31	5.747	90.0	21005	19735	22.55	20688	19395	22.95
32	5.747	95.0	20534	19229	23.15	20241	18914	23.55
33	5.747	100.0	20099	18761	23.75	19828	18468	24.13

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CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 300.20862
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 300.48706

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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 300.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	121350 *	121055	5.24	96732	96361	6.58
2	23.623	-5.0	272395	270157	9.66	272395	270157	9.66
3	20.323	-5.0	249984	248181	9.04	244720	242878	9.24
4	16.168	-10.0	259387	258291	6.91	255079	253965	7.03
5	5.747	-40.0	623133	623076	1.02	905609	905569	0.70
6	5.747	-35.0	547891	547826	1.16	769069	769022	0.82
7	5.747	-30.0	472935	472859	1.34	633072	633015	1.00
8	5.747	-25.0	398509	398419	1.59	498108	498037	1.27
9	5.747	-20.0	325163	325053	1.95	365844	365746	1.73
10	5.747	-15.0	254086	253945	2.50	242384	242237	2.62
11	5.747	-10.0	186487	186295	3.40	146905	146662	4.32
12	5.747	-5.0	121347	121052	5.24	96705	96334	6.59
13	5.747	0.0	86676	86262	7.36	73431	72940	8.70
14	5.747	5.0	68703	68179	9.31	60834	60240	10.54
15	5.747	10.0	58140	57517	11.04	52919	52233	12.17
16	5.747	15.0	51180	50471	12.59	47438	46670	13.62
17	5.747	20.0	46220	45431	14.00	43382	42539	14.95
18	5.747	25.0	42473	41611	15.29	40235	39323	16.19
19	5.747	30.0	39529	38600	16.49	37709	36732	17.34
20	5.747	35.0	37143	36151	17.62	35627	34588	18.42
21	5.747	40.0	35162	34109	18.68	33874	32778	19.45
22	5.747	45.0	33485	32375	19.70	32375	31224	20.43
23	5.747	50.0	32044	30880	20.66	31075	29870	21.37
24	5.747	55.0	30788	29572	21.59	29932	28677	22.27
25	5.747	60.0	29685	28418	22.48	28921	27617	23.14
26	5.747	65.0	28703	27387	23.33	28018	26667	23.98
27	5.747	70.0	27823	26461	24.17	27205	25808	24.79
28	5.747	75.0	27031	25624	24.97	26469	25028	25.58
29	5.747	80.0	26312	24861	25.75	25798	24314	26.34
30	5.747	85.0	25656	24162	26.51	25185	23658	27.09
31	5.747	90.0	25055	23519	27.25	24620	23053	27.81
32	5.747	95.0	24502	22926	27.97	24099	22492	28.52
33	5.747	100.0	23991	22375	28.68	23617	21970	29.22

CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 350.34695
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 350.71341

LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 350.00 DATE : 01-10-2008

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			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	121350 *	120948	7.14	97936	97437	8.86
2	23.623	-5.0	290118	287252	12.37	290118	287252	12.37
3	20.323	-5.0	264937	262618	11.64	259620	257252	11.88
4	16.168	-10.0	266892	265441	9.15	260175	258685	9.39
5	5.747	-40.0	604699	604619	1.43	857489	857432	1.01
6	5.747	-35.0	529698	529606	1.63	721402	721335	1.20
7	5.747	-30.0	455228	455121	1.90	586105	586022	1.47
8	5.747	-25.0	381544	381416	2.26	452706	452599	1.91
9	5.747	-20.0	309508	309351	2.79	324418	324268	2.66
10	5.747	-15.0	240954	240752	3.59	211968	211738	4.08
11	5.747	-10.0	175784	175507	4.92	136258	135900	6.35
12	5.747	-5.0	121347	120944	7.14	97937	97437	8.86
13	5.747	0.0	91725	91191	9.47	78217	77589	11.14
14	5.747	5.0	75093	74438	11.61	66542	65802	13.14
15	5.747	10.0	64700	63938	13.52	58781	57939	14.93
16	5.747	15.0	57586	56727	15.25	53213	52280	16.56
17	5.747	20.0	52368	51419	16.83	48991	47973	18.05
18	5.747	25.0	48363	47331	18.30	45660	44564	19.44
19	5.747	30.0	45173	44065	19.67	42950	41781	20.75
20	5.747	35.0	42562	41382	20.95	40695	39456	21.99
21	5.747	40.0	40377	39127	22.17	38782	37477	23.16
22	5.747	45.0	38519	37204	23.33	37135	35767	24.28
23	5.747	50.0	36912	35535	24.44	35699	34270	25.36
24	5.747	55.0	35508	34070	25.51	34433	32946	26.39
25	5.747	60.0	34268	32772	26.53	33307	31764	27.39
26	5.747	65.0	33162	31611	27.52	32297	30699	28.35
27	5.747	70.0	32170	30565	28.48	31387	29737	29.29
28	5.747	75.0	31274	29617	29.41	30560	28858	30.20
29	5.747	80.0	30459	28750	30.31	29806	28054	31.08
30	5.747	85.0	29715	27957	31.19	29114	27313	31.94
31	5.747	90.0	29032	27226	32.05	28476	26629	32.78
32	5.747	95.0	28402	26549	32.88	27887	25993	33.60
33	5.747	100.0	27820	25920	33.70	27341	25402	34.40

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CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 400.58179
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 401.03610

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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 400.00 DATE : 01-10-2008

****

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	5.747	-5.0	117995	117454	9.60	97558	96901	11.65
2	23.623	-5.0	303375	299788	15.49	303375 *	299788	15.49
3	20.323	-5.0	275595	272677	14.64	270366	267390	14.93
4	16.168	-10.0	270075	268199	11.84	261848	259911	12.22
5	5.747	-40.0	575764	575654	1.96	793775	793695	1.42
6	5.747	-35.0	501217	501090	2.25	658328	658232	1.71
7	5.747	-30.0	427407	427259	2.64	524399	524278	2.15
8	5.747	-25.0	354940	354761	3.18	394167	394005	2.86
9	5.747	-20.0	285148	284925	3.96	274261	274029	4.11
10	5.747	-15.0	220832	220544	5.11	180833	180480	6.25
11	5.747	-10.0	160381	159984	7.05	126104	125598	8.98
12	5.747	-5.0	117977	117436	9.61	97557	96901	11.65
13	5.747	0.0	93942	93260	12.10	81266	80475	14.03
14	5.747	5.0	79357	78547	14.37	70828	69918	16.16
15	5.747	10.0	69674	68748	16.43	63520	62501	18.08
16	5.747	15.0	62764	61732	18.31	58089	56970	19.85
17	5.747	20.0	57560	56431	20.04	53867	52656	21.49
18	5.747	25.0	53480	52259	21.65	50474	49177	23.02
19	5.747	30.0	50178	48872	23.17	47676	46297	24.47
20	5.747	35.0	47443	46057	24.60	45320	43864	25.84
21	5.747	40.0	45134	43671	25.95	43305	41775	27.15
22	5.747	45.0	43153	41618	27.25	41557	39956	28.40
23	5.747	50.0	41431	39825	28.49	40023	38355	29.60
24	5.747	55.0	39918	38244	29.69	38664	36931	30.76
25	5.747	60.0	38575	36837	30.84	37451	35654	31.88
26	5.747	65.0	37375	35574	31.95	36359	34501	32.96
27	5.747	70.0	36293	34431	33.03	35370	33453	34.01
28	5.747	75.0	35313	33392	34.08	34469	32494	35.04
29	5.747	80.0	34420	32442	35.10	33645	31614	36.03
30	5.747	85.0	33602	31568	36.09	32888	30802	37.00
31	5.747	90.0	32850	30761	37.05	32189	30050	37.95
32	5.747	95.0	32155	30014	38.00	31542	29350	38.88
33	5.747	100.0	31512	29318	38.92	30940	28698	39.78

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Figure E-2 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Conductor 2126-A1/A4-91 (60.0 mm Diameter)
(75 mm Ice)

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DATE : 01-10-2008


PROBLEM TITLE       :       LOWER CHURCHILL 450KV
CABLE DESIGNATION   :       2126-A1-A4-91
TITLE FOR SAG TABLE :       60CONDUCTOR

CABLE DATA :
------------
            DIA                (MM) =  60
            AREA              (MM2) =  2126
            MASS             (KG/M) =  5.747
            TEMPERATURE COEFF  (C) =  .00023
            RTS                (KN) =  404.5
            EVERY DAY TEMP.     (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1        45.00            91.00
       2        31.00           300.00

FINAL AND CREEP MODULUS (GPA) :  56        32


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT   SAG TYPE
                                                       1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    30.00    1
       2      75.0    0.90    0.00       -5.0    75.00    2
       3      70.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00


    CRITICAL LOAD NUMBER    =  2   INITIAL UNSTRESSED LENGTH (M) =   250.18666
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   250.47093
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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 250.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	107484	107253	4.11	77646	77324	5.70
2	34.363	-5.0	303375	300417	8.78	303375 *	300417	8.78
3	26.898	-5.0	262862	260775	7.91	253818	251655	8.20
4	16.168	-10.0	238941	238116	5.21	217022	216113	5.74
5	5.747	-40.0	619144	619104	0.71	874495	874467	0.50
6	5.747	-35.0	543768	543722	0.81	737744	737710	0.60
7	5.747	-30.0	468564	468511	0.94	601480	601439	0.73
8	5.747	-25.0	393753	393689	1.12	466115	466062	0.94
9	5.747	-20.0	319721	319643	1.38	333276	333202	1.32
10	5.747	-15.0	247503	247403	1.78	209678	209559	2.10
11	5.747	-10.0	174737	174595	2.52	119406	119198	3.69
12	5.747	-5.0	107455	107224	4.11	77646	77325	5.70
13	5.747	0.0	74090	73753	5.97	59365	58944	7.48
14	5.747	5.0	57941	57509	7.67	49488	48980	9.00
15	5.747	10.0	48759	48244	9.14	43243	42660	10.34
16	5.747	15.0	42810	42221	10.45	38890	38240	11.55
17	5.747	20.0	38604	37949	11.64	35647	34934	12.65
18	5.747	25.0	35450	34733	12.72	33120	32350	13.66
19	5.747	30.0	32976	32202	13.73	31084	30260	14.62
20	5.747	35.0	30974	30148	14.67	29400	28526	15.51
21	5.747	40.0	29313	28436	15.56	27980	27058	16.36
22	5.747	45.0	27912	26987	16.41	26763	25795	17.18
23	5.747	50.0	26708	25738	17.21	25704	24693	17.95
24	5.747	55.0	25659	24645	17.99	24774	23720	18.70
25	5.747	60.0	24736	23681	18.73	23949	22855	19.42
26	5.747	65.0	23917	22821	19.45	23211	22077	20.11
27	5.747	70.0	23184	22049	20.14	22546	21374	20.79
28	5.747	75.0	22523	21350	20.81	21943	20735	21.44
29	5.747	80.0	21923	20714	21.46	21393	20149	22.08
30	5.747	85.0	21376	20131	22.10	20890	19611	22.69
31	5.747	90.0	20876	19596	22.71	20427	19114	23.30
32	5.747	95.0	20415	19101	23.31	19999	18653	23.89
33	5.747	100.0	19988	18641	23.90	19603	18224	24.46

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 300.67139
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 301.01169

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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 300.00 DATE : 01-10-2008

****

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	5.747	-5.0	79348	78894	8.04	66108	65562	9.68
2	34.363	-5.0	303376	299094	12.71	303376 *	299094	12.71
3	26.898	-5.0	256743	253651	11.72	249312	246125	12.08
4	16.168	-10.0	209045	207681	8.60	189861	188357	9.48
5	5.747	-40.0	523254	523186	1.21	700412	700361	0.91
6	5.747	-35.0	448330	448250	1.41	564591	564527	1.12
7	5.747	-30.0	374063	373967	1.70	430430	430347	1.47
8	5.747	-25.0	301179	301060	2.11	301038	300920	2.11
9	5.747	-20.0	231317	231162	2.74	188181	187991	3.37
10	5.747	-15.0	160843	160620	3.95	116236	115928	5.47
11	5.747	-10.0	106871	106535	5.95	82737	82303	7.71
12	5.747	-5.0	79347	78894	8.04	66108	65562	9.68
13	5.747	0.0	64533	63974	9.93	56330	55687	11.41
14	5.747	5.0	55459	54806	11.59	49845	49116	12.94
15	5.747	10.0	49302	48565	13.09	45185	44377	14.33
16	5.747	15.0	44816	44002	14.45	41643	40763	15.61
17	5.747	20.0	41377	40491	15.72	38844	37897	16.80
18	5.747	25.0	38645	37693	16.89	36565	35555	17.92
19	5.747	30.0	36411	35397	18.00	34665	33595	18.97
20	5.747	35.0	34541	33468	19.05	33052	31926	19.98
21	5.747	40.0	32953	31824	20.04	31661	30481	20.93
22	5.747	45.0	31580	30397	20.99	30447	29216	21.85
23	5.747	50.0	30380	29145	21.91	29377	28095	22.74
24	5.747	55.0	29320	28036	22.79	28424	27095	23.59
25	5.747	60.0	28376	27044	23.64	27570	26194	24.42
26	5.747	65.0	27528	26150	24.46	26798	25377	25.22
27	5.747	70.0	26763	25340	25.25	26098	24633	25.99
28	5.747	75.0	26067	24600	26.03	25457	23950	26.75
29	5.747	80.0	25431	23921	26.78	24870	23321	27.49
30	5.747	85.0	24847	23296	27.52	24330	22740	28.20
31	5.747	90.0	24309	22718	28.23	23829	22200	28.91
32	5.747	95.0	23812	22181	28.93	23365	21698	29.59
33	5.747	100.0	23350	21680	29.62	22933	21228	30.27

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CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 351.41290
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 351.80890

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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 350.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	67932	67207	12.86	60734	59920	14.43
2	34.363	-5.0	303376	297513	17.40	303376 *	297513	17.40
3	26.898	-5.0	252275	247966	16.34	246295	241877	16.75
4	16.168	-10.0	188461	186392	13.05	174629	172391	14.11
5	5.747	-40.0	409308	409189	2.11	493574	493475	1.75
6	5.747	-35.0	336294	336149	2.57	362696	362562	2.38
7	5.747	-30.0	265885	265702	3.25	243134	242934	3.55
8	5.747	-25.0	201186	200944	4.30	154219	153903	5.61
9	5.747	-20.0	137767	137413	6.28	106592	106133	8.14
10	5.747	-15.0	100457	99970	8.64	82871	82279	10.50
11	5.747	-10.0	80139	79527	10.87	69401	68692	12.58
12	5.747	-5.0	67940	67215	12.86	60728	59914	14.44
13	5.747	0.0	59836	59010	14.66	54631	53723	16.11
14	5.747	5.0	54034	53116	16.29	50071	49077	17.64
15	5.747	10.0	49648	48645	17.80	46513	45438	19.07
16	5.747	15.0	46199	45117	19.20	43643	42493	20.40
17	5.747	20.0	43402	42246	20.52	41269	40048	21.66
18	5.747	25.0	41078	39851	21.77	39267	37979	22.85
19	5.747	30.0	39112	37819	22.95	37549	36197	23.99
20	5.747	35.0	37423	36066	24.08	36057	34644	25.08
21	5.747	40.0	35952	34534	25.16	34746	33274	26.13
22	5.747	45.0	34657	33180	26.20	33583	32054	27.14
23	5.747	50.0	33507	31974	27.20	32543	30959	28.11
24	5.747	55.0	32478	30890	28.18	31606	29969	29.06
25	5.747	60.0	31550	29909	29.12	30757	29068	29.97
26	5.747	65.0	30708	29015	30.03	29983	28244	30.87
27	5.747	70.0	29940	28197	30.92	29274	27486	31.74
28	5.747	75.0	29237	27446	31.78	28623	26786	32.58
29	5.747	80.0	28589	26751	32.63	28021	26138	33.41
30	5.747	85.0	27991	26106	33.45	27463	25535	34.22
31	5.747	90.0	27437	25506	34.26	26945	24971	35.01
32	5.747	95.0	26921	24946	35.05	26461	24444	35.79
33	5.747	100.0	26440	24421	35.82	26009	23949	36.55

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CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 402.46567
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 402.91669

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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 400.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	62271	61230	18.46	57746	56620	19.97
2	34.363	-5.0	303378	295664	22.89	303378 *	295664	22.89
3	26.898	-5.0	248989	243245	21.77	244211	238348	22.22
4	16.168	-10.0	174881	171949	18.49	165523	162418	19.59
5	5.747	-40.0	281641	281415	4.01	269858	269623	4.18
6	5.747	-35.0	217459	217166	5.19	177563	177205	6.36
7	5.747	-30.0	157050	156645	7.20	124224	123710	9.12
8	5.747	-25.0	115951	115400	9.78	96444	95780	11.78
9	5.747	-20.0	92663	91971	12.27	80525	79727	14.16
10	5.747	-15.0	78493	77673	14.54	70287	69369	16.28
11	5.747	-10.0	69039	68104	16.59	63100	62073	18.21
12	5.747	-5.0	62265	61225	18.46	57746	56620	19.97
13	5.747	0.0	57156	56018	20.19	53578	52360	21.61
14	5.747	5.0	53140	51911	21.80	50223	48919	23.14
15	5.747	10.0	49885	48571	23.31	47455	46069	24.59
16	5.747	15.0	47186	45792	24.74	45122	43659	25.96
17	5.747	20.0	44905	43434	26.10	43126	41589	27.27
18	5.747	25.0	42947	41403	27.39	41393	39785	28.52
19	5.747	30.0	41243	39629	28.64	39872	38197	29.72
20	5.747	35.0	39745	38064	29.83	38524	36783	30.88
21	5.747	40.0	38415	36669	30.98	37319	35515	32.00
22	5.747	45.0	37226	35417	32.10	36235	34370	33.09
23	5.747	50.0	36153	34284	33.18	35253	33329	34.14
24	5.747	55.0	35182	33253	34.22	34358	32376	35.17
25	5.747	60.0	34296	32310	35.24	33540	31502	36.16
26	5.747	65.0	33484	31442	36.23	32787	30695	37.14
27	5.747	70.0	32738	30641	37.20	32093	29947	38.09
28	5.747	75.0	32049	29899	38.15	31450	29251	39.01
29	5.747	80.0	31411	29209	39.07	30852	28602	39.92
30	5.747	85.0	30816	28563	39.98	30295	27994	40.81
31	5.747	90.0	30262	27959	40.86	29773	27424	41.68
32	5.747	95.0	29745	27393	41.73	29285	26888	42.54
33	5.747	100.0	29259	26859	42.59	28827	26382	43.38

Figure E-3 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Conductor 2126-A1/A4-91 (60.0 mm Diameter)
(110 mm Ice)

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DATE : 01-10-2008


PROBLEM TITLE       :       LOWER CHURCHILL 450KV
CABLE DESIGNATION   :       2126-A1-A4-91
TITLE FOR SAG TABLE :       60CONDUCTOR

CABLE DATA :
------------
            DIA                (MM) =  60
            AREA              (MM2) =  2126
            MASS             (KG/M) =  5.747
            TEMPERATURE COEFF  (C) =  .00023
            RTS                (KN) =  404.5
            EVERY DAY TEMP.     (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1        45.00            91.00
       2        31.00           300.00

FINAL AND CREEP MODULUS (GPA) :  56        32


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT   SAG TYPE
                                                       1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    30.00    1
       2      %110.0    0.90    0.00       -5.0    75.00    2
       3      %100.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00


    CRITICAL LOAD NUMBER    =  2   INITIAL UNSTRESSED LENGTH (M) =   251.85603
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   252.13742
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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 250.00 DATE : 01-10-2008

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			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	36029	35324	12.51	33630	32873	13.45
2	58.597	-5.0	303380	294579	15.32	303380 *	294579	15.32
3	38.694	-5.0	214563	209162	14.23	208385	202813	14.68
4	16.168	-10.0	104751	102835	12.08	98462	96417	12.89
5	5.747	-40.0	195970	195843	2.25	138354	138174	3.19
6	5.747	-35.0	120392	120185	3.66	85236	84944	5.19
7	5.747	-30.0	79862	79550	5.54	62895	62497	7.05
8	5.747	-25.0	60831	60420	7.30	51492	51004	8.65
9	5.747	-20.0	50458	49961	8.83	44532	43967	10.04
10	5.747	-15.0	43924	43350	10.18	39792	39156	11.28
11	5.747	-10.0	39385	38743	11.40	36312	35613	12.40
12	5.747	-5.0	36029	35324	12.51	33630	32873	13.45
13	5.747	0.0	33421	32658	13.53	31487	30674	14.42
14	5.747	5.0	31327	30510	14.50	29726	28862	15.33
15	5.747	10.0	29599	28731	15.40	28248	27335	16.20
16	5.747	15.0	28145	27229	16.26	26986	26027	17.02
17	5.747	20.0	26901	25938	17.08	25892	24889	17.81
18	5.747	25.0	25822	24815	17.86	24934	23888	18.57
19	5.747	30.0	24874	23825	18.62	24086	22999	19.29
20	5.747	35.0	24035	22945	19.34	23329	22202	20.00
21	5.747	40.0	23286	22156	20.04	22649	21483	20.68
22	5.747	45.0	22610	21443	20.72	22032	20830	21.34
23	5.747	50.0	21999	20794	21.38	21471	20232	21.98
24	5.747	55.0	21442	20201	22.02	20958	19684	22.61
25	5.747	60.0	20933	19657	22.64	20487	19178	23.22
26	5.747	65.0	20464	19154	23.25	20052	18710	23.81
27	5.747	70.0	20031	18688	23.84	19649	18274	24.39
28	5.747	75.0	19631	18254	24.42	19275	17868	24.96
29	5.747	80.0	19258	17850	24.99	18926	17488	25.52
30	5.747	85.0	18911	17472	25.54	18600	17131	26.07
31	5.747	90.0	18587	17117	26.09	18295	16796	26.60
32	5.747	95.0	18283	16782	26.62	18008	16479	27.13
33	5.747	100.0	17997	16467	27.15	17738	16180	27.65

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CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 303.67035
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 304.00562

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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 300.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	33461	32350	19.71	32141	30980	20.59
2	58.597	-5.0	303390	290509	22.42	303390 *	290509	22.42
3	38.694	-5.0	209832	201750	21.30	205656	197393	21.78
4	16.168	-10.0	96154	93100	19.26	92716	89539	20.04
5	5.747	-40.0	58693	58076	10.94	52354	51661	12.30
6	5.747	-35.0	51494	50788	12.51	46980	46204	13.76
7	5.747	-30.0	46398	45612	13.94	42991	42140	15.10
8	5.747	-25.0	42574	41714	15.25	39893	38973	16.33
9	5.747	-20.0	39580	38651	16.47	37404	36418	17.49
10	5.747	-15.0	37160	36167	17.61	35350	34303	18.58
11	5.747	-10.0	35155	34101	18.69	33621	32516	19.61
12	5.747	-5.0	33461	32350	19.71	32141	30980	20.59
13	5.747	0.0	32007	30842	20.69	30856	29642	21.54
14	5.747	5.0	30743	29525	21.62	29728	28463	22.44
15	5.747	10.0	29632	28363	22.52	28728	27414	23.31
16	5.747	15.0	28646	27328	23.39	27835	26473	24.15
17	5.747	20.0	27763	26397	24.22	27031	25623	24.97
18	5.747	25.0	26968	25557	25.04	26302	24850	25.76
19	5.747	30.0	26246	24791	25.82	25638	24143	26.53
20	5.747	35.0	25589	24091	26.59	25031	23493	27.28
21	5.747	40.0	24987	23446	27.34	24472	22894	28.01
22	5.747	45.0	24433	22851	28.06	23957	22338	28.72
23	5.747	50.0	23921	22300	28.77	23479	21821	29.42
24	5.747	55.0	23447	21786	29.47	23035	21338	30.10
25	5.747	60.0	23006	21307	30.15	22621	20887	30.77
26	5.747	65.0	22595	20858	30.82	22234	20463	31.43
27	5.747	70.0	22210	20436	31.47	21871	20064	32.07
28	5.747	75.0	21849	20040	32.11	21531	19688	32.70
29	5.747	80.0	21511	19666	32.74	21210	19332	33.32
30	5.747	85.0	21192	19312	33.36	20908	18995	33.93
31	5.747	90.0	20891	18976	33.97	20622	18676	34.53
32	5.747	95.0	20606	18658	34.57	20351	18372	35.12
33	5.747	100.0	20337	18355	35.16	20095	18082	35.71

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CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 356.41013
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 356.79791

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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 350.00 DATE : 01-10-2008

****

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	5.747	-5.0	32141	30535	28.51	31328	29674	29.35
2	58.597	-5.0	303415	285522	31.14	303415 *	285522	31.14
3	38.694	-5.0	206896	195510	30.01	203999	192427	30.50
4	16.168	-10.0	91721	87273	28.05	89620	85054	28.80
5	5.747	-40.0	42778	41603	20.84	40805	39569	21.92
6	5.747	-35.0	40523	39278	22.09	38845	37542	23.12
7	5.747	-30.0	38614	37303	23.27	37163	35796	24.26
8	5.747	-25.0	36969	35594	24.40	35700	34271	25.36
9	5.747	-20.0	35535	34098	25.49	34413	32925	26.41
10	5.747	-15.0	34271	32776	26.53	33271	31726	27.42
11	5.747	-10.0	33148	31596	27.54	32249	30648	28.40
12	5.747	-5.0	32141	30534	28.51	31328	29674	29.35
13	5.747	0.0	31233	29573	29.45	30492	28786	30.27
14	5.747	5.0	30408	28696	30.37	29731	27975	31.17
15	5.747	10.0	29656	27894	31.26	29034	27228	32.04
16	5.747	15.0	28966	27155	32.13	28392	26538	32.89
17	5.747	20.0	28331	26472	32.98	27800	25899	33.73
18	5.747	25.0	27744	25839	33.81	27250	25303	34.54
19	5.747	30.0	27200	25249	34.62	26739	24748	35.34
20	5.747	35.0	26693	24697	35.41	26263	24227	36.12
21	5.747	40.0	26220	24181	36.19	25817	23739	36.88
22	5.747	45.0	25778	23696	36.95	25399	23278	37.63
23	5.747	50.0	25364	23239	37.70	25007	22844	38.37
24	5.747	55.0	24974	22808	38.43	24637	22434	39.09
25	5.747	60.0	24607	22400	39.15	24288	22045	39.80
26	5.747	65.0	24260	22013	39.86	23958	21676	40.51
27	5.747	70.0	23932	21646	40.56	23646	21325	41.20
28	5.747	75.0	23622	21297	41.25	23350	20990	41.88
29	5.747	80.0	23328	20965	41.93	23069	20671	42.55
30	5.747	85.0	23048	20647	42.60	22802	20367	43.21
31	5.747	90.0	22782	20344	43.26	22547	20075	43.86
32	5.747	95.0	22529	20054	43.91	22304	19796	44.50
33	5.747	100.0	22287	19777	44.55	22073	19529	45.14

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 410.37802
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 410.81665

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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 400.00 DATE : 01-10-2008

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	5.747	-5.0	31364	29158	39.14	30835	28583	39.95
2	58.597	-5.0	303469	279506	41.70	303469 *	279506	41.70
3	38.694	-5.0	204983	189590	40.57	202942	187361	41.06
4	16.168	-10.0	89112	82979	38.68	87755	81508	39.40
5	5.747	-40.0	37296	35491	32.03	36345	34487	32.98
6	5.747	-35.0	36196	34329	33.13	35335	33416	34.05
7	5.747	-30.0	35203	33275	34.20	34417	32439	35.10
8	5.747	-25.0	34298	32312	35.24	33578	31543	36.12
9	5.747	-20.0	33471	31428	36.25	32808	30717	37.11
10	5.747	-15.0	32713	30614	37.24	32099	29953	38.08
11	5.747	-10.0	32012	29859	38.20	31443	29244	39.02
12	5.747	-5.0	31364	29158	39.14	30835	28583	39.95
13	5.747	0.0	30762	28504	40.06	30268	27965	40.85
14	5.747	5.0	30201	27892	40.96	29739	27386	41.74
15	5.747	10.0	29678	27319	41.85	29243	26842	42.61
16	5.747	15.0	29187	26779	42.72	28779	26329	43.47
17	5.747	20.0	28726	26271	43.57	28342	25844	44.31
18	5.747	25.0	28293	25790	44.41	27930	25386	45.14
19	5.747	30.0	27885	25336	45.23	27541	24952	45.95
20	5.747	35.0	27499	24904	46.04	27173	24539	46.75
21	5.747	40.0	27134	24494	46.84	26825	24146	47.54
22	5.747	45.0	26788	24105	47.62	26495	23772	48.31
23	5.747	50.0	26460	23733	48.39	26180	23415	49.08
24	5.747	55.0	26148	23378	49.16	25882	23073	49.83
25	5.747	60.0	25851	23039	49.91	25597	22747	50.58
26	5.747	65.0	25569	22714	50.65	25325	22434	51.31
27	5.747	70.0	25299	22403	51.38	25066	22133	52.04
28	5.747	75.0	25041	22104	52.11	24818	21845	52.75
29	5.747	80.0	24794	21817	52.82	24581	21568	53.46
30	5.747	85.0	24559	21542	53.53	24354	21301	54.16
31	5.747	90.0	24333	21276	54.23	24136	21044	54.86
32	5.747	95.0	24116	21021	54.92	23927	20796	55.54
33	5.747	100.0	23908	20774	55.60	23726	20557	56.22

Figure E-4 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Conductor 2126-A1/A4-91 (60.0 mm Diameter)
(140 mm Ice)

```
DATE : 01-10-2008


PROBLEM TITLE       :       LOWER CHURCHILL 450KV
CABLE DESIGNATION   :       2126-A1-A4-91
TITLE FOR SAG TABLE :       60CONDUCTOR

CABLE DATA :
------------
            DIA               (MM) =  60
            AREA             (MM2) =  2126
            MASS            (KG/M) =  5.747
            TEMPERATURE COEFF  (C) =  .00023
            RTS               (KN) =  404.5
            EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1        45.00            91.00
       2        31.00           300.00

FINAL AND CREEP MODULUS (GPA) :  56        32


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                       1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    30.00    1
       2      %140.0    0.90    0.00       -5.0    75.00    2
       3      %130.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00



    CRITICAL LOAD NUMBER    =  2   INITIAL UNSTRESSED LENGTH (M) =   255.00281
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   255.27916


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LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 250.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	22086	20886	21.28	21567	20334	21.87
2	84.881	-5.0	303424	284161	23.14	303424 *	284161	23.14
3	52.985	-5.0	195625	184045	22.29	192911	181142	22.65
4	16.168	-10.0	63237	59930	20.86	61820	58427	21.41
5	5.747	-40.0	28466	27561	16.06	27302	26354	16.81
6	5.747	-35.0	27163	26210	16.90	26154	25162	17.61
7	5.747	-30.0	26037	25039	17.70	25153	24117	18.39
8	5.747	-25.0	25053	24012	18.47	24270	23192	19.13
9	5.747	-20.0	24183	23101	19.21	23485	22366	19.85
10	5.747	-15.0	23409	22287	19.92	22781	21623	20.54
11	5.747	-10.0	22714	21552	20.61	22145	20949	21.22
12	5.747	-5.0	22086	20886	21.28	21567	20334	21.87
13	5.747	0.0	21514	20278	21.93	21040	19771	22.51
14	5.747	5.0	20993	19721	22.56	20556	19253	23.13
15	5.747	10.0	20514	19207	23.18	20111	18773	23.73
16	5.747	15.0	20072	18732	23.78	19699	18328	24.32
17	5.747	20.0	19664	18290	24.37	19317	17913	24.90
18	5.747	25.0	19285	17879	24.95	18961	17526	25.46
19	5.747	30.0	18932	17494	25.51	18629	17162	26.02
20	5.747	35.0	18602	17133	26.06	18318	16821	26.56
21	5.747	40.0	18293	16794	26.60	18026	16499	27.09
22	5.747	45.0	18004	16474	27.14	17752	16195	27.62
23	5.747	50.0	17731	16172	27.66	17494	15908	28.13
24	5.747	55.0	17474	15887	28.17	17250	15636	28.64
25	5.747	60.0	17232	15616	28.68	17019	15377	29.14
26	5.747	65.0	17002	15358	29.18	16800	15131	29.63
27	5.747	70.0	16785	15113	29.67	16593	14896	30.11
28	5.747	75.0	16579	14880	30.15	16396	14672	30.59
29	5.747	80.0	16383	14657	30.62	16209	14458	31.06
30	5.747	85.0	16196	14444	31.09	16030	14253	31.53
31	5.747	90.0	16018	14240	31.56	15860	14057	31.98
32	5.747	95.0	15849	14045	32.01	15697	13869	32.44
33	5.747	100.0	15687	13857	32.46	15542	13688	32.88

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 309.71616
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 310.04208

****

LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 300.00 DATE : 01-10-2008

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	5.747	-5.0	21415	19560	32.92	21134	19247	33.47
2	84.881	-5.0	303376	274485	34.71	303376 *	274485	34.71
3	52.985	-5.0	193027	175427	33.87	191470	173687	34.22
4	16.168	-10.0	60866	55712	32.51	60109	54874	33.02
5	5.747	-40.0	24352	22764	28.17	23904	22280	28.80
6	5.747	-35.0	23837	22209	28.90	23421	21757	29.51
7	5.747	-30.0	23359	21691	29.60	22972	21270	30.20
8	5.747	-25.0	22916	21209	30.29	22555	20814	30.88
9	5.747	-20.0	22503	20757	30.97	22165	20386	31.55
10	5.747	-15.0	22117	20334	31.63	21799	19984	32.20
11	5.747	-10.0	21755	19936	32.28	21456	19605	32.84
12	5.747	-5.0	21415	19560	32.92	21134	19247	33.47
13	5.747	0.0	21096	19205	33.55	20830	18908	34.09
14	5.747	5.0	20794	18869	34.17	20543	18587	34.70
15	5.747	10.0	20510	18550	34.78	20271	18282	35.30
16	5.747	15.0	20240	18246	35.37	20014	17991	35.90
17	5.747	20.0	19985	17958	35.96	19770	17714	36.48
18	5.747	25.0	19742	17683	36.54	19537	17449	37.05
19	5.747	30.0	19512	17420	37.12	19317	17196	37.62
20	5.747	35.0	19293	17169	37.68	19106	16954	38.18
21	5.747	40.0	19083	16928	38.24	18905	16722	38.73
22	5.747	45.0	18884	16698	38.79	18713	16500	39.27
23	5.747	50.0	18693	16477	39.33	18530	16286	39.81
24	5.747	55.0	18511	16264	39.87	18354	16081	40.34
25	5.747	60.0	18336	16060	40.40	18186	15883	40.87
26	5.747	65.0	18169	15863	40.92	18025	15692	41.39
27	5.747	70.0	18009	15673	41.44	17870	15509	41.91
28	5.747	75.0	17855	15490	41.96	17722	15331	42.41
29	5.747	80.0	17707	15314	42.46	17579	15160	42.92
30	5.747	85.0	17565	15143	42.97	17441	14994	43.42
31	5.747	90.0	17428	14979	43.46	17309	14834	43.91
32	5.747	95.0	17297	14819	43.96	17182	14679	44.40
33	5.747	100.0	17170	14665	44.45	17059	14529	44.88

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 367.49130
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 367.86328

LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 350.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	21043	18324	48.24	20887	18139	48.76
2	84.881	-5.0	303384	261802	49.95	303384 *	261802	49.95
3	52.985	-5.0	191502	165962	49.15	190624	164914	49.48
4	16.168	-10.0	59556	51972	47.84	59142	51482	48.31
5	5.747	-40.0	22582	20115	43.77	22371	19873	44.32
6	5.747	-35.0	22330	19826	44.43	22129	19594	44.98
7	5.747	-30.0	22091	19550	45.09	21899	19327	45.63
8	5.747	-25.0	21862	19284	45.73	21678	19071	46.27
9	5.747	-20.0	21643	19030	46.37	21467	18824	46.90
10	5.747	-15.0	21434	18785	47.00	21266	18587	47.53
11	5.747	-10.0	21234	18550	47.63	21073	18359	48.15
12	5.747	-5.0	21043	18324	48.24	20887	18139	48.76
13	5.747	0.0	20859	18106	48.85	20709	17927	49.36
14	5.747	5.0	20682	17895	49.46	20539	17723	49.96
15	5.747	10.0	20513	17692	50.06	20374	17525	50.56
16	5.747	15.0	20350	17496	50.65	20217	17334	51.14
17	5.747	20.0	20193	17306	51.23	20065	17149	51.72
18	5.747	25.0	20042	17122	51.81	19918	16971	52.30
19	5.747	30.0	19897	16944	52.38	19777	16797	52.87
20	5.747	35.0	19757	16772	52.95	19641	16629	53.43
21	5.747	40.0	19621	16605	53.52	19510	16466	53.99
22	5.747	45.0	19491	16443	54.08	19383	16308	54.55
23	5.747	50.0	19365	16286	54.63	19260	16155	55.10
24	5.747	55.0	19243	16133	55.18	19142	16006	55.65
25	5.747	60.0	19125	15985	55.72	19027	15861	56.19
26	5.747	65.0	19011	15841	56.26	18916	15720	56.72
27	5.747	70.0	18901	15700	56.80	18809	15582	57.26
28	5.747	75.0	18795	15564	57.33	18705	15449	57.79
29	5.747	80.0	18691	15431	57.86	18605	15318	58.31
30	5.747	85.0	18591	15301	58.38	18507	15192	58.83
31	5.747	90.0	18494	15175	58.90	18413	15068	59.35
32	5.747	95.0	18400	15052	59.42	18321	14947	59.86
33	5.747	100.0	18309	14932	59.93	18232	14830	60.37

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 430.66278
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 431.07535

LOWER CHURCHILL 450KV
2126-A1-A4-91
RULING SPAN (M) = 400.00 DATE : 01-10-2008

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			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	5.747	-5.0	20814	16918	69.13	20734	16811	69.60
2	84.881	-5.0	303432	244543	70.75	303432 *	244543	70.75
3	52.985	-5.0	190551	154184	69.99	190098	153577	70.29
4	16.168	-10.0	58752	47855	68.72	58540	47575	69.16
5	5.747	-40.0	21612	17956	64.86	21513	17829	65.35
6	5.747	-35.0	21486	17796	65.49	21390	17672	65.97
7	5.747	-30.0	21365	17640	66.10	21272	17519	66.59
8	5.747	-25.0	21248	17488	66.72	21158	17370	67.20
9	5.747	-20.0	21134	17340	67.33	21047	17225	67.81
10	5.747	-15.0	21024	17196	67.93	20939	17084	68.41
11	5.747	-10.0	20917	17055	68.53	20835	16946	69.00
12	5.747	-5.0	20814	16918	69.13	20734	16811	69.60
13	5.747	0.0	20714	16784	69.72	20636	16680	70.19
14	5.747	5.0	20616	16654	70.31	20540	16552	70.77
15	5.747	10.0	20522	16527	70.89	20448	16427	71.35
16	5.747	15.0	20430	16402	71.47	20358	16304	71.93
17	5.747	20.0	20341	16280	72.04	20271	16185	72.50
18	5.747	25.0	20254	16162	72.62	20186	16068	73.07
19	5.747	30.0	20170	16045	73.19	20104	15954	73.64
20	5.747	35.0	20088	15932	73.75	20024	15842	74.20
21	5.747	40.0	20009	15821	74.31	19946	15733	74.76
22	5.747	45.0	19931	15712	74.87	19870	15625	75.32
23	5.747	50.0	19856	15605	75.43	19797	15521	75.87
24	5.747	55.0	19783	15501	75.98	19725	15418	76.42
25	5.747	60.0	19712	15399	76.53	19655	15317	76.97
26	5.747	65.0	19642	15298	77.07	19587	15219	77.51
27	5.747	70.0	19575	15200	77.62	19521	15122	78.05
28	5.747	75.0	19509	15104	78.16	19456	15027	78.59
29	5.747	80.0	19445	15010	78.69	19394	14934	79.13
30	5.747	85.0	19382	14917	79.23	19332	14843	79.66
31	5.747	90.0	19321	14826	79.76	19273	14753	80.19
32	5.747	95.0	19262	14737	80.29	19215	14666	80.72
33	5.747	100.0	19204	14650	80.81	19158	14579	81.24

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Figure E-5 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Conductor 800-A2/S3A-54/19 (41.9 mm Diameter)
(55 mm Ice)

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DATE : 01-10-2008


PROBLEM TITLE       :       LOWER CHURCHILL 450KV
CABLE DESIGNATION   :       800-A2-S3A-54-19
TITLE FOR SAG TABLE :       METALLIC RETURN-55

CABLE DATA :
------------
            DIA               (MM) =  41.9
            AREA             (MM2) =  1037
            MASS            (KG/M) =  3.456
            TEMPERATURE COEFF  (C) =  .0000196
            RTS               (KN) =  445.3
            EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1        57.00            93.00
       2        42.50           200.00

FINAL AND CREEP MODULUS (GPA) :  70.5      35


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                       1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    16.50    1
       2      55.0    0.90    0.00       -5.0    75.00    2
       3      50.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00


    CRITICAL LOAD NUMBER    =  1   INITIAL UNSTRESSED LENGTH (M) =   249.85274
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   250.11247


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LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 250.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73352	3.61	52923	52753	5.02
2	18.518	-5.0	177369	175903	8.08	177369	175903	8.08
3	16.614	-5.0	166534	165278	7.71	164382	163110	7.81
4	11.105	-10.0	134859	134168	6.35	125828	125086	6.81
5	3.456	-40.0	98613	98522	2.69	69677	69548	3.81
6	3.456	-35.0	94977	94883	2.79	66687	66552	3.98
7	3.456	-30.0	90963	90865	2.91	63924	63784	4.15
8	3.456	-25.0	87119	87016	3.04	61348	61201	4.33
9	3.456	-20.0	83444	83336	3.18	58983	58831	4.50
10	3.456	-15.0	79911	79799	3.32	56802	56643	4.68
11	3.456	-10.0	76603	76486	3.46	54785	54621	4.85
12	3.456	-5.0	73471	73348	3.61	52923	52753	5.02
13	3.456	0.0	70513	70385	3.76	51200	51024	5.19
14	3.456	5.0	67731	67598	3.92	49582	49401	5.36
15	3.456	10.0	65110	64972	4.08	48094	47907	5.53
16	3.456	15.0	62678	62535	4.24	46710	46517	5.70
17	3.456	20.0	60395	60246	4.40	45420	45222	5.86
18	3.456	25.0	58268	58113	4.56	44216	44012	6.02
19	3.456	30.0	56281	56121	4.72	43090	42880	6.18
20	3.456	35.0	54406	54240	4.88	42034	41819	6.34
21	3.456	40.0	52672	52501	5.05	41045	40825	6.49
22	3.456	45.0	51050	50874	5.21	40115	39889	6.64
23	3.456	50.0	49537	49355	5.37	39237	39007	6.79
24	3.456	55.0	48121	47934	5.53	38410	38175	6.94
25	3.456	60.0	46806	46613	5.68	37630	37389	7.09
26	3.456	65.0	45554	45356	5.84	36890	36645	7.23
27	3.456	70.0	44386	44183	6.00	36189	35939	7.38
28	3.456	75.0	43290	43081	6.15	35530	35275	7.52
29	3.456	80.0	42257	42043	6.30	34896	34637	7.65
30	3.456	85.0	41280	41062	6.45	34294	34030	7.79
31	3.456	90.0	40371	40147	6.60	33718	33450	7.93
32	3.456	95.0	39506	39277	6.75	33171	32898	8.06
33	3.456	100.0	38690	38456	6.89	32648	32370	8.19

CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 299.89706
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 300.25140

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 300.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73298	5.20	54181	53941	7.07
2	18.518	-5.0	193233	191291	10.70	193233	191291	10.70
3	16.614	-5.0	180861	179192	10.24	178612	176922	10.38
4	11.105	-10.0	144090	143157	8.57	134802	133804	9.17
5	3.456	-40.0	94936	94799	4.02	66900	66707	5.72
6	3.456	-35.0	91389	91248	4.18	64686	64485	5.92
7	3.456	-30.0	88008	87861	4.34	62628	62421	6.11
8	3.456	-25.0	84783	84630	4.51	60706	60493	6.31
9	3.456	-20.0	81726	81567	4.68	58917	58697	6.50
10	3.456	-15.0	78820	78655	4.85	57223	56996	6.69
11	3.456	-10.0	76052	75882	5.03	55650	55417	6.89
12	3.456	-5.0	73467	73291	5.20	54180	53941	7.07
13	3.456	0.0	71024	70841	5.38	52799	52553	7.26
14	3.456	5.0	68706	68517	5.57	51505	51253	7.45
15	3.456	10.0	66549	66354	5.75	50286	50027	7.63
16	3.456	15.0	64505	64304	5.93	49137	48872	7.81
17	3.456	20.0	62584	62377	6.12	48052	47781	7.99
18	3.456	25.0	60780	60567	6.30	47030	46753	8.16
19	3.456	30.0	59084	58864	6.48	46061	45779	8.34
20	3.456	35.0	57471	57245	6.66	45144	44855	8.51
21	3.456	40.0	55965	55733	6.85	44275	43981	8.68
22	3.456	45.0	54542	54303	7.03	43448	43148	8.85
23	3.456	50.0	53201	52957	7.21	42663	42358	9.01
24	3.456	55.0	51937	51687	7.38	41915	41604	9.18
25	3.456	60.0	50741	50485	7.56	41203	40887	9.34
26	3.456	65.0	49611	49349	7.73	40523	40201	9.50
27	3.456	70.0	48541	48273	7.91	39880	39553	9.65
28	3.456	75.0	47525	47251	8.08	39257	38925	9.81
29	3.456	80.0	46563	46283	8.25	38661	38323	9.96
30	3.456	85.0	45651	45366	8.41	38089	37746	10.12
31	3.456	90.0	44778	44487	8.58	37542	37194	10.27
32	3.456	95.0	43956	43660	8.74	37016	36663	10.42
33	3.456	100.0	43161	42859	8.91	36511	36153	10.56

CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 349.98193
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 350.44067

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 350.00 DATE : 01-10-2008

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			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73234	7.09	55576	55258	9.40
2	18.518	-5.0	207680	205214	13.58	207680	205214	13.58
3	16.614	-5.0	193873	191749	13.03	191551	189401	13.20
4	11.105	-10.0	152387	151184	11.04	142960	141677	11.79
5	3.456	-40.0	91209	91015	5.70	65665	65396	7.94
6	3.456	-35.0	88274	88075	5.89	63944	63668	8.16
7	3.456	-30.0	85474	85268	6.09	62340	62056	8.37
8	3.456	-25.0	82815	82602	6.29	60829	60538	8.58
9	3.456	-20.0	80288	80068	6.48	59402	59105	8.79
10	3.456	-15.0	77893	77666	6.69	58055	57750	8.99
11	3.456	-10.0	75604	75370	6.89	56781	56470	9.20
12	3.456	-5.0	73466	73226	7.09	55576	55257	9.40
13	3.456	0.0	71440	71192	7.29	54434	54108	9.60
14	3.456	5.0	69518	69264	7.50	53350	53018	9.80
15	3.456	10.0	67696	67435	7.70	52321	51982	9.99
16	3.456	15.0	65968	65700	7.90	51342	50997	10.19
17	3.456	20.0	64343	64069	8.11	50412	50060	10.38
18	3.456	25.0	62801	62520	8.31	49523	49165	10.57
19	3.456	30.0	61338	61050	8.51	48677	48312	10.76
20	3.456	35.0	59957	59662	8.71	47868	47497	10.94
21	3.456	40.0	58630	58328	8.90	47095	46718	11.12
22	3.456	45.0	57378	57070	9.10	46356	45973	11.30
23	3.456	50.0	56191	55876	9.30	45647	45258	11.48
24	3.456	55.0	55061	54739	9.49	44968	44572	11.66
25	3.456	60.0	53985	53657	9.68	44316	43915	11.84
26	3.456	65.0	52961	52627	9.87	43697	43290	12.01
27	3.456	70.0	51986	51645	10.06	43094	42681	12.18
28	3.456	75.0	51053	50706	10.25	42514	42096	12.35
29	3.456	80.0	50163	49810	10.43	41956	41532	12.52
30	3.456	85.0	49312	48952	10.61	41419	40989	12.68
31	3.456	90.0	48497	48131	10.80	40901	40465	12.85
32	3.456	95.0	47717	47345	10.98	40400	39959	13.01
33	3.456	100.0	46970	46592	11.15	39917	39471	13.17

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CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 400.11453
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 400.68588

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LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 400.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73160	9.27	56963	56556	12.00
2	18.518	-5.0	220900	217866	16.71	220900	217866	16.71
3	16.614	-5.0	205726	203107	16.08	203367	200716	16.27
4	11.105	-10.0	159834	158334	13.78	150374	148777	14.67
5	3.456	-40.0	88095	87833	7.72	65212	64858	10.46
6	3.456	-35.0	85681	85412	7.94	63849	63487	10.69
7	3.456	-30.0	83389	83112	8.16	62555	62186	10.91
8	3.456	-25.0	81201	80917	8.38	61324	60947	11.13
9	3.456	-20.0	79120	78828	8.60	60155	59770	11.35
10	3.456	-15.0	77142	76843	8.83	59040	58648	11.57
11	3.456	-10.0	75260	74953	9.05	57978	57578	11.79
12	3.456	-5.0	73464	73149	9.27	56963	56556	12.00
13	3.456	0.0	71768	71446	9.49	55994	55581	12.21
14	3.456	5.0	70155	69826	9.72	55069	54648	12.42
15	3.456	10.0	68606	68269	9.94	54183	53755	12.63
16	3.456	15.0	67139	66795	10.16	53334	52899	12.83
17	3.456	20.0	65747	65395	10.37	52521	52079	13.03
18	3.456	25.0	64431	64072	10.59	51740	51292	13.23
19	3.456	30.0	63163	62797	10.80	50990	50535	13.43
20	3.456	35.0	61958	61584	11.02	50270	49808	13.63
21	3.456	40.0	60807	60427	11.23	49578	49109	13.82
22	3.456	45.0	59695	59307	11.44	48911	48436	14.02
23	3.456	50.0	58640	58245	11.65	48268	47787	14.21
24	3.456	55.0	57632	57230	11.86	47656	47168	14.40
25	3.456	60.0	56666	56257	12.06	47058	46564	14.58
26	3.456	65.0	55740	55325	12.27	46481	45980	14.77
27	3.456	70.0	54855	54432	12.47	45924	45417	14.95
28	3.456	75.0	54002	53573	12.67	45384	44871	15.13
29	3.456	80.0	53186	52749	12.87	44864	44345	15.32
30	3.456	85.0	52400	51957	13.06	44360	43835	15.49
31	3.456	90.0	51644	51195	13.26	43872	43341	15.67
32	3.456	95.0	50917	50461	13.45	43399	42862	15.85
33	3.456	100.0	50216	49753	13.64	42941	42398	16.02

Figure E-6 (5-pages)
Sag and Tension Calculations for $\pm$450 kVdc
Conductor 800-A2/S3A-54/19 (41.9 mm Diameter)
(75 mm Ice)

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DATE : 01-10-2008


PROBLEM TITLE       :       LOWER CHURCHILL 450KV
CABLE DESIGNATION   :       800-A2-S3A-54-19
TITLE FOR SAG TABLE :       METALLIC RETURN-55

CABLE DATA :
------------
            DIA                (MM) =  41.9
            AREA              (MM2) =  1037
            MASS             (KG/M) =  3.456
            TEMPERATURE COEFF  (C) =  .0000196
            RTS                (KN) =  445.3
            EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1        57.00           93.00
       2        42.50          200.00

FINAL AND CREEP MODULUS (GPA) :  70.5      35


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                       1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    16.50    1
       2      75.0    0.90    0.00       -5.0    75.00    2
       3      70.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00


    CRITICAL LOAD NUMBER    =  1   INITIAL UNSTRESSED LENGTH (M) =   249.85274
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   250.22658

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LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 250.00 DATE : 01-10-2008

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			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73352	3.61	45857	45660	5.80
2	28.235	-5.0	228192	225531	9.61	228192	225531	9.61
3	22.686	-5.0	199980	198024	8.79	194767	192758	9.03
4	11.105	-10.0	134859	134168	6.35	116594	115793	7.36
5	3.456	-40.0	98613	98522	2.69	57538	57381	4.62
6	3.456	-35.0	94977	94883	2.79	55472	55310	4.79
7	3.456	-30.0	90963	90865	2.91	53545	53377	4.96
8	3.456	-25.0	87119	87016	3.04	51783	51609	5.13
9	3.456	-20.0	83444	83336	3.18	50122	49942	5.30
10	3.456	-15.0	79911	79799	3.32	48599	48414	5.47
11	3.456	-10.0	76603	76486	3.46	47186	46995	5.64
12	3.456	-5.0	73471	73348	3.61	45856	45660	5.80
13	3.456	0.0	70513	70385	3.76	44632	44430	5.96
14	3.456	5.0	67731	67598	3.92	43469	43261	6.13
15	3.456	10.0	65110	64972	4.08	42390	42177	6.28
16	3.456	15.0	62678	62535	4.24	41378	41160	6.44
17	3.456	20.0	60395	60246	4.40	40436	40213	6.59
18	3.456	25.0	58268	58113	4.56	39534	39306	6.74
19	3.456	30.0	56281	56121	4.72	38689	38455	6.89
20	3.456	35.0	54406	54240	4.88	37894	37656	7.04
21	3.456	40.0	52672	52501	5.05	37138	36894	7.18
22	3.456	45.0	51050	50874	5.21	36417	36169	7.33
23	3.456	50.0	49537	49355	5.37	35745	35492	7.47
24	3.456	55.0	48121	47934	5.53	35102	34844	7.61
25	3.456	60.0	46806	46613	5.68	34497	34234	7.74
26	3.456	65.0	45554	45356	5.84	33909	33642	7.88
27	3.456	70.0	44386	44183	6.00	33352	33080	8.01
28	3.456	75.0	43290	43081	6.15	32821	32545	8.15
29	3.456	80.0	42257	42043	6.30	32313	32033	8.28
30	3.456	85.0	41280	41062	6.45	31830	31545	8.41
31	3.456	90.0	40371	40147	6.60	31363	31073	8.53
32	3.456	95.0	39506	39277	6.75	30916	30623	8.66
33	3.456	100.0	38690	38456	6.89	30488	30190	8.78

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CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 299.89706
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 300.40732

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LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 300.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73298	5.20	47736	47463	8.04
2	28.235	-5.0	251125	247634	12.61	251125	247634	12.61
3	22.686	-5.0	219002	216424	11.59	213494	210848	11.89
4	11.105	-10.0	144090	143157	8.57	125449	124374	9.86
5	3.456	-40.0	94936	94799	4.02	56741	56513	6.75
6	3.456	-35.0	91389	91248	4.18	55208	54973	6.94
7	3.456	-30.0	88008	87861	4.34	53776	53534	7.13
8	3.456	-25.0	84783	84630	4.51	52411	52163	7.32
9	3.456	-20.0	81726	81567	4.68	51135	50881	7.50
10	3.456	-15.0	78820	78655	4.85	49938	49678	7.68
11	3.456	-10.0	76052	75882	5.03	48803	48537	7.86
12	3.456	-5.0	73467	73291	5.20	47739	47466	8.04
13	3.456	0.0	71024	70841	5.38	46731	46453	8.22
14	3.456	5.0	68706	68517	5.57	45782	45497	8.39
15	3.456	10.0	66549	66354	5.75	44880	44590	8.56
16	3.456	15.0	64505	64304	5.93	44026	43730	8.73
17	3.456	20.0	62584	62377	6.12	43209	42908	8.90
18	3.456	25.0	60780	60567	6.30	42440	42133	9.06
19	3.456	30.0	59084	58864	6.48	41698	41386	9.22
20	3.456	35.0	57471	57245	6.66	40994	40676	9.39
21	3.456	40.0	55965	55733	6.85	40320	39996	9.55
22	3.456	45.0	54542	54303	7.03	39681	39352	9.70
23	3.456	50.0	53201	52957	7.21	39068	38734	9.86
24	3.456	55.0	51937	51687	7.38	38484	38145	10.01
25	3.456	60.0	50741	50485	7.56	37919	37574	10.16
26	3.456	65.0	49611	49349	7.73	37377	37028	10.31
27	3.456	70.0	48541	48273	7.91	36858	36503	10.46
28	3.456	75.0	47525	47251	8.08	36359	35999	10.61
29	3.456	80.0	46563	46283	8.25	35883	35518	10.75
30	3.456	85.0	45651	45366	8.41	35419	35049	10.90
31	3.456	90.0	44778	44487	8.58	34972	34598	11.04
32	3.456	95.0	43956	43660	8.74	34542	34163	11.18
33	3.456	100.0	43161	42859	8.91	34127	33744	11.32

CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 349.98193
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 350.64368

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 350.00 DATE : 01-10-2008

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			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73234	7.09	49601	49244	10.55
2	28.235	-5.0	272210	267814	15.87	272210	267814	15.87
3	22.686	-5.0	236419	233161	14.64	230655	227313	15.02
4	11.105	-10.0	152387	151184	11.04	133535	132158	12.64
5	3.456	-40.0	91209	91015	5.70	56899	56588	9.18
6	3.456	-35.0	88274	88075	5.89	55683	55365	9.38
7	3.456	-30.0	85474	85268	6.09	54530	54205	9.58
8	3.456	-25.0	82815	82602	6.29	53448	53116	9.78
9	3.456	-20.0	80288	80068	6.48	52405	52067	9.98
10	3.456	-15.0	77893	77666	6.69	51424	51080	10.17
11	3.456	-10.0	75604	75370	6.89	50492	50141	10.36
12	3.456	-5.0	73466	73226	7.09	49601	49244	10.55
13	3.456	0.0	71440	71192	7.29	48756	48392	10.74
14	3.456	5.0	69518	69264	7.50	47939	47569	10.92
15	3.456	10.0	67696	67435	7.70	47162	46786	11.11
16	3.456	15.0	65968	65700	7.90	46421	46038	11.29
17	3.456	20.0	64343	64069	8.11	45708	45320	11.47
18	3.456	25.0	62801	62520	8.31	45026	44631	11.64
19	3.456	30.0	61338	61050	8.51	44368	43967	11.82
20	3.456	35.0	59957	59662	8.71	43742	43335	11.99
21	3.456	40.0	58630	58328	8.90	43139	42727	12.17
22	3.456	45.0	57378	57070	9.10	42563	42145	12.33
23	3.456	50.0	56191	55876	9.30	42000	41576	12.50
24	3.456	55.0	55061	54739	9.49	41460	41031	12.67
25	3.456	60.0	53985	53657	9.68	40941	40506	12.83
26	3.456	65.0	52961	52627	9.87	40439	39999	13.00
27	3.456	70.0	51986	51645	10.06	39960	39514	13.16
28	3.456	75.0	51053	50706	10.25	39490	39039	13.32
29	3.456	80.0	50163	49810	10.43	39037	38580	13.48
30	3.456	85.0	49312	48952	10.61	38599	38137	13.64
31	3.456	90.0	48497	48131	10.80	38174	37707	13.79
32	3.456	95.0	47717	47345	10.98	37765	37292	13.95
33	3.456	100.0	46970	46592	11.15	37368	36890	14.10

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CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 400.11453
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 400.94089

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LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 400.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73160	9.27	51373	50921	13.33
2	28.235	-5.0	291724	286352	19.40	291724	286352	19.40
3	22.686	-5.0	252439	248444	17.96	246477	242381	18.41
4	11.105	-10.0	159834	158334	13.78	140937	139230	15.68
5	3.456	-40.0	88095	87833	7.72	57467	57064	11.89
6	3.456	-35.0	85681	85412	7.94	56478	56068	12.10
7	3.456	-30.0	83389	83112	8.16	55534	55117	12.31
8	3.456	-25.0	81201	80917	8.38	54629	54204	12.52
9	3.456	-20.0	79120	78828	8.60	53762	53331	12.73
10	3.456	-15.0	77142	76843	8.83	52932	52494	12.93
11	3.456	-10.0	75260	74953	9.05	52132	51687	13.13
12	3.456	-5.0	73464	73149	9.27	51373	50922	13.33
13	3.456	0.0	71768	71446	9.49	50633	50174	13.53
14	3.456	5.0	70155	69826	9.72	49925	49460	13.73
15	3.456	10.0	68606	68269	9.94	49245	48773	13.92
16	3.456	15.0	67139	66795	10.16	48587	48109	14.11
17	3.456	20.0	65747	65395	10.37	47958	47474	14.30
18	3.456	25.0	64431	64072	10.59	47351	46859	14.49
19	3.456	30.0	63163	62797	10.80	46763	46265	14.68
20	3.456	35.0	61958	61584	11.02	46200	45696	14.86
21	3.456	40.0	60807	60427	11.23	45650	45141	15.04
22	3.456	45.0	59695	59307	11.44	45120	44604	15.23
23	3.456	50.0	58640	58245	11.65	44607	44085	15.41
24	3.456	55.0	57632	57230	11.86	44112	43584	15.58
25	3.456	60.0	56666	56257	12.06	43632	43098	15.76
26	3.456	65.0	55740	55325	12.27	43170	42630	15.93
27	3.456	70.0	54855	54432	12.47	42717	42171	16.11
28	3.456	75.0	54002	53573	12.67	42279	41727	16.28
29	3.456	80.0	53186	52749	12.87	41854	41297	16.45
30	3.456	85.0	52400	51957	13.06	41441	40878	16.62
31	3.456	90.0	51644	51195	13.26	41040	40471	16.79
32	3.456	95.0	50917	50461	13.45	40651	40076	16.95
33	3.456	100.0	50216	49753	13.64	40272	39692	17.12

****

Figure E-7 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Conductor 800-A2/S3A-54/19 (41.9 mm Diameter)
(110 mm Ice)

```
DATE : 01-11-2008


PROBLEM TITLE       :       LOWER CHURCHILL 450KV
CABLE DESIGNATION   :       800-A2-S3A-54-19
TITLE FOR SAG TABLE :       METALLIC RETURN-110

CABLE DATA :
------------
            DIA               (MM) =  41.9
            AREA             (MM2) =  1037
            MASS            (KG/M) =  3.456
            TEMPERATURE COEFF  (C) =  .0000196
            RTS               (KN) =  445.3
            EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1        57.00            93.00
       2        42.50           200.00

FINAL AND CREEP MODULUS (GPA) :  70.5      35


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT   SAG TYPE
                                                      1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    16.50    1
       2      %110.0    0.90    0.00       -5.0    75.00    2
       3      %100.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00



    CRITICAL LOAD NUMBER    =  1   INITIAL UNSTRESSED LENGTH (M) =   249.85274
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   250.45171

*******************************************************************************
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LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 250.00 DATE : 01-11-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	73475 *	73352	3.61	37007	36762	7.21
2	50.679	-5.0	328374	322370	12.08	328374	322370	12.08
3	33.668	-5.0	254204	250800	10.31	241687	238101	10.86
4	11.105	-10.0	134859	134168	6.35	102266	101350	8.41
5	3.456	-40.0	98613	98522	2.69	43273	43065	6.15
6	3.456	-35.0	94977	94883	2.79	42206	41992	6.31
7	3.456	-30.0	90963	90865	2.91	41205	40986	6.47
8	3.456	-25.0	87119	87016	3.04	40265	40040	6.62
9	3.456	-20.0	83444	83336	3.18	39379	39150	6.77
10	3.456	-15.0	79911	79799	3.32	38548	38314	6.92
11	3.456	-10.0	76603	76486	3.46	37755	37515	7.07
12	3.456	-5.0	73471	73348	3.61	37007	36763	7.21
13	3.456	0.0	70513	70385	3.76	36299	36050	7.35
14	3.456	5.0	67731	67598	3.92	35630	35376	7.49
15	3.456	10.0	65110	64972	4.08	34990	34731	7.63
16	3.456	15.0	62678	62535	4.24	34382	34119	7.77
17	3.456	20.0	60395	60246	4.40	33800	33532	7.91
18	3.456	25.0	58268	58113	4.56	33252	32979	8.04
19	3.456	30.0	56281	56121	4.72	32724	32447	8.17
20	3.456	35.0	54406	54240	4.88	32223	31941	8.30
21	3.456	40.0	52672	52501	5.05	31739	31453	8.43
22	3.456	45.0	51050	50874	5.21	31276	30986	8.56
23	3.456	50.0	49537	49355	5.37	30833	30539	8.68
24	3.456	55.0	48121	47934	5.53	30408	30110	8.81
25	3.456	60.0	46806	46613	5.68	30000	29697	8.93
26	3.456	65.0	45554	45356	5.84	29608	29301	9.05
27	3.456	70.0	44386	44183	6.00	29227	28917	9.17
28	3.456	75.0	43290	43081	6.15	28863	28548	9.29
29	3.456	80.0	42257	42043	6.30	28513	28194	9.41
30	3.456	85.0	41280	41062	6.45	28173	27850	9.53
31	3.456	90.0	40371	40147	6.60	27844	27517	9.64
32	3.456	95.0	39506	39277	6.75	27528	27197	9.76
33	3.456	100.0	38690	38456	6.89	27222	26888	9.87

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 300.55646
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 301.28979

****

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 300.00 DATE : 01-11-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	42097	41787	9.14	30965	30541	12.51
2	50.679	-5.0	333979	325402	17.26	333979 *	325402	17.26
3	33.668	-5.0	249496	244462	15.25	239360	234102	15.93
4	11.105	-10.0	111866	110658	11.09	92563	91094	13.49
5	3.456	-40.0	48108	47837	7.98	33360	32967	11.59
6	3.456	-35.0	47114	46837	8.15	32983	32586	11.72
7	3.456	-30.0	46176	45894	8.32	32619	32217	11.86
8	3.456	-25.0	45274	44986	8.48	32267	31861	11.99
9	3.456	-20.0	44421	44128	8.65	31926	31516	12.12
10	3.456	-15.0	43607	43309	8.81	31598	31183	12.25
11	3.456	-10.0	42831	42527	8.98	31276	30856	12.38
12	3.456	-5.0	42089	41779	9.14	30962	30538	12.51
13	3.456	0.0	41390	41075	9.29	30663	30235	12.64
14	3.456	5.0	40715	40395	9.45	30370	29937	12.77
15	3.456	10.0	40071	39745	9.61	30086	29649	12.89
16	3.456	15.0	39455	39125	9.76	29808	29367	13.02
17	3.456	20.0	38859	38523	9.91	29536	29091	13.14
18	3.456	25.0	38291	37950	10.06	29275	28826	13.26
19	3.456	30.0	37745	37399	10.21	29020	28566	13.38
20	3.456	35.0	37223	36872	10.36	28771	28313	13.50
21	3.456	40.0	36714	36359	10.50	28530	28068	13.62
22	3.456	45.0	36229	35868	10.65	28293	27827	13.74
23	3.456	50.0	35760	35394	10.79	28062	27592	13.86
24	3.456	55.0	35309	34939	10.93	27837	27363	13.97
25	3.456	60.0	34875	34499	11.07	27618	27140	14.09
26	3.456	65.0	34456	34076	11.21	27405	26924	14.20
27	3.456	70.0	34048	33664	11.35	27195	26710	14.32
28	3.456	75.0	33658	33269	11.48	26990	26501	14.43
29	3.456	80.0	33274	32881	11.62	26790	26297	14.54
30	3.456	85.0	32908	32510	11.75	26595	26098	14.66
31	3.456	90.0	32551	32148	11.88	26403	25903	14.77
32	3.456	95.0	32205	31798	12.02	26217	25712	14.88
33	3.456	100.0	31871	31460	12.15	26034	25526	14.99

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 351.84686
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 352.70135

****

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 350.00 DATE : 01-11-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	32567	32016	16.26	27757	27105	19.22
2	50.679	-5.0	333985	322174	23.76	333985 *	322174	23.76
3	33.668	-5.0	242123	234984	21.62	234443	227052	22.39
4	11.105	-10.0	96925	95007	17.61	85735	83552	20.04
5	3.456	-40.0	34540	34022	15.29	28947	28324	18.39
6	3.456	-35.0	34236	33713	15.43	28767	28140	18.51
7	3.456	-30.0	33940	33412	15.57	28591	27959	18.63
8	3.456	-25.0	33652	33119	15.71	28418	27782	18.75
9	3.456	-20.0	33371	32834	15.85	28248	27608	18.87
10	3.456	-15.0	33097	32555	15.99	28081	27438	18.99
11	3.456	-10.0	32829	32283	16.12	27917	27270	19.11
12	3.456	-5.0	32567	32017	16.26	27757	27105	19.22
13	3.456	0.0	32312	31757	16.39	27599	26943	19.34
14	3.456	5.0	32063	31503	16.52	27444	26784	19.45
15	3.456	10.0	31820	31256	16.65	27291	26628	19.57
16	3.456	15.0	31584	31015	16.78	27142	26475	19.68
17	3.456	20.0	31349	30776	16.91	26994	26323	19.80
18	3.456	25.0	31121	30543	17.04	26850	26175	19.91
19	3.456	30.0	30900	30318	17.17	26708	26029	20.02
20	3.456	35.0	30682	30095	17.30	26568	25885	20.14
21	3.456	40.0	30469	29878	17.43	26431	25745	20.25
22	3.456	45.0	30260	29665	17.55	26296	25606	20.36
23	3.456	50.0	30056	29457	17.68	26162	25469	20.47
24	3.456	55.0	29856	29252	17.80	26031	25334	20.58
25	3.456	60.0	29659	29052	17.93	25902	25201	20.69
26	3.456	65.0	29467	28856	18.05	25775	25070	20.80
27	3.456	70.0	29281	28665	18.17	25650	24942	20.91
28	3.456	75.0	29095	28475	18.29	25527	24815	21.01
29	3.456	80.0	28914	28290	18.41	25406	24690	21.12
30	3.456	85.0	28736	28107	18.53	25286	24567	21.23
31	3.456	90.0	28561	27929	18.65	25168	24445	21.33
32	3.456	95.0	28389	27753	18.77	25053	24326	21.44
33	3.456	100.0	28222	27581	18.89	24938	24208	21.55

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 403.76581
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 404.74103

****

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 400.00 DATE : 01-11-2008

****

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	3.456	-5.0	28813	27988	24.34	26109	25191	27.07
2	50.679	-5.0	333997	318354	31.48	333997 *	318354	31.48
3	33.668	-5.0	236975	227316	29.25	231137	221208	30.07
4	11.105	-10.0	88794	86022	25.45	81851	78823	27.81
5	3.456	-40.0	29800	29004	23.48	26823	25932	26.29
6	3.456	-35.0	29653	28853	23.60	26717	25822	26.40
7	3.456	-30.0	29508	28704	23.72	26612	25714	26.51
8	3.456	-25.0	29366	28558	23.85	26509	25607	26.63
9	3.456	-20.0	29225	28413	23.97	26407	25501	26.74
10	3.456	-15.0	29086	28270	24.09	26306	25396	26.85
11	3.456	-10.0	28949	28129	24.21	26207	25293	26.96
12	3.456	-5.0	28815	27990	24.34	26109	25191	27.07
13	3.456	0.0	28682	27853	24.46	26012	25090	27.18
14	3.456	5.0	28551	27719	24.58	25916	24991	27.29
15	3.456	10.0	28423	27586	24.70	25821	24892	27.40
16	3.456	15.0	28296	27455	24.81	25727	24795	27.51
17	3.456	20.0	28171	27326	24.93	25635	24699	27.62
18	3.456	25.0	28047	27198	25.05	25544	24604	27.72
19	3.456	30.0	27925	27072	25.17	25453	24510	27.83
20	3.456	35.0	27806	26949	25.29	25364	24417	27.94
21	3.456	40.0	27687	26827	25.40	25276	24325	28.05
22	3.456	45.0	27571	26706	25.52	25188	24234	28.15
23	3.456	50.0	27456	26587	25.63	25102	24144	28.26
24	3.456	55.0	27342	26470	25.75	25017	24055	28.36
25	3.456	60.0	27231	26354	25.86	24933	23968	28.47
26	3.456	65.0	27119	26239	25.98	24849	23881	28.58
27	3.456	70.0	27010	26126	26.09	24767	23795	28.68
28	3.456	75.0	26902	26014	26.20	24685	23710	28.78
29	3.456	80.0	26796	25904	26.32	24605	23625	28.89
30	3.456	85.0	26691	25795	26.43	24525	23542	28.99
31	3.456	90.0	26587	25688	26.54	24446	23460	29.10
32	3.456	95.0	26485	25581	26.65	24368	23378	29.20
33	3.456	100.0	26383	25476	26.76	24290	23297	29.30

****

Figure E-8 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Conductor 800-A2/S3A-54/19 (41.9 mm Diameter)
(140 mm Ice)

```
DATE : 01-10-2008


PROBLEM TITLE       :       LOWER CHURCHILL 450KV
CABLE DESIGNATION   :       800-A2-S3A-54-19
TITLE FOR SAG TABLE :       METALLIC RETURN-55

CABLE DATA :
------------
            DIA               (MM) =  41.9
            AREA             (MM2) =  1037
            MASS            (KG/M) =  3.456
            TEMPERATURE COEFF  (C) =  .0000196
            RTS               (KN) =  445.3
            EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1        57.00            93.00
       2        42.50           200.00

FINAL AND CREEP MODULUS (GPA) :  70.5      35


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT   SAG TYPE
                                                      1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    16.50    1
       2      %140.0    0.90    0.00       -5.0    75.00    2
       3      %130.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00



    CRITICAL LOAD NUMBER    =  2   INITIAL UNSTRESSED LENGTH (M) =   251.75270
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   252.36269


*******************************************************************************
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LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 250.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	20759	20316	13.08	18187	17677	15.05
2	75.429	-5.0	333989	320562	18.15	333989 *	320562	18.15
3	47.112	-5.0	227739	220120	16.49	220295	212395	17.10
4	11.105	-10.0	64089	62603	13.64	57233	55557	15.39
5	3.456	-40.0	21750	21327	12.46	18831	18340	14.50
6	3.456	-35.0	21599	21174	12.55	18735	18241	14.58
7	3.456	-30.0	21452	21023	12.64	18640	18143	14.66
8	3.456	-25.0	21307	20876	12.73	18547	18048	14.74
9	3.456	-20.0	21166	20732	12.82	18455	17953	14.82
10	3.456	-15.0	21027	20590	12.90	18364	17859	14.90
11	3.456	-10.0	20892	20451	12.99	18275	17768	14.97
12	3.456	-5.0	20759	20315	13.08	18187	17677	15.05
13	3.456	0.0	20628	20182	13.17	18101	17588	15.13
14	3.456	5.0	20501	20051	13.25	18015	17500	15.20
15	3.456	10.0	20375	19923	13.34	17932	17414	15.28
16	3.456	15.0	20252	19797	13.43	17849	17329	15.36
17	3.456	20.0	20131	19674	13.51	17768	17244	15.43
18	3.456	25.0	20013	19552	13.60	17687	17162	15.51
19	3.456	30.0	19896	19433	13.68	17608	17080	15.58
20	3.456	35.0	19782	19316	13.76	17530	17000	15.66
21	3.456	40.0	19670	19201	13.85	17453	16920	15.73
22	3.456	45.0	19560	19088	13.93	17378	16842	15.80
23	3.456	50.0	19452	18977	14.01	17303	16765	15.88
24	3.456	55.0	19345	18867	14.09	17229	16689	15.95
25	3.456	60.0	19240	18760	14.17	17157	16614	16.02
26	3.456	65.0	19137	18654	14.26	17085	16540	16.10
27	3.456	70.0	19036	18551	14.34	17014	16467	16.17
28	3.456	75.0	18937	18448	14.42	16945	16394	16.24
29	3.456	80.0	18839	18348	14.50	16876	16323	16.31
30	3.456	85.0	18743	18249	14.57	16808	16253	16.38
31	3.456	90.0	18648	18152	14.65	16741	16183	16.45
32	3.456	95.0	18555	18056	14.73	16675	16115	16.53
33	3.456	100.0	18463	17961	14.81	16610	16047	16.60

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 304.19949
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 304.92993

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 300.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	18195	17449	22.01	16971	16165	23.78
2	75.429	-5.0	334019	314226	26.76	334019 *	314226	26.76
3	47.112	-5.0	221034	209465	25.04	216134	204265	25.69
4	11.105	-10.0	57433	54989	22.44	53941	51319	24.08
5	3.456	-40.0	18614	17886	21.46	17301	16513	23.27
6	3.456	-35.0	18552	17822	21.54	17253	16462	23.35
7	3.456	-30.0	18491	17758	21.62	17205	16411	23.42
8	3.456	-25.0	18430	17695	21.70	17157	16361	23.49
9	3.456	-20.0	18371	17633	21.77	17110	16311	23.57
10	3.456	-15.0	18312	17571	21.85	17063	16262	23.64
11	3.456	-10.0	18253	17510	21.93	17017	16213	23.71
12	3.456	-5.0	18195	17449	22.01	16971	16165	23.78
13	3.456	0.0	18138	17389	22.08	16926	16117	23.85
14	3.456	5.0	18081	17330	22.16	16881	16070	23.92
15	3.456	10.0	18025	17272	22.24	16836	16023	24.00
16	3.456	15.0	17970	17213	22.31	16792	15976	24.07
17	3.456	20.0	17915	17156	22.39	16748	15930	24.14
18	3.456	25.0	17860	17099	22.46	16705	15884	24.21
19	3.456	30.0	17807	17043	22.54	16662	15839	24.28
20	3.456	35.0	17753	16987	22.61	16619	15794	24.35
21	3.456	40.0	17701	16932	22.69	16577	15749	24.42
22	3.456	45.0	17648	16877	22.76	16535	15705	24.49
23	3.456	50.0	17597	16823	22.84	16493	15661	24.56
24	3.456	55.0	17545	16769	22.91	16452	15618	24.63
25	3.456	60.0	17495	16716	22.99	16411	15574	24.70
26	3.456	65.0	17445	16663	23.06	16371	15532	24.77
27	3.456	70.0	17395	16611	23.13	16331	15489	24.84
28	3.456	75.0	17346	16559	23.21	16291	15447	24.91
29	3.456	80.0	17297	16508	23.28	16252	15405	24.98
30	3.456	85.0	17249	16457	23.35	16213	15364	25.04
31	3.456	90.0	17201	16407	23.43	16174	15323	25.11
32	3.456	95.0	17154	16357	23.50	16135	15282	25.18
33	3.456	100.0	17107	16308	23.57	16097	15241	25.25

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 358.08911
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 358.93967

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 350.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	17036	15918	32.98	16346	15172	34.64
2	75.429	-5.0	334095	306336	37.53	334095 *	306336	37.53
3	47.112	-5.0	216902	200368	35.79	213630	196786	36.46
4	11.105	-10.0	54212	50579	33.36	52188	48386	34.91
5	3.456	-40.0	17261	16160	32.48	16539	15382	34.16
6	3.456	-35.0	17228	16125	32.55	16511	15351	34.23
7	3.456	-30.0	17195	16090	32.62	16483	15321	34.30
8	3.456	-25.0	17163	16055	32.69	16455	15291	34.37
9	3.456	-20.0	17131	16020	32.77	16428	15261	34.44
10	3.456	-15.0	17099	15986	32.84	16400	15231	34.51
11	3.456	-10.0	17067	15952	32.91	16373	15201	34.57
12	3.456	-5.0	17036	15918	32.98	16346	15172	34.64
13	3.456	0.0	17004	15884	33.05	16319	15143	34.71
14	3.456	5.0	16973	15850	33.13	16292	15113	34.78
15	3.456	10.0	16942	15817	33.20	16266	15085	34.85
16	3.456	15.0	16912	15784	33.27	16239	15056	34.92
17	3.456	20.0	16881	15751	33.34	16213	15027	34.99
18	3.456	25.0	16851	15719	33.41	16187	14999	35.05
19	3.456	30.0	16821	15686	33.48	16161	14970	35.12
20	3.456	35.0	16791	15654	33.55	16135	14942	35.19
21	3.456	40.0	16761	15622	33.62	16109	14914	35.26
22	3.456	45.0	16732	15590	33.69	16084	14886	35.33
23	3.456	50.0	16702	15558	33.76	16058	14859	35.39
24	3.456	55.0	16673	15527	33.83	16033	14831	35.46
25	3.456	60.0	16644	15495	33.90	16008	14804	35.53
26	3.456	65.0	16616	15464	33.97	15983	14777	35.59
27	3.456	70.0	16587	15433	34.04	15958	14750	35.66
28	3.456	75.0	16559	15403	34.11	15934	14723	35.73
29	3.456	80.0	16531	15372	34.18	15909	14696	35.80
30	3.456	85.0	16503	15342	34.25	15885	14669	35.86
31	3.456	90.0	16475	15312	34.32	15861	14643	35.93
32	3.456	95.0	16447	15281	34.39	15837	14617	35.99
33	3.456	100.0	16419	15252	34.46	15813	14590	36.06

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 414.06302
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 415.03259

****

LOWER CHURCHILL 450KV
800-A2-S3A-54-19
RULING SPAN (M) = 400.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	16378	14799	46.61	15965	14332	48.18
2	75.429	-5.0	333979	296269	50.98	333979 *	296269	50.98
3	47.112	-5.0	214057	191305	49.25	211879	188814	49.92
4	11.105	-10.0	52329	47216	46.95	51098	45823	48.43
5	3.456	-40.0	16511	14948	46.13	16085	14467	47.72
6	3.456	-35.0	16492	14926	46.20	16067	14448	47.78
7	3.456	-30.0	16473	14905	46.27	16050	14428	47.85
8	3.456	-25.0	16454	14883	46.34	16033	14409	47.92
9	3.456	-20.0	16435	14862	46.40	16016	14390	47.98
10	3.456	-15.0	16416	14841	46.47	15999	14370	48.05
11	3.456	-10.0	16397	14820	46.54	15982	14351	48.12
12	3.456	-5.0	16378	14799	46.61	15965	14332	48.18
13	3.456	0.0	16360	14778	46.68	15948	14313	48.25
14	3.456	5.0	16341	14757	46.75	15932	14294	48.32
15	3.456	10.0	16323	14736	46.81	15915	14275	48.38
16	3.456	15.0	16305	14716	46.88	15898	14256	48.45
17	3.456	20.0	16286	14695	46.95	15882	14238	48.51
18	3.456	25.0	16268	14675	47.02	15865	14219	48.58
19	3.456	30.0	16250	14654	47.09	15849	14200	48.65
20	3.456	35.0	16232	14634	47.15	15833	14182	48.71
21	3.456	40.0	16214	14614	47.22	15817	14163	48.78
22	3.456	45.0	16196	14594	47.29	15800	14145	48.84
23	3.456	50.0	16178	14574	47.36	15784	14127	48.91
24	3.456	55.0	16161	14554	47.42	15768	14109	48.98
25	3.456	60.0	16143	14534	47.49	15752	14090	49.04
26	3.456	65.0	16126	14514	47.56	15737	14072	49.11
27	3.456	70.0	16108	14494	47.62	15721	14054	49.17
28	3.456	75.0	16091	14474	47.69	15705	14036	49.24
29	3.456	80.0	16074	14455	47.76	15689	14019	49.30
30	3.456	85.0	16056	14435	47.83	15674	14001	49.37
31	3.456	90.0	16039	14416	47.89	15658	13983	49.43
32	3.456	95.0	16022	14397	47.96	15643	13965	49.50
33	3.456	100.0	16005	14377	48.03	15627	13948	49.56

Figure E-9 (2-pages)
Sag and Tension Calculations for ± 450 kVdc
With Conductor 900-A2/S3A-72/7 (42.8 mm Diameter)
110 mm Ice

```
DATE : 09-11-2007


PROBLEM TITLE       :     LOWER CHURCHILL 450kV DC
CABLE DESIGNATION   :     900-A2/S3A-72/7
TITLE FOR SAG TABLE :     CONDUCTOR

CABLE DATA :
------------
          DIA              (MM) =  42.8
          AREA            (MM2) =  1081
          MASS           (KG/M) =  3.207
          TEMPERATURE COEFF  (C) =  .0000216
          RTS              (KN) =  379
          EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

          MODULUS (GPA)    LIMIT STRESS (MPA)
     1       48.50           77.00
     2       31.50          200.00

FINAL AND CREEP MODULUS (GPA) :  62.5     38


NUMBER OF CONSTRAINING LOADS =  4

          ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                  1=INIT & 2=FINAL

     1      0.0    0.00    0.00      -5.0    18.00    1
     2     %110.0   0.90    0.00      -5.0    75.00    2
     3     %100.0   0.50    0.88      -5.0    75.00    2
     4      0.0    0.00    2.47     -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  1
RULING SPANS (M) :
   300.00
```

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 301.50842
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 302.48795

##

LOWER CHURCHILL 450kV DC
900-A2/S3A-72/7
RULING SPAN (M) = 300.00 DATE : 09-11-2007

##

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.207	-5.0	26590	26164	13.56	21449	20914	16.99
2	50.710	-5.0	284259	274044	20.54	284259 *	274044	20.54
3	33.558	-5.0	206741	200638	18.55	197871	191473	19.44
4	11.247	-10.0	85739	84107	14.80	72647	70702	17.63
5	3.207	-40.0	28499	28102	12.62	22408	21898	16.22
6	3.207	-35.0	28201	27800	12.76	22262	21748	16.33
7	3.207	-30.0	27912	27507	12.89	22119	21602	16.44
8	3.207	-25.0	27633	27224	13.03	21980	21459	16.55
9	3.207	-20.0	27360	26946	13.16	21843	21319	16.66
10	3.207	-15.0	27097	26679	13.30	21709	21181	16.77
11	3.207	-10.0	26841	26418	13.43	21577	21046	16.88
12	3.207	-5.0	26591	26165	13.56	21449	20914	16.99
13	3.207	0.0	26348	25918	13.69	21322	20784	17.10
14	3.207	5.0	26113	25678	13.82	21197	20656	17.20
15	3.207	10.0	25883	25444	13.95	21075	20531	17.31
16	3.207	15.0	25659	25216	14.07	20955	20407	17.41
17	3.207	20.0	25441	24995	14.20	20837	20286	17.52
18	3.207	25.0	25229	24778	14.32	20722	20167	17.62
19	3.207	30.0	25022	24567	14.45	20608	20050	17.73
20	3.207	35.0	24821	24363	14.57	20496	19936	17.83
21	3.207	40.0	24623	24161	14.69	20387	19823	17.93
22	3.207	45.0	24431	23965	14.81	20279	19712	18.04
23	3.207	50.0	24243	23773	14.93	20173	19602	18.14
24	3.207	55.0	24059	23585	15.05	20068	19494	18.24
25	3.207	60.0	23880	23402	15.17	19965	19388	18.34
26	3.207	65.0	23704	23223	15.29	19864	19284	18.44
27	3.207	70.0	23532	23048	15.40	19765	19182	18.54
28	3.207	75.0	23365	22877	15.52	19668	19082	18.64
29	3.207	80.0	23201	22710	15.64	19571	18982	18.74
30	3.207	85.0	23041	22546	15.75	19477	18885	18.83
31	3.207	90.0	22885	22386	15.86	19384	18788	18.93
32	3.207	95.0	22730	22228	15.98	19292	18694	19.03
33	3.207	100.0	22580	22074	16.09	19202	18600	19.12

##

Figure E-10 (2-pages)
Sag and Tension Calculations for ±450 kVdc
With Conductor 710-A2/S3A-54/19 (39.5 mm Diameter)
110 mm Ice

```
DATE : 10-18-2007


PROBLEM TITLE       :      LOWER CHURCHILL 450kV DC
CABLE DESIGNATION   :      710-A2/S3A-54/19
TITLE FOR SAG TABLE :      CONDUCTOR

CABLE DATA :
------------
          DIA              (MM) =  39.5
          AREA            (MM2) =  920.7
          MASS           (KG/M) =  3.067
          TEMPERATURE COEFF  (C) =  .0000196
          RTS              (KN) =  395.2
          EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

          MODULUS (GPA)     LIMIT STRESS (MPA)
      1       57.00           91.00
      2       42.50          200.00

FINAL AND CREEP MODULUS (GPA) :  70.5      35


NUMBER OF CONSTRAINING LOADS =  2

          ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                   1=INIT & 2=FINAL

      1      0.0    0.00    0.00      -5.0    16.50    1
      2     %110.0    0.90    0.00      -5.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 75    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  1
RULING SPANS (M) :
    300.00
```

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 301.15500
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 301.89108

LOWER CHURCHILL 450kV DC
710-A2/S3A-54/19
RULING SPAN (M) = 300.00 DATE : 10-18-2007

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.067	-5.0	28486	28124	12.06	23207	22758	14.92
2	49.544	-5.0	296406	287107	19.14	296406 *	287107	19.14
3	3.067	-40.0	30835	30501	11.11	24442	24017	14.13
4	3.067	-35.0	30465	30126	11.25	24255	23826	14.24
5	3.067	-30.0	30108	29766	11.39	24070	23638	14.36
6	3.067	-25.0	29762	29415	11.53	23889	23454	14.47
7	3.067	-20.0	29427	29076	11.66	23713	23274	14.58
8	3.067	-15.0	29104	28749	11.79	23540	23098	14.70
9	3.067	-10.0	28789	28430	11.93	23372	22926	14.81
10	3.067	-5.0	28488	28126	12.06	23207	22758	14.92
11	3.067	0.0	28192	27825	12.19	23046	22594	15.03
12	3.067	5.0	27906	27535	12.32	22888	22432	15.13
13	3.067	10.0	27629	27255	12.44	22733	22275	15.24
14	3.067	15.0	27359	26981	12.57	22580	22119	15.35
15	3.067	20.0	27097	26716	12.70	22433	21968	15.46
16	3.067	25.0	26845	26459	12.82	22288	21820	15.56
17	3.067	30.0	26595	26205	12.94	22145	21674	15.67
18	3.067	35.0	26354	25961	13.07	22006	21531	15.77
19	3.067	40.0	26119	25723	13.19	21869	21392	15.88
20	3.067	45.0	25893	25492	13.31	21735	21254	15.98
21	3.067	50.0	25670	25266	13.43	21603	21120	16.08
22	3.067	55.0	25452	25045	13.55	21474	20987	16.18
23	3.067	60.0	25241	24830	13.66	21347	20857	16.29
24	3.067	65.0	25035	24620	13.78	21223	20730	16.39
25	3.067	70.0	24833	24415	13.90	21101	20605	16.49
26	3.067	75.0	24637	24216	14.01	20981	20482	16.59

Figure E-11 (2-pages)
Sag and Tension Calculations for ±500 kVdc
With Conductor 1000-A2/S3A-72/7 (45.1 mm Diameter)
110 mm Ice

```
DATE : 08-22-2007


PROBLEM TITLE       :      LOWER CHURCHILL 500 kV DC
CABLE DESIGNATION   :      1000-A2/S3A-72/7
TITLE FOR SAG TABLE :      CONDUCTOR

CABLE DATA :
------------
          DIA              (MM) =  45.1
          AREA            (MM2) =  1201
          MASS           (KG/M) =  3.563
          TEMPERATURE COEFF  (C) =  .0000216
          RTS              (KN) =  421.2
          EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

          MODULUS (GPA)     LIMIT STRESS (MPA)
     1        48.50              77.00
     2        31.50             200.00

FINAL AND CREEP MODULUS (GPA) :  62.5      38


NUMBER OF CONSTRAINING LOADS =  4

          ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                      1=INIT & 2=FINAL

     1       0.0    0.00    0.00       -5.0    18.00    1
     2     %110.0    0.90    0.00       -5.0    75.00    2
     3     %100.0    0.50    0.88       -5.0    75.00    2
     4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  1
RULING SPANS (M) :
   300.00
```

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 300.88846
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 301.86923

****

LOWER CHURCHILL 500 kV DC
1000-A2/S3A-72/7
RULING SPAN (M) = 300.00 DATE : 08-22-2007

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.563	-5.0	36656	36277	10.85	27119	26601	14.82
2	51.781	-5.0	315906	306389	18.74	315906 *	306389	18.74
3	34.240	-5.0	233540	227953	16.64	221971	216075	17.56
4	11.905	-10.0	106024	104554	12.59	86375	84555	15.59
5	3.563	-40.0	40822	40483	9.72	28743	28255	13.95
6	3.563	-35.0	40143	39798	9.89	28494	28002	14.08
7	3.563	-30.0	39501	39149	10.06	28248	27752	14.21
8	3.563	-25.0	38884	38527	10.22	28010	27509	14.33
9	3.563	-20.0	38291	37929	10.38	27778	27273	14.46
10	3.563	-15.0	37725	37357	10.54	27552	27042	14.58
11	3.563	-10.0	37179	36805	10.70	27331	26818	14.70
12	3.563	-5.0	36656	36277	10.85	27119	26601	14.83
13	3.563	0.0	36154	35769	11.01	26907	26385	14.95
14	3.563	5.0	35673	35283	11.16	26702	26176	15.07
15	3.563	10.0	35205	34810	11.31	26502	25972	15.19
16	3.563	15.0	34756	34356	11.46	26307	25772	15.30
17	3.563	20.0	34323	33917	11.61	26115	25577	15.42
18	3.563	25.0	33904	33493	11.76	25929	25386	15.54
19	3.563	30.0	33505	33089	11.90	25746	25198	15.66
20	3.563	35.0	33117	32696	12.05	25566	25015	15.77
21	3.563	40.0	32740	32314	12.19	25391	24836	15.89
22	3.563	45.0	32377	31946	12.33	25220	24661	16.00
23	3.563	50.0	32024	31588	12.47	25052	24489	16.11
24	3.563	55.0	31683	31242	12.61	24889	24322	16.22
25	3.563	60.0	31352	30906	12.75	24727	24157	16.34
26	3.563	65.0	31029	30579	12.89	24569	23995	16.45
27	3.563	70.0	30721	30266	13.02	24415	23836	16.56
28	3.563	75.0	30418	29958	13.15	24263	23681	16.67
29	3.563	80.0	30125	29661	13.29	24114	23528	16.78
30	3.563	85.0	29841	29372	13.42	23969	23379	16.88
31	3.563	90.0	29564	29090	13.55	23826	23233	16.99
32	3.563	95.0	29294	28816	13.68	23686	23088	17.10
33	3.563	100.0	29032	28550	13.81	23548	22946	17.21

****

Figure E-12 (2-pages)
Sag and Tension Calculations for ±500 kVdc
With Conductor 1120-A2/S3A-72/19 (47.7 mm Diameter)
110 mm Ice

```
DATE : 09-12-2007


PROBLEM TITLE       :      LOWER CHURCHILL 500kV DC
CABLE DESIGNATION   :      1120-A2/S3A-72/19
TITLE FOR SAG TABLE :      CONDUCTOR

CABLE DATA :
------------
          DIA              (MM) =  47.7
          AREA            (MM2) =  1343
          MASS           (KG/M) =  3.982
          TEMPERATURE COEFF  (C) =  .0000216
          RTS              (KN) =  472.1
          EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

          MODULUS (GPA)     LIMIT STRESS (MPA)
      1       48.50           77.00
      2       31.50          200.00

FINAL AND CREEP MODULUS (GPA) :  62.5      30


NUMBER OF CONSTRAINING LOADS =  4

          ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                   1=INIT & 2=FINAL

      1      0.0    0.00    0.00       -5.0    18.00    1
      2     %110.0    0.90    0.00       -5.0    75.00    2
      3     %100.0    0.50    0.88       -5.0    75.00    2
      4      0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  1
RULING SPANS (M) :
    300.00
```

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 300.33939
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 301.32379

LOWER CHURCHILL 500kV DC
1120-A2/S3A-72/19
RULING SPAN (M) = 300.00 DATE : 09-12-2007

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	3.982	-5.0	55538	55227	7.96	35308	34814	12.65
2	53.009	-5.0	354079	345236	17.01	354079 *	345236	17.01
3	35.026	-5.0	266924	261839	14.81	251786	246379	15.74
4	12.657	-10.0	134878	133578	10.47	104784	103098	13.58
5	3.982	-40.0	66805	66547	6.61	38282	37828	11.64
6	3.982	-35.0	64883	64617	6.80	37813	37352	11.79
7	3.982	-30.0	63082	62809	7.00	37362	36896	11.93
8	3.982	-25.0	61373	61092	7.20	36924	36452	12.08
9	3.982	-20.0	59779	59491	7.39	36496	36019	12.22
10	3.982	-15.0	58281	57985	7.58	36087	35604	12.37
11	3.982	-10.0	56871	56568	7.77	35691	35202	12.51
12	3.982	-5.0	55541	55230	7.96	35308	34814	12.65
13	3.982	0.0	54285	53967	8.15	34937	34438	12.79
14	3.982	5.0	53100	52774	8.33	34579	34074	12.92
15	3.982	10.0	51977	51645	8.52	34228	33718	13.06
16	3.982	15.0	50914	50574	8.70	33889	33374	13.20
17	3.982	20.0	49906	49559	8.87	33561	33040	13.33
18	3.982	25.0	48948	48594	9.05	33242	32716	13.46
19	3.982	30.0	48039	47679	9.23	32932	32401	13.60
20	3.982	35.0	47173	46807	9.40	32632	32096	13.73
21	3.982	40.0	46346	45973	9.57	32335	31794	13.86
22	3.982	45.0	45559	45178	9.74	32052	31506	13.98
23	3.982	50.0	44802	44415	9.91	31776	31225	14.11
24	3.982	55.0	44090	43697	10.07	31504	30948	14.24
25	3.982	60.0	43403	43004	10.23	31240	30679	14.36
26	3.982	65.0	42746	42340	10.39	30982	30417	14.49
27	3.982	70.0	42116	41704	10.55	30732	30161	14.61
28	3.982	75.0	41508	41090	10.71	30487	29912	14.73
29	3.982	80.0	40927	40502	10.87	30250	29670	14.85
30	3.982	85.0	40368	39938	11.02	30017	29432	14.98
31	3.982	90.0	39833	39397	11.17	29790	29200	15.10
32	3.982	95.0	39312	38870	11.32	29567	28973	15.21
33	3.982	100.0	38813	38365	11.47	29351	28752	15.33

Figure E-13 (2-pages)
Sag and Tension Calculations for ±500 kVdc
With Conductor 1250-A2/S3A-72/19 (50.4 mm Diameter)
110 mm Ice

```
DATE : 09-12-2007


PROBLEM TITLE       :      LOWER CHURCHILL 500kV DC
CABLE DESIGNATION   :      1250-A2/S3A-72/19
TITLE FOR SAG TABLE :      CONDUCTOR

CABLE DATA :
------------
          DIA              (MM) =  50.4
          AREA            (MM2) =  1499
          MASS           (KG/M) =  4.445
          TEMPERATURE COEFF  (C) =  .0000216
          RTS              (KN) =  526.9
          EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

          MODULUS (GPA)     LIMIT STRESS (MPA)
      1       48.50            77.00
      2       31.50           200.00

FINAL AND CREEP MODULUS (GPA) :  62.5      30


NUMBER OF CONSTRAINING LOADS =  4

          ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                   1=INIT & 2=FINAL

      1      0.0    0.00    0.00      -5.0    18.00    1
      2     %110.0    0.90    0.00      -5.0    75.00    2
      3     %100.0    0.50    0.88      -5.0    75.00    2
      4      0.0    0.00    2.47     -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  1
RULING SPANS (M) :
   300.00
```

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 299.91830
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 300.90326

****

LOWER CHURCHILL 500kV DC
1250-A2/S3A-72/19
RULING SPAN (M) = 300.00 DATE : 09-12-2007

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	4.445	-5.0	90810	90574	5.42	46293	45826	10.72
2	54.311	-5.0	395177	386900	15.54	395177 *	386900	15.54
3	35.868	-5.0	303886	299222	13.26	284666	279674	14.19
4	13.450	-10.0	170801	169645	8.76	127023	125459	11.85
5	4.445	-40.0	118263	118082	4.15	51833	51416	9.55
6	4.445	-35.0	114422	114234	4.29	50927	50503	9.72
7	4.445	-30.0	109911	109716	4.47	50063	49632	9.89
8	4.445	-25.0	105639	105437	4.65	49238	48799	10.06
9	4.445	-20.0	101595	101384	4.84	48450	48004	10.23
10	4.445	-15.0	97780	97561	5.03	47700	47247	10.40
11	4.445	-10.0	94186	93958	5.22	46986	46526	10.56
12	4.445	-5.0	90813	90577	5.42	46294	45826	10.72
13	4.445	0.0	87626	87381	5.61	45632	45157	10.88
14	4.445	5.0	84663	84409	5.81	45002	44521	11.03
15	4.445	10.0	81882	81620	6.01	44389	43901	11.19
16	4.445	15.0	79284	79014	6.21	43803	43309	11.34
17	4.445	20.0	76830	76551	6.41	43239	42738	11.50
18	4.445	25.0	74543	74255	6.61	42695	42187	11.65
19	4.445	30.0	72403	72106	6.81	42172	41658	11.80
20	4.445	35.0	70395	70090	7.00	41672	41151	11.94
21	4.445	40.0	68495	68181	7.20	41180	40653	12.09
22	4.445	45.0	66716	66394	7.39	40708	40175	12.23
23	4.445	50.0	65048	64717	7.58	40250	39710	12.38
24	4.445	55.0	63476	63137	7.77	39813	39268	12.52
25	4.445	60.0	61993	61646	7.96	39387	38836	12.66
26	4.445	65.0	60595	60240	8.15	38975	38417	12.80
27	4.445	70.0	59271	58908	8.33	38576	38013	12.93
28	4.445	75.0	58023	57652	8.52	38186	37616	13.07
29	4.445	80.0	56836	56457	8.70	37809	37234	13.20
30	4.445	85.0	55714	55327	8.87	37443	36862	13.34
31	4.445	90.0	54645	54251	9.05	37089	36501	13.47
32	4.445	95.0	53633	53231	9.22	36743	36150	13.60
33	4.445	100.0	52666	52257	9.40	36411	35813	13.73

****

Figure E-14 (2-pages)
Sag and Tension Calculations for $\pm$400 kVdc
With Conductor 800-A2/S3A-54/19 (41.9 mm Diameter)
110 mm Ice

```
DATE : 09-11-2007


PROBLEM TITLE       :      LOWER CHURCHILL 400kV DC
CABLE DESIGNATION   :      800-A2/S3A-54/19
TITLE FOR SAG TABLE :      CONDUCTOR

CABLE DATA :
------------
          DIA               (MM) =  41.9
          AREA             (MM2) =  1037
          MASS            (KG/M) =  3.456
          TEMPERATURE COEFF  (C) =  .0000196
          RTS               (KN) =  445.3
          EVERY DAY TEMP.    (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  2

          MODULUS (GPA)     LIMIT STRESS (MPA)
      1       57.00            93.00
      2       42.50           200.00

FINAL AND CREEP MODULUS (GPA) :  70.5      35


NUMBER OF CONSTRAINING LOADS =  4

          ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                      1=INIT & 2=FINAL

      1      0.0    0.00    0.00      -5.0    16.50    1
      2    %110.0    0.90    0.00      -5.0    75.00    2
      3    %100.0    0.50    0.88      -5.0    75.00    2
      4      0.0    0.00    2.47     -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  1
RULING SPANS (M) :
    300.00
```

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 300.55646
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 301.28979

##

LOWER CHURCHILL 400kV DC
800-A2/S3A-54/19
RULING SPAN (M) = 300.00 DATE : 09-11-2007

##

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	3.456	-5.0	42097	41787	9.14	30965	30541	12.51
2	50.679	-5.0	333979	325402	17.26	333979 *	325402	17.26
3	33.589	-5.0	249075	244056	15.24	238893	233649	15.92
4	11.105	-10.0	111866	110658	11.09	92563	91094	13.49
5	3.456	-40.0	48108	47837	7.98	33360	32967	11.59
6	3.456	-35.0	47114	46837	8.15	32983	32586	11.72
7	3.456	-30.0	46176	45894	8.32	32619	32217	11.86
8	3.456	-25.0	45274	44986	8.48	32267	31861	11.99
9	3.456	-20.0	44421	44128	8.65	31926	31516	12.12
10	3.456	-15.0	43607	43309	8.81	31598	31183	12.25
11	3.456	-10.0	42831	42527	8.98	31276	30856	12.38
12	3.456	-5.0	42089	41779	9.14	30962	30538	12.51
13	3.456	0.0	41390	41075	9.29	30663	30235	12.64
14	3.456	5.0	40715	40395	9.45	30370	29937	12.77
15	3.456	10.0	40071	39745	9.61	30086	29649	12.89
16	3.456	15.0	39455	39125	9.76	29808	29367	13.02
17	3.456	20.0	38859	38523	9.91	29536	29091	13.14
18	3.456	25.0	38291	37950	10.06	29275	28826	13.26
19	3.456	30.0	37745	37399	10.21	29020	28566	13.38
20	3.456	35.0	37223	36872	10.36	28771	28313	13.50
21	3.456	40.0	36714	36359	10.50	28530	28068	13.62
22	3.456	45.0	36229	35868	10.65	28293	27827	13.74
23	3.456	50.0	35760	35394	10.79	28062	27592	13.86
24	3.456	55.0	35309	34939	10.93	27837	27363	13.97
25	3.456	60.0	34875	34499	11.07	27618	27140	14.09
26	3.456	65.0	34456	34076	11.21	27405	26924	14.20
27	3.456	70.0	34048	33664	11.35	27195	26710	14.32
28	3.456	75.0	33658	33269	11.48	26990	26501	14.43
29	3.456	80.0	33274	32881	11.62	26790	26297	14.54
30	3.456	85.0	32908	32510	11.75	26595	26098	14.66
31	3.456	90.0	32551	32148	11.88	26403	25903	14.77
32	3.456	95.0	32205	31798	12.02	26217	25712	14.88
33	3.456	100.0	31871	31460	12.15	26034	25526	14.99

##

Figure E-15 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Optical Ground Wire (OPGW)
(55 mm Ice)

```
DATE : 01-10-2008


PROBLEM TITLE       :       CHURCHILL FALLS 450KV
CABLE DESIGNATION   :       OPGW
TITLE FOR SAG TABLE :       OPTICAL GW

CABLE DATA :
------------
            DIA                (MM) =  28
            AREA              (MM2) =  430
            MASS             (KG/M) =  2.35
            TEMPERATURE COEFF  (C) =  .0000138
            RTS                (KN) =  400
            EVERY DAY TEMP.     (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  1

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1       125.00           300.00

FINAL AND CREEP MODULUS (GPA) :  125       0


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT   SAG TYPE
                                                       1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    12.60    1
       2      55.0    0.90    0.00       -5.0    75.00    2
       3      50.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00



    CRITICAL LOAD NUMBER    =  1   INITIAL UNSTRESSED LENGTH (M) =   249.91942
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   249.91940


*******************************************************************************
```

CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 250.00 DATE : 01-10-2008

****

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	50400 *	50318	3.58	50400	50318	3.58
2	15.252	-5.0	154416	153274	7.63	154416	153274	7.63
3	14.274	-5.0	148038	146996	7.45	148038	146996	7.45
4	7.434	-10.0	99913	99496	5.73	99913	99496	5.73
5	2.350	-40.0	64752	64688	2.78	64752	64688	2.78
6	2.350	-35.0	62391	62324	2.89	62391	62324	2.89
7	2.350	-30.0	60135	60066	3.00	60135	60066	3.00
8	2.350	-25.0	58002	57930	3.11	58002	57930	3.11
9	2.350	-20.0	55962	55888	3.22	55962	55888	3.22
10	2.350	-15.0	54013	53936	3.34	54013	53936	3.34
11	2.350	-10.0	52158	52079	3.46	52158	52079	3.46
12	2.350	-5.0	50407	50324	3.58	50407	50324	3.58
13	2.350	0.0	48746	48660	3.70	48746	48660	3.70
14	2.350	5.0	47175	47087	3.82	47175	47087	3.82
15	2.350	10.0	45693	45602	3.95	45693	45602	3.95
16	2.350	15.0	44294	44200	4.07	44294	44200	4.07
17	2.350	20.0	42971	42874	4.20	42971	42874	4.20
18	2.350	25.0	41722	41622	4.33	41722	41622	4.33
19	2.350	30.0	40545	40442	4.45	40545	40442	4.45
20	2.350	35.0	39440	39334	4.58	39440	39334	4.58
21	2.350	40.0	38406	38297	4.70	38406	38297	4.70
22	2.350	45.0	37410	37298	4.83	37410	37298	4.83
23	2.350	50.0	36475	36361	4.95	36475	36361	4.95
24	2.350	55.0	35601	35484	5.08	35601	35484	5.08
25	2.350	60.0	34771	34651	5.20	34771	34651	5.20
26	2.350	65.0	33986	33863	5.32	33986	33863	5.32
27	2.350	70.0	33246	33120	5.44	33246	33120	5.44
28	2.350	75.0	32533	32405	5.56	32533	32405	5.56
29	2.350	80.0	31864	31734	5.68	31864	31734	5.68
30	2.350	85.0	31231	31098	5.79	31231	31098	5.79
31	2.350	90.0	30620	30484	5.91	30620	30484	5.91
32	2.350	95.0	30042	29903	6.03	30042	29903	6.03
33	2.350	100.0	29495	29353	6.14	29495	29353	6.14

****

CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 299.97580
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 299.97604

****

CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 300.00 DATE : 01-10-2008

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	50400 *	50281	5.16	50400	50281	5.16
2	15.252	-5.0	168953	167448	10.06	168953	167448	10.06
3	14.274	-5.0	161740	160363	9.83	161740	160363	9.83
4	7.434	-10.0	106768	106204	7.73	106768	106204	7.73
5	2.350	-40.0	61957	61860	4.19	61957	61860	4.19
6	2.350	-35.0	60074	59975	4.32	60035	59935	4.33
7	2.350	-30.0	58239	58136	4.46	58239	58136	4.46
8	2.350	-25.0	56522	56416	4.60	56522	56416	4.60
9	2.350	-20.0	54876	54767	4.74	54876	54767	4.74
10	2.350	-15.0	53307	53194	4.88	53307	53194	4.88
11	2.350	-10.0	51819	51704	5.02	51819	51704	5.02
12	2.350	-5.0	50409	50290	5.16	50378	50259	5.16
13	2.350	0.0	49069	48947	5.30	49030	48908	5.30
14	2.350	5.0	47777	47651	5.44	47777	47651	5.44
15	2.350	10.0	46569	46440	5.59	46569	46440	5.59
16	2.350	15.0	45420	45288	5.73	45420	45288	5.73
17	2.350	20.0	44329	44194	5.87	44329	44194	5.87
18	2.350	25.0	43292	43154	6.01	43292	43154	6.01
19	2.350	30.0	42318	42177	6.15	42288	42146	6.15
20	2.350	35.0	41377	41232	6.29	41357	41211	6.29
21	2.350	40.0	40485	40337	6.43	40485	40337	6.43
22	2.350	45.0	39640	39489	6.57	39640	39489	6.57
23	2.350	50.0	38832	38678	6.71	38832	38678	6.71
24	2.350	55.0	38063	37906	6.84	38063	37906	6.84
25	2.350	60.0	37332	37171	6.98	37332	37171	6.98
26	2.350	65.0	36627	36463	7.12	36627	36463	7.12
27	2.350	70.0	35970	35803	7.25	35970	35803	7.25
28	2.350	75.0	35333	35163	7.38	35333	35163	7.38
29	2.350	80.0	34724	34551	7.51	34724	34551	7.51
30	2.350	85.0	34144	33968	7.64	34128	33952	7.64
31	2.350	90.0	33581	33402	7.77	33581	33402	7.77
32	2.350	95.0	33046	32864	7.90	33046	32864	7.90
33	2.350	100.0	32534	32349	8.02	32521	32336	8.03

CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 350.07199
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 350.07208

CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 350.00 DATE : 01-10-2008

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			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	2.350	-5.0	50400 *	50238	7.03	50400	50238	7.03
2	15.252	-5.0	182016	180111	12.74	182016	180111	12.74
3	14.274	-5.0	173994	172249	12.46	173994	172249	12.46
4	7.434	-10.0	112703	111975	9.98	112703	111975	9.98
5	2.350	-40.0	59697	59560	5.93	59697	59560	5.93
6	2.350	-35.0	58157	58017	6.08	58157	58017	6.08
7	2.350	-30.0	56724	56581	6.24	56724	56581	6.24
8	2.350	-25.0	55340	55193	6.40	55340	55193	6.40
9	2.350	-20.0	54021	53870	6.55	54021	53870	6.55
10	2.350	-15.0	52761	52607	6.71	52761	52607	6.71
11	2.350	-10.0	51560	51402	6.87	51560	51402	6.87
12	2.350	-5.0	50401	50239	7.03	50401	50239	7.03
13	2.350	0.0	49306	49140	7.19	49306	49140	7.19
14	2.350	5.0	48260	48090	7.34	48260	48090	7.34
15	2.350	10.0	47260	47087	7.50	47260	47087	7.50
16	2.350	15.0	46310	46133	7.65	46310	46133	7.65
17	2.350	20.0	45398	45218	7.81	45398	45218	7.81
18	2.350	25.0	44528	44344	7.96	44528	44344	7.96
19	2.350	30.0	43694	43507	8.12	43694	43507	8.12
20	2.350	35.0	42897	42706	8.27	42897	42706	8.27
21	2.350	40.0	42136	41942	8.42	42136	41942	8.42
22	2.350	45.0	41411	41214	8.57	41411	41214	8.57
23	2.350	50.0	40707	40506	8.72	40707	40506	8.72
24	2.350	55.0	40033	39829	8.87	40033	39829	8.87
25	2.350	60.0	39394	39186	9.01	39394	39186	9.01
26	2.350	65.0	38770	38559	9.16	38770	38559	9.16
27	2.350	70.0	38174	37960	9.31	38174	37960	9.31
28	2.350	75.0	37601	37383	9.45	37601	37383	9.45
29	2.350	80.0	37055	36834	9.59	37055	36834	9.59
30	2.350	85.0	36524	36299	9.73	36524	36299	9.73
31	2.350	90.0	36014	35787	9.87	36014	35787	9.87
32	2.350	95.0	35524	35293	10.01	35524	35293	10.01
33	2.350	100.0	35051	34817	10.15	35051	34817	10.15

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CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 400.21503
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 400.21512

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CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 400.00 DATE : 01-10-2008

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LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	50400 *	50188	9.19	50400	50188	9.19
2	15.252	-5.0	193781	191439	15.66	193781	191439	15.66
3	14.274	-5.0	184995	182848	15.34	184995	182848	15.34
4	7.434	-10.0	117857	116947	12.48	117857	116947	12.48
5	2.350	-40.0	57913	57729	7.99	57913	57729	7.99
6	2.350	-35.0	56698	56510	8.16	56698	56510	8.16
7	2.350	-30.0	55535	55343	8.33	55535	55343	8.33
8	2.350	-25.0	54421	54225	8.51	54421	54225	8.51
9	2.350	-20.0	53357	53157	8.68	53357	53157	8.68
10	2.350	-15.0	52324	52120	8.85	52324	52120	8.85
11	2.350	-10.0	51341	51133	9.02	51341	51133	9.02
12	2.350	-5.0	50401	50189	9.19	50401	50189	9.19
13	2.350	0.0	49498	49282	9.36	49498	49282	9.36
14	2.350	5.0	48632	48412	9.53	48632	48412	9.53
15	2.350	10.0	47799	47576	9.70	47799	47576	9.70
16	2.350	15.0	47002	46775	9.86	47002	46775	9.86
17	2.350	20.0	46235	46004	10.03	46235	46004	10.03
18	2.350	25.0	45498	45263	10.19	45498	45263	10.19
19	2.350	30.0	44788	44549	10.36	44788	44549	10.36
20	2.350	35.0	44105	43863	10.52	44105	43863	10.52
21	2.350	40.0	43447	43201	10.68	43447	43201	10.68
22	2.350	45.0	42814	42565	10.84	42814	42565	10.84
23	2.350	50.0	42204	41951	11.00	42204	41951	11.00
24	2.350	55.0	41616	41358	11.16	41616	41358	11.16
25	2.350	60.0	41052	40791	11.31	41052	40791	11.31
26	2.350	65.0	40499	40235	11.47	40499	40235	11.47
27	2.350	70.0	39971	39703	11.62	39971	39703	11.62
28	2.350	75.0	39464	39193	11.77	39452	39180	11.78
29	2.350	80.0	38964	38689	11.93	38964	38689	11.93
30	2.350	85.0	38483	38205	12.08	38483	38205	12.08
31	2.350	90.0	38018	37737	12.23	38018	37737	12.23
32	2.350	95.0	37575	37290	12.38	37575	37290	12.38
33	2.350	100.0	37140	36852	12.52	37140	36852	12.52

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Figure E-16 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Optical Ground Wire (OPGW)
(75 mm Ice)

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DATE : 01-10-2008


PROBLEM TITLE       :       CHURCHILL FALLS 450KV
CABLE DESIGNATION   :       OPGW
TITLE FOR SAG TABLE :       OPTICAL GW

CABLE DATA :
------------
            DIA                 (MM) =  28
            AREA               (MM2) =  430
            MASS              (KG/M) =  2.35
            TEMPERATURE COEFF  (C) =  .0000138
            RTS                 (KN) =  400
            EVERY DAY TEMP.      (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  1

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1       125.00           300.00

FINAL AND CREEP MODULUS (GPA) :  125       0


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT   SAG TYPE
                                                       1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    12.60    1
       2      75.0    0.90    0.00       -5.0    75.00    2
       3      70.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00


    CRITICAL LOAD NUMBER    =  1   INITIAL UNSTRESSED LENGTH (M) =   249.91942
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   249.91939


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CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 250.00 DATE : 01-10-2008

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LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	50400 *	50318	3.58	50400	50318	3.58
2	24.183	-5.0	207637	205495	9.03	207637	205495	9.03
3	19.986	-5.0	183596	181944	8.43	183596	181944	8.43
4	7.434	-10.0	99913	99496	5.73	99913	99496	5.73
5	2.350	-40.0	64752	64688	2.78	64752	64688	2.78
6	2.350	-35.0	62391	62324	2.89	62391	62324	2.89
7	2.350	-30.0	60135	60066	3.00	60135	60066	3.00
8	2.350	-25.0	58002	57930	3.11	58002	57930	3.11
9	2.350	-20.0	55962	55888	3.22	55962	55888	3.22
10	2.350	-15.0	54013	53936	3.34	54013	53936	3.34
11	2.350	-10.0	52158	52079	3.46	52158	52079	3.46
12	2.350	-5.0	50407	50324	3.58	50407	50324	3.58
13	2.350	0.0	48746	48660	3.70	48746	48660	3.70
14	2.350	5.0	47175	47087	3.82	47175	47087	3.82
15	2.350	10.0	45693	45602	3.95	45693	45602	3.95
16	2.350	15.0	44294	44200	4.07	44294	44200	4.07
17	2.350	20.0	42971	42874	4.20	42971	42874	4.20
18	2.350	25.0	41722	41622	4.33	41722	41622	4.33
19	2.350	30.0	40545	40442	4.45	40545	40442	4.45
20	2.350	35.0	39440	39334	4.58	39440	39334	4.58
21	2.350	40.0	38406	38297	4.70	38406	38297	4.70
22	2.350	45.0	37410	37298	4.83	37410	37298	4.83
23	2.350	50.0	36475	36361	4.95	36475	36361	4.95
24	2.350	55.0	35601	35484	5.08	35601	35484	5.08
25	2.350	60.0	34771	34651	5.20	34771	34651	5.20
26	2.350	65.0	33986	33863	5.32	33986	33863	5.32
27	2.350	70.0	33246	33120	5.44	33246	33120	5.44
28	2.350	75.0	32533	32405	5.56	32533	32405	5.56
29	2.350	80.0	31864	31734	5.68	31864	31734	5.68
30	2.350	85.0	31231	31098	5.79	31231	31098	5.79
31	2.350	90.0	30620	30484	5.91	30620	30484	5.91
32	2.350	95.0	30042	29903	6.03	30042	29903	6.03
33	2.350	100.0	29495	29353	6.14	29495	29353	6.14

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CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 299.97580
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 299.97556

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CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 300.00 DATE : 01-10-2008

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LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	50400 *	50281	5.16	50400	50281	5.16
2	24.183	-5.0	229304	226505	11.80	229304	226505	11.80
3	19.986	-5.0	202052	199886	11.05	202052	199886	11.05
4	7.434	-10.0	106768	106204	7.73	106768	106204	7.73
5	2.350	-40.0	61957	61860	4.19	62002	61905	4.19
6	2.350	-35.0	60074	59975	4.32	60074	59975	4.32
7	2.350	-30.0	58239	58136	4.46	58281	58178	4.46
8	2.350	-25.0	56522	56416	4.60	56522	56416	4.60
9	2.350	-20.0	54876	54767	4.74	54876	54767	4.74
10	2.350	-15.0	53307	53194	4.88	53307	53194	4.88
11	2.350	-10.0	51819	51704	5.02	51819	51704	5.02
12	2.350	-5.0	50409	50290	5.16	50409	50290	5.16
13	2.350	0.0	49069	48947	5.30	49069	48947	5.30
14	2.350	5.0	47777	47651	5.44	47777	47651	5.44
15	2.350	10.0	46569	46440	5.59	46569	46440	5.59
16	2.350	15.0	45420	45288	5.73	45420	45288	5.73
17	2.350	20.0	44329	44194	5.87	44329	44194	5.87
18	2.350	25.0	43292	43154	6.01	43292	43154	6.01
19	2.350	30.0	42318	42177	6.15	42318	42177	6.15
20	2.350	35.0	41377	41232	6.29	41377	41232	6.29
21	2.350	40.0	40485	40337	6.43	40485	40337	6.43
22	2.350	45.0	39640	39489	6.57	39640	39489	6.57
23	2.350	50.0	38832	38678	6.71	38832	38678	6.71
24	2.350	55.0	38063	37906	6.84	38081	37923	6.84
25	2.350	60.0	37332	37171	6.98	37348	37188	6.98
26	2.350	65.0	36627	36463	7.12	36652	36488	7.11
27	2.350	70.0	35970	35803	7.25	35970	35803	7.25
28	2.350	75.0	35333	35163	7.38	35333	35163	7.38
29	2.350	80.0	34724	34551	7.51	34724	34551	7.51
30	2.350	85.0	34144	33968	7.64	34144	33968	7.64
31	2.350	90.0	33581	33402	7.77	33581	33402	7.77
32	2.350	95.0	33046	32864	7.90	33046	32864	7.90
33	2.350	100.0	32534	32349	8.02	32534	32349	8.02

****

CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 350.07199
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 350.07199

****

CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 350.00 DATE : 01-10-2008

****

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	50400 *	50238	7.03	50400	50238	7.03
2	24.183	-5.0	249010	245494	14.83	249010	245494	14.83
3	19.986	-5.0	218751	216023	13.92	218751	216023	13.92
4	7.434	-10.0	112703	111975	9.98	112703	111975	9.98
5	2.350	-40.0	59697	59560	5.93	59697	59560	5.93
6	2.350	-35.0	58157	58017	6.08	58157	58017	6.08
7	2.350	-30.0	56724	56581	6.24	56724	56581	6.24
8	2.350	-25.0	55340	55193	6.40	55340	55193	6.40
9	2.350	-20.0	54021	53870	6.55	54021	53870	6.55
10	2.350	-15.0	52761	52607	6.71	52761	52607	6.71
11	2.350	-10.0	51560	51402	6.87	51560	51402	6.87
12	2.350	-5.0	50401	50239	7.03	50401	50239	7.03
13	2.350	0.0	49306	49140	7.19	49306	49140	7.19
14	2.350	5.0	48260	48090	7.34	48260	48090	7.34
15	2.350	10.0	47260	47087	7.50	47260	47087	7.50
16	2.350	15.0	46310	46133	7.65	46310	46133	7.65
17	2.350	20.0	45398	45218	7.81	45398	45218	7.81
18	2.350	25.0	44528	44344	7.96	44528	44344	7.96
19	2.350	30.0	43694	43507	8.12	43694	43507	8.12
20	2.350	35.0	42897	42706	8.27	42897	42706	8.27
21	2.350	40.0	42136	41942	8.42	42136	41942	8.42
22	2.350	45.0	41411	41214	8.57	41411	41214	8.57
23	2.350	50.0	40707	40506	8.72	40707	40506	8.72
24	2.350	55.0	40033	39829	8.87	40033	39829	8.87
25	2.350	60.0	39394	39186	9.01	39394	39186	9.01
26	2.350	65.0	38770	38559	9.16	38770	38559	9.16
27	2.350	70.0	38174	37960	9.31	38174	37960	9.31
28	2.350	75.0	37601	37383	9.45	37601	37383	9.45
29	2.350	80.0	37055	36834	9.59	37055	36834	9.59
30	2.350	85.0	36524	36299	9.73	36524	36299	9.73
31	2.350	90.0	36014	35787	9.87	36014	35787	9.87
32	2.350	95.0	35524	35293	10.01	35524	35293	10.01
33	2.350	100.0	35051	34817	10.15	35051	34817	10.15

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CRITICAL LOAD NUMBER = 1 INITIAL UNSTRESSED LENGTH (M) = 400.21503
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 400.21497

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CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 400.00 DATE : 01-10-2008

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	50400 *	50188	9.19	50400	50188	9.19
2	24.183	-5.0	267080	262789	18.10	267080	262789	18.10
3	19.986	-5.0	233965	230625	17.04	233965	230625	17.04
4	7.434	-10.0	117857	116947	12.48	117857	116947	12.48
5	2.350	-40.0	57913	57729	7.99	57913	57729	7.99
6	2.350	-35.0	56698	56510	8.16	56698	56510	8.16
7	2.350	-30.0	55535	55343	8.33	55535	55343	8.33
8	2.350	-25.0	54421	54225	8.51	54421	54225	8.51
9	2.350	-20.0	53357	53157	8.68	53357	53157	8.68
10	2.350	-15.0	52324	52120	8.85	52324	52120	8.85
11	2.350	-10.0	51341	51133	9.02	51341	51133	9.02
12	2.350	-5.0	50401	50189	9.19	50401	50189	9.19
13	2.350	0.0	49498	49282	9.36	49498	49282	9.36
14	2.350	5.0	48632	48412	9.53	48632	48412	9.53
15	2.350	10.0	47799	47576	9.70	47799	47576	9.70
16	2.350	15.0	47002	46775	9.86	47002	46775	9.86
17	2.350	20.0	46235	46004	10.03	46235	46004	10.03
18	2.350	25.0	45498	45263	10.19	45498	45263	10.19
19	2.350	30.0	44788	44549	10.36	44788	44549	10.36
20	2.350	35.0	44105	43863	10.52	44105	43863	10.52
21	2.350	40.0	43447	43201	10.68	43447	43201	10.68
22	2.350	45.0	42814	42565	10.84	42814	42565	10.84
23	2.350	50.0	42204	41951	11.00	42204	41951	11.00
24	2.350	55.0	41616	41358	11.16	41616	41358	11.16
25	2.350	60.0	41052	40791	11.31	41052	40791	11.31
26	2.350	65.0	40499	40235	11.47	40499	40235	11.47
27	2.350	70.0	39971	39703	11.62	39971	39703	11.62
28	2.350	75.0	39464	39193	11.77	39464	39193	11.77
29	2.350	80.0	38964	38689	11.93	38964	38689	11.93
30	2.350	85.0	38483	38205	12.08	38483	38205	12.08
31	2.350	90.0	38018	37737	12.23	38018	37737	12.23
32	2.350	95.0	37575	37290	12.38	37575	37290	12.38
33	2.350	100.0	37140	36852	12.52	37140	36852	12.52

Figure E-17 (5-pages)
Sag and Tension Calculations for ±450 kVdc
Optical Ground Wire (OPGW)
(110 mm Ice)

```
DATE : 01-10-2008


PROBLEM TITLE       :       CHURCHILL FALLS 450KV
CABLE DESIGNATION   :       OPGW
TITLE FOR SAG TABLE :       OPTICAL GW

CABLE DATA :
------------
            DIA                (MM) =  28
            AREA              (MM2) =  430
            MASS             (KG/M) =  2.35
            TEMPERATURE COEFF  (C) =  .0000138
            RTS                (KN) =  400
            EVERY DAY TEMP.     (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  1

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1       125.00           300.00

FINAL AND CREEP MODULUS (GPA) :  125       0


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                      1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    12.60    1
       2     %110.0    0.90    0.00       -5.0    75.00    2
       3     %100.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00



    CRITICAL LOAD NUMBER    =  2   INITIAL UNSTRESSED LENGTH (M) =   250.09990
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   250.09990


********************************************************************************
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CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 250.00 DATE : 01-10-2008

****

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	36973	36861	4.89	36973	36861	4.89
2	45.252	-5.0	300001	294766	11.80	300001 *	294766	11.80
3	30.373	-5.0	228010	224921	10.37	228010	224921	10.37
4	7.434	-10.0	86510	86027	6.63	86510	86027	6.63
5	2.350	-40.0	45040	44948	4.01	45040	44948	4.01
6	2.350	-35.0	43673	43578	4.13	43673	43578	4.13
7	2.350	-30.0	42383	42285	4.26	42383	42285	4.26
8	2.350	-25.0	41167	41066	4.39	41167	41066	4.39
9	2.350	-20.0	40024	39920	4.51	40024	39920	4.51
10	2.350	-15.0	38949	38842	4.64	38949	38842	4.64
11	2.350	-10.0	37928	37818	4.76	37928	37818	4.76
12	2.350	-5.0	36969	36857	4.89	36969	36857	4.89
13	2.350	0.0	36057	35941	5.01	36057	35941	5.01
14	2.350	5.0	35208	35090	5.13	35208	35090	5.13
15	2.350	10.0	34398	34277	5.26	34398	34277	5.26
16	2.350	15.0	33634	33510	5.38	33634	33510	5.38
17	2.350	20.0	32914	32787	5.49	32914	32787	5.49
18	2.350	25.0	32215	32085	5.62	32215	32085	5.62
19	2.350	30.0	31561	31429	5.73	31561	31429	5.73
20	2.350	35.0	30937	30802	5.85	30937	30802	5.85
21	2.350	40.0	30344	30207	5.96	30344	30207	5.96
22	2.350	45.0	29776	29636	6.08	29776	29636	6.08
23	2.350	50.0	29244	29101	6.19	29244	29101	6.19
24	2.350	55.0	28730	28585	6.30	28730	28585	6.30
25	2.350	60.0	28244	28096	6.41	28244	28096	6.41
26	2.350	65.0	27768	27617	6.53	27768	27617	6.53
27	2.350	70.0	27326	27173	6.63	27326	27173	6.63
28	2.350	75.0	26895	26740	6.74	26895	26740	6.74
29	2.350	80.0	26487	26329	6.85	26487	26329	6.85
30	2.350	85.0	26089	25929	6.95	26089	25929	6.95
31	2.350	90.0	25710	25547	7.06	25710	25547	7.06
32	2.350	95.0	25344	25179	7.16	25344	25179	7.16
33	2.350	100.0	24995	24828	7.26	24995	24828	7.26

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 300.94391
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 300.94391

****

CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 300.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	2.350	-5.0	24034	23782	10.92	24034	23782	10.92
2	45.252	-5.0	300003	292394	17.15	300003 *	292394	17.15
3	30.373	-5.0	220207	215560	15.60	220207	215560	15.60
4	7.434	-10.0	69056	68177	12.05	69056	68177	12.05
5	2.350	-40.0	25712	25477	10.19	25712	25477	10.19
6	2.350	-35.0	25452	25215	10.30	25452	25215	10.30
7	2.350	-30.0	25199	24960	10.40	25199	24960	10.40
8	2.350	-25.0	24954	24712	10.51	24954	24712	10.51
9	2.350	-20.0	24714	24469	10.61	24714	24469	10.61
10	2.350	-15.0	24483	24236	10.72	24483	24236	10.72
11	2.350	-10.0	24256	24007	10.82	24256	24007	10.82
12	2.350	-5.0	24037	23785	10.92	24037	23785	10.92
13	2.350	0.0	23823	23569	11.02	23823	23569	11.02
14	2.350	5.0	23612	23356	11.12	23612	23356	11.12
15	2.350	10.0	23408	23150	11.22	23408	23150	11.22
16	2.350	15.0	23210	22949	11.32	23210	22949	11.32
17	2.350	20.0	23015	22752	11.42	23015	22752	11.42
18	2.350	25.0	22826	22560	11.51	22826	22560	11.51
19	2.350	30.0	22643	22375	11.61	22643	22375	11.61
20	2.350	35.0	22462	22192	11.71	22462	22192	11.71
21	2.350	40.0	22286	22014	11.80	22286	22014	11.80
22	2.350	45.0	22114	21840	11.90	22114	21840	11.90
23	2.350	50.0	21946	21670	11.99	21946	21670	11.99
24	2.350	55.0	21782	21504	12.08	21782	21504	12.08
25	2.350	60.0	21622	21341	12.18	21622	21341	12.18
26	2.350	65.0	21463	21180	12.27	21463	21180	12.27
27	2.350	70.0	21309	21024	12.36	21309	21024	12.36
28	2.350	75.0	21158	20871	12.45	21158	20871	12.45
29	2.350	80.0	21011	20722	12.54	21011	20722	12.54
30	2.350	85.0	20867	20575	12.63	20867	20575	12.63
31	2.350	90.0	20725	20432	12.72	20725	20432	12.72
32	2.350	95.0	20587	20292	12.81	20587	20292	12.81
33	2.350	100.0	20450	20153	12.90	20450	20153	12.90

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 352.28149
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 352.28149

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CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 350.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	2.350	-5.0	20354	19945	17.75	20354	19945	17.75
2	45.252	-5.0	300008	289531	23.61	300008 *	289531	23.61
3	30.373	-5.0	215026	208476	21.99	215026	208476	21.99
4	7.434	-10.0	61473	60114	18.64	61473	60114	18.64
5	2.350	-40.0	21068	20673	17.12	21068	20673	17.12
6	2.350	-35.0	20962	20565	17.21	20962	20565	17.21
7	2.350	-30.0	20857	20458	17.31	20857	20458	17.31
8	2.350	-25.0	20754	20353	17.39	20754	20353	17.39
9	2.350	-20.0	20651	20248	17.49	20651	20248	17.49
10	2.350	-15.0	20551	20146	17.58	20551	20146	17.58
11	2.350	-10.0	20452	20045	17.66	20452	20045	17.66
12	2.350	-5.0	20355	19946	17.75	20355	19946	17.75
13	2.350	0.0	20259	19848	17.84	20259	19848	17.84
14	2.350	5.0	20164	19751	17.93	20164	19751	17.93
15	2.350	10.0	20071	19656	18.02	20071	19656	18.02
16	2.350	15.0	19979	19562	18.10	19979	19562	18.10
17	2.350	20.0	19888	19469	18.19	19888	19469	18.19
18	2.350	25.0	19799	19378	18.28	19799	19378	18.28
19	2.350	30.0	19712	19289	18.36	19712	19289	18.36
20	2.350	35.0	19625	19200	18.45	19625	19200	18.45
21	2.350	40.0	19540	19112	18.53	19540	19112	18.53
22	2.350	45.0	19456	19027	18.62	19456	19027	18.62
23	2.350	50.0	19372	18941	18.70	19372	18941	18.70
24	2.350	55.0	19289	18856	18.79	19289	18856	18.79
25	2.350	60.0	19208	18773	18.87	19208	18773	18.87
26	2.350	65.0	19128	18691	18.95	19128	18691	18.95
27	2.350	70.0	19049	18610	19.04	19049	18610	19.04
28	2.350	75.0	18971	18530	19.12	18971	18530	19.12
29	2.350	80.0	18894	18451	19.20	18894	18451	19.20
30	2.350	85.0	18818	18373	19.28	18818	18373	19.28
31	2.350	90.0	18743	18296	19.37	18743	18296	19.37
32	2.350	95.0	18669	18220	19.45	18669	18220	19.45
33	2.350	100.0	18595	18145	19.53	18595	18145	19.53

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 404.23749
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 404.23749

****

CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 400.00 DATE : 01-10-2008

****

LOAD NO	MASS KG/M	TEMP DEG.C	INITIAL TENSION MAX (N)	INITIAL TENSION HOR (N)	INITIAL SAG (M)	FINAL TENSION MAX (N)	FINAL TENSION HOR (N)	FINAL SAG (M)
1	2.350	-5.0	18667	18076	25.64	18667	18076	25.64
2	45.252	-5.0	300019	286144	31.27	300019 *	286144	31.27
3	30.373	-5.0	211484	202666	29.61	211484	202666	29.61
4	7.434	-10.0	57467	55542	26.40	57467	55542	26.40
5	2.350	-40.0	19065	18488	25.06	19065	18488	25.06
6	2.350	-35.0	19007	18427	25.14	19007	18427	25.14
7	2.350	-30.0	18949	18367	25.23	18949	18367	25.23
8	2.350	-25.0	18891	18308	25.31	18891	18308	25.31
9	2.350	-20.0	18834	18249	25.39	18834	18249	25.39
10	2.350	-15.0	18778	18191	25.47	18778	18191	25.47
11	2.350	-10.0	18722	18133	25.56	18722	18133	25.56
12	2.350	-5.0	18667	18076	25.64	18667	18076	25.64
13	2.350	0.0	18612	18019	25.72	18612	18019	25.72
14	2.350	5.0	18558	17963	25.80	18558	17963	25.80
15	2.350	10.0	18504	17907	25.88	18504	17907	25.88
16	2.350	15.0	18451	17852	25.96	18451	17852	25.96
17	2.350	20.0	18398	17798	26.04	18398	17798	26.04
18	2.350	25.0	18345	17743	26.12	18345	17743	26.12
19	2.350	30.0	18294	17690	26.20	18294	17690	26.20
20	2.350	35.0	18242	17637	26.28	18242	17637	26.28
21	2.350	40.0	18191	17584	26.36	18191	17584	26.36
22	2.350	45.0	18141	17532	26.44	18141	17532	26.44
23	2.350	50.0	18091	17480	26.52	18091	17480	26.52
24	2.350	55.0	18042	17429	26.60	18042	17429	26.60
25	2.350	60.0	17992	17378	26.68	17992	17378	26.68
26	2.350	65.0	17944	17327	26.76	17944	17327	26.76
27	2.350	70.0	17896	17277	26.84	17896	17277	26.84
28	2.350	75.0	17848	17228	26.91	17848	17228	26.91
29	2.350	80.0	17801	17179	26.99	17801	17179	26.99
30	2.350	85.0	17754	17130	27.07	17754	17130	27.07
31	2.350	90.0	17707	17081	27.15	17707	17081	27.15
32	2.350	95.0	17661	17033	27.22	17661	17033	27.22
33	2.350	100.0	17615	16986	27.30	17615	16986	27.30

****

Figure E-18 (5-pages)
Sag and Tension Calculations for ± 450 kVdc
Optical Ground Wire (OPGW)
(140 mm Ice)

```
DATE : 01-10-2008


PROBLEM TITLE       :       CHURCHILL FALLS 450KV
CABLE DESIGNATION   :       OPGW
TITLE FOR SAG TABLE :       OPTICAL GW

CABLE DATA :
------------
            DIA                (MM) =  28
            AREA              (MM2) =  430
            MASS             (KG/M) =  2.35
            TEMPERATURE COEFF  (C) =  .0000138
            RTS                (KN) =  400
            EVERY DAY TEMP.     (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =  1

            MODULUS (GPA)     LIMIT STRESS (MPA)
       1       125.00           300.00

FINAL AND CREEP MODULUS (GPA) :  125       0


NUMBER OF CONSTRAINING LOADS =  4

            ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                      1=INIT & 2=FINAL

       1       0.0    0.00    0.00       -5.0    12.60    1
       2      %140.0    0.90    0.00       -5.0    75.00    2
       3      %130.0    0.50    0.88       -5.0    75.00    2
       4       0.0    0.00    2.47      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-40    MAX. = 100    RATE OF CHANGE = 5


NUMBER OF RULING SPANS =  4
RULING SPANS (M) :
    250.00       300.00       350.00       400.00



    CRITICAL LOAD NUMBER    =  2   INITIAL UNSTRESSED LENGTH (M) =   252.22289
    BIFURCATION LOAD NUMBER =  2   FINAL   UNSTRESSED LENGTH (M) =   252.22289


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CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 250.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	2.350	-5.0	12710	12373	14.62	12710	12373	14.62
2	68.823	-5.0	300014	287549	18.47	300014 *	287549	18.47
3	43.187	-5.0	200542	193245	17.23	200542	193245	17.23
4	7.434	-10.0	39343	38252	14.96	39343	38252	14.96
5	2.350	-40.0	13042	12714	14.22	13042	12714	14.22
6	2.350	-35.0	12993	12664	14.28	12993	12664	14.28
7	2.350	-30.0	12944	12614	14.34	12944	12614	14.34
8	2.350	-25.0	12896	12565	14.39	12896	12565	14.39
9	2.350	-20.0	12849	12516	14.45	12849	12516	14.45
10	2.350	-15.0	12802	12468	14.51	12802	12468	14.51
11	2.350	-10.0	12756	12420	14.56	12756	12420	14.56
12	2.350	-5.0	12710	12373	14.62	12710	12373	14.62
13	2.350	0.0	12665	12326	14.67	12665	12326	14.67
14	2.350	5.0	12620	12280	14.73	12620	12280	14.73
15	2.350	10.0	12576	12235	14.78	12576	12235	14.78
16	2.350	15.0	12532	12190	14.84	12532	12190	14.84
17	2.350	20.0	12489	12145	14.89	12489	12145	14.89
18	2.350	25.0	12446	12101	14.95	12446	12101	14.95
19	2.350	30.0	12403	12058	15.00	12403	12058	15.00
20	2.350	35.0	12362	12015	15.06	12362	12015	15.06
21	2.350	40.0	12320	11972	15.11	12320	11972	15.11
22	2.350	45.0	12279	11930	15.17	12279	11930	15.17
23	2.350	50.0	12239	11888	15.22	12239	11888	15.22
24	2.350	55.0	12198	11846	15.27	12198	11846	15.27
25	2.350	60.0	12159	11806	15.33	12159	11806	15.33
26	2.350	65.0	12119	11765	15.38	12119	11765	15.38
27	2.350	70.0	12081	11725	15.43	12081	11725	15.43
28	2.350	75.0	12042	11685	15.49	12042	11685	15.49
29	2.350	80.0	12004	11646	15.54	12004	11646	15.54
30	2.350	85.0	11966	11607	15.59	11966	11607	15.59
31	2.350	90.0	11929	11568	15.64	11929	11568	15.64
32	2.350	95.0	11892	11530	15.70	11892	11530	15.70
33	2.350	100.0	11855	11493	15.75	11855	11493	15.75

****

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 304.84500
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 304.84500

****

CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 300.00 DATE : 01-10-2008

****

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	2.350	-5.0	11626	11082	23.59	11626	11082	23.59
2	68.823	-5.0	300044	281653	27.25	300044 *	281653	27.25
3	43.187	-5.0	196161	185155	25.99	196161	185155	25.99
4	7.434	-10.0	36384	34643	23.87	36384	34643	23.87
5	2.350	-40.0	11786	11251	23.23	11786	11251	23.23
6	2.350	-35.0	11763	11226	23.28	11763	11226	23.28
7	2.350	-30.0	11739	11202	23.33	11739	11202	23.33
8	2.350	-25.0	11716	11177	23.38	11716	11177	23.38
9	2.350	-20.0	11693	11153	23.43	11693	11153	23.43
10	2.350	-15.0	11670	11129	23.48	11670	11129	23.48
11	2.350	-10.0	11648	11106	23.53	11648	11106	23.53
12	2.350	-5.0	11625	11082	23.59	11625	11082	23.59
13	2.350	0.0	11603	11058	23.64	11603	11058	23.64
14	2.350	5.0	11581	11035	23.69	11581	11035	23.69
15	2.350	10.0	11559	11012	23.74	11559	11012	23.74
16	2.350	15.0	11537	10989	23.79	11537	10989	23.79
17	2.350	20.0	11515	10966	23.84	11515	10966	23.84
18	2.350	25.0	11494	10943	23.89	11494	10943	23.89
19	2.350	30.0	11472	10921	23.94	11472	10921	23.94
20	2.350	35.0	11451	10898	23.99	11451	10898	23.99
21	2.350	40.0	11430	10876	24.04	11430	10876	24.04
22	2.350	45.0	11409	10853	24.09	11409	10853	24.09
23	2.350	50.0	11388	10831	24.14	11388	10831	24.14
24	2.350	55.0	11367	10809	24.19	11367	10809	24.19
25	2.350	60.0	11346	10788	24.24	11346	10788	24.24
26	2.350	65.0	11326	10766	24.29	11326	10766	24.29
27	2.350	70.0	11305	10744	24.34	11305	10744	24.34
28	2.350	75.0	11285	10723	24.39	11285	10723	24.39
29	2.350	80.0	11265	10702	24.44	11265	10702	24.44
30	2.350	85.0	11245	10680	24.49	11245	10680	24.49
31	2.350	90.0	11225	10659	24.54	11225	10659	24.54
32	2.350	95.0	11205	10638	24.59	11205	10638	24.59
33	2.350	100.0	11185	10618	24.63	11185	10618	24.63

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CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 358.97971
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 358.97971

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CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 350.00 DATE : 01-10-2008

			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	2.350	-5.0	11092	10291	34.73	11092	10291	34.73
2	68.823	-5.0	300119	274296	38.26	300119 *	274296	38.26
3	43.187	-5.0	193513	177845	37.00	193513	177845	37.00
4	7.434	-10.0	34874	32323	34.98	34874	32323	34.98
5	2.350	-40.0	11183	10390	34.39	11183	10390	34.39
6	2.350	-35.0	11170	10376	34.44	11170	10376	34.44
7	2.350	-30.0	11157	10362	34.49	11157	10362	34.49
8	2.350	-25.0	11144	10348	34.54	11144	10348	34.54
9	2.350	-20.0	11130	10333	34.59	11130	10333	34.59
10	2.350	-15.0	11118	10319	34.63	11118	10319	34.63
11	2.350	-10.0	11105	10305	34.68	11105	10305	34.68
12	2.350	-5.0	11092	10291	34.73	11092	10291	34.73
13	2.350	0.0	11079	10277	34.78	11079	10277	34.78
14	2.350	5.0	11066	10263	34.83	11066	10263	34.83
15	2.350	10.0	11053	10250	34.88	11053	10250	34.88
16	2.350	15.0	11041	10236	34.92	11041	10236	34.92
17	2.350	20.0	11028	10222	34.97	11028	10222	34.97
18	2.350	25.0	11016	10209	35.02	11016	10209	35.02
19	2.350	30.0	11003	10195	35.07	11003	10195	35.07
20	2.350	35.0	10990	10181	35.12	10990	10181	35.12
21	2.350	40.0	10978	10168	35.16	10978	10168	35.16
22	2.350	45.0	10966	10154	35.21	10966	10154	35.21
23	2.350	50.0	10953	10141	35.26	10953	10141	35.26
24	2.350	55.0	10941	10128	35.31	10941	10128	35.31
25	2.350	60.0	10929	10114	35.35	10929	10114	35.35
26	2.350	65.0	10917	10101	35.40	10917	10101	35.40
27	2.350	70.0	10905	10088	35.45	10905	10088	35.45
28	2.350	75.0	10893	10075	35.50	10893	10075	35.50
29	2.350	80.0	10881	10062	35.54	10881	10062	35.54
30	2.350	85.0	10869	10049	35.59	10869	10049	35.59
31	2.350	90.0	10857	10036	35.64	10857	10036	35.64
32	2.350	95.0	10845	10023	35.69	10845	10023	35.69
33	2.350	100.0	10833	10010	35.73	10833	10010	35.73

CRITICAL LOAD NUMBER = 2 INITIAL UNSTRESSED LENGTH (M) = 415.32257
BIFURCATION LOAD NUMBER = 2 FINAL UNSTRESSED LENGTH (M) = 415.32257

CHURCHILL FALLS 450KV
OPGW
RULING SPAN (M) = 400.00 DATE : 01-10-2008

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			INITIAL			FINAL		
LOAD NO	MASS KG/M	TEMP DEG.C	TENSION MAX (N)	TENSION HOR (N)	SAG (M)	TENSION MAX (N)	TENSION HOR (N)	SAG (M)
1	2.350	-5.0	10774	9653	48.66	10774	9653	48.66
2	68.823	-5.0	300004	264857	52.08	300004 *	264857	52.08
3	43.187	-5.0	191661	170138	50.82	191661	170138	50.82
4	7.434	-10.0	33957	30392	48.90	33957	30392	48.90
5	2.350	-40.0	10829	9715	48.34	10829	9715	48.34
6	2.350	-35.0	10821	9706	48.38	10821	9706	48.38
7	2.350	-30.0	10813	9697	48.43	10813	9697	48.43
8	2.350	-25.0	10806	9688	48.48	10806	9688	48.48
9	2.350	-20.0	10798	9679	48.52	10798	9679	48.52
10	2.350	-15.0	10790	9670	48.57	10790	9670	48.57
11	2.350	-10.0	10782	9662	48.62	10782	9662	48.62
12	2.350	-5.0	10774	9653	48.66	10774	9653	48.66
13	2.350	0.0	10766	9644	48.71	10766	9644	48.71
14	2.350	5.0	10759	9635	48.76	10759	9635	48.76
15	2.350	10.0	10751	9626	48.80	10751	9626	48.80
16	2.350	15.0	10743	9617	48.85	10743	9617	48.85
17	2.350	20.0	10735	9609	48.90	10735	9609	48.90
18	2.350	25.0	10728	9600	48.94	10728	9600	48.94
19	2.350	30.0	10720	9591	48.99	10720	9591	48.99
20	2.350	35.0	10712	9582	49.03	10712	9582	49.03
21	2.350	40.0	10705	9574	49.08	10705	9574	49.08
22	2.350	45.0	10697	9565	49.13	10697	9565	49.13
23	2.350	50.0	10690	9556	49.17	10690	9556	49.17
24	2.350	55.0	10682	9548	49.22	10682	9548	49.22
25	2.350	60.0	10675	9539	49.26	10675	9539	49.26
26	2.350	65.0	10667	9531	49.31	10667	9531	49.31
27	2.350	70.0	10660	9522	49.36	10660	9522	49.36
28	2.350	75.0	10652	9514	49.40	10652	9514	49.40
29	2.350	80.0	10645	9505	49.45	10645	9505	49.45
30	2.350	85.0	10637	9497	49.49	10637	9497	49.49
31	2.350	90.0	10630	9488	49.54	10630	9488	49.54
32	2.350	95.0	10623	9480	49.58	10623	9480	49.58
33	2.350	100.0	10615	9471	49.63	10615	9471	49.63

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