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CLEAN LINE ENERGY

GRAIN BELT EXPRESS HVDC LINE
PRELIMINARY DESIGN CRITERIA

PROJECT NUMBER:
121586

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POWER ENGINEERS

PRELIMINARY DESIGN CRITERIA

PREPARED FOR: CLEAN LINE ENERGY
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REVISION HISTORY		
DATE	REVISED BY	REVISION
A	BHB	DRAFT for Review

TABLE OF CONTENTS

ABBREVIATIONS

ACSR:	Aluminum Conductor, Steel Reinforced
ACSS:	Aluminum Conductor, Steel Supported
ACCR:	Aluminum Conductor Composite Reinforced
ADSS:	All Dielectric Self-Supporting Fiber Optic Cable
AFL:	America Fujikura Ltd.
AGS:	Armor Grip Support
ASCE:	American Society of Civil Engineers
FC:	Sag Tension Limit, Final After Creep Condition
FL:	Sag Tension Limit, Final After Load Condition
Hz:	Hertz
I:	Sag Tension Limit, Initial Condition
kcmil:	1000 Circular Mills
kips:	1000 pounds
kV:	kilovolts
Manual No. 74	ASCE Manual and Report on Engineering Practice No. 74 “Guidelines for Electrical Transmission Line Structural Loading
N/A	Not Applicable
NESC:	National Electrical Safety Code, 2007
OHSW:	Overhead Shield Wire
OPGW:	Fiber Optic Ground Wire
ROW:	Right-of-Way
RUS:	Rural Utilities Service
TBD:	To Be Determined
TW:	Trapezoidal Shaped Conductor

GENERAL

Project Information

Owner's Name:	Clean Line Energy Partners ("Clean Line")
Project Name:	Grain Belt Express HVDC transmission line
Length:	Approximately 500 miles
Voltage:	+/- 600 kV DC (Bi-Pole)
Planned Energization Date:	Approximately 2015 or 2016

Correspondence/Project Personnel

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Project Description

This project involves developing a Preliminary Design and Budgetary Cost Estimate for Clean Line Energy Partner's ("Clean Line") proposed Grain Belt Express HVDC transmission line. This project is currently in the conceptual stage. The purpose of the Preliminary Design is to advance the project definition from the current conceptual level to a preliminary design level, which will serve as the basis for developing budgetary cost estimates for the transmission line. These estimates will, in turn, be used by Clean Line in their on-going project economic analyses.

Clean Line has stated that the desired operating voltage for the project is +/- 600 kV. However, they are also interested in having a ball-park estimate for the project if constructed for an operating voltage of +/- 500 kV. Therefore, while the preliminary design will be performed assuming +/- 600 kV, enough data and analysis will be performed at the appropriate tasks to allow development of the desired estimate for a +/- 500 kV project.

This preliminary design work requires creation of an initial design criterion, selection of several representative conductor configurations, conceptual design of several potential families of line structures, development of a conceptual PLS_CADD line model for the preferred line corridor, general engineering/technical support for line routing activities (by Others), field reconnaissance of potential line routes, and preparation of budgetary cost estimates for line construction. The basis for the criteria and selections included in our work plan will largely be POWER's experience in this area with reference to appropriate existing projects, and will be supplemented by analysis when appropriate.

Is desired by Clean Line, POWER can provide the value-added tasks described in Task 7 of POWER's Work Plan. These services will allow Clean Line to refine its conceptual design and better understand the cost and design limits of each corridor or route it analyzes. The value added tasks include:

- Identify Potential Locations for Ground Electrodes

CODE(S) AND LOADING CONDITIONS

Controlling Code(s)

NESC:	NESC Heavy District NESC Extreme Wind, adjusted for 100-year return period NESC Extreme Ice with Concurrent Wind, adjusted for 100-year return period
Location or State Specific:	TBD in final design, if appropriate
Client Specific:	TBD

Loading Conditions For Non-Deadend Structures

Case	Description	Weather Case	Ref	Cable Condition	Vert. Load Factor	Wind Load Factor	Tension Load Factor	Strength Reduction Factor
1	NESC HEAVY ALL WIRES INTACT (STEEL & CONCRETE)	0°F, 0.5" ICE, 4 PSF	NESC 253-1 / 261-1A	Initial	1.5	2.5	1.65	1
2	EXTREME WIND ALL WIRES INTACT (STEEL & CONCRETE)	60°F 97 MPH (100 YR RP) ASSUME 200' STR WITH 500' SPAN 24.3 PSF ON WIRE 26.3 PSF ON STR	NESC 253-1 / 261-1A	Initial	1.0	1.0	1.0	1
3	NESC EXTREME ICE WITH CONCURRENT WIND ALL WIRES INTACT (STEEL & CONCRETE)	15°F 1.25" ICE (100 YR) 4.1 PSF WIND	NESC 253-1 / 261-1A	Initial	1.0	1.0	1.0	1
4	F2 TORNADIC WIND <u>ON STRUCTURE WITH</u> <u>NO WIRES</u>	60°F, 157 MPH (63.1 PSF)	ASCE #74 2.7.1	Not Applicable	1.0	1.0	1.0	1
5	EVERYDAY LOADS	60°F		Initial	1.0	1.0	1.0	1
6	CONSTRUCTION, SNUB-OFF, 3:1	0°F		Initial	1.5	1.5	1.5	1
7	STRINGING/BROKEN SHIELD WIRE LOAD	0°F, 4 PSF		Initial	1.5	1.5	1.5	1
8	STRINGING/BROKEN CONDUCTOR LOAD	0°F, 4 PSF		Initial	1.5	1.5	1.5	1

Notes:

1. Load cases 1 through 4 shall be analyzed assuming a foundation rotation of 1.72° (3%) when used with pole structures.
2. Load case 2 is a maximum deflection case when used with pole structures. Deflection at the pole tip shall be limited to 9% of the above ground structure height under this load condition. The total of 9% includes 1.72° (3%) due to foundation rotation.
3. Load case 5 is for deflection control of pole structures under every day conditions. The maximum deflection for tangent structures is one pole tip diameter. The maximum deflection for angle structures at the pole tip is 1 ½ % of the above ground height. Angle structures not meeting this requirement shall be cambered.
4. For structure load calculations, the vertical span will be approximately 1.5 times the horizontal span unless actual span conditions are worse.
5. Load Case 2 shall be analyzed with the wind in a transverse direction, at a 45° yawed angle and with a longitudinal wind.
6. Load Case 6, snub-off, is applied with wires snubbed off at three horizontal to one vertical. For single circuit structures, all wires shall be snubbed off. For double circuit structures, all wires on one circuit and two shield wires shall be snubbed off.
7. Load Case 7, stringing shield wire, accounts for a stringing block getting hung up. The longitudinal load applied to the structure at any one shield wire position shall be equal to 100% of the tension in the shield wire. All other wire loads should be assumed intact.

8. Load Case 8, stringing conductor, accounts for a stringing block getting hung up. The insulator string is assumed to swing longitudinally at a 45° angle. The longitudinal load to be applied at any one conductor pole position shall be equal to the stringing tension x number of sub-conductors per pole x .6 residual tension factor x 1.1 overload factor. The other conductor pole and both shield wire locations should be assumed intact.
9. All load cases shall include the weight of the insulators and hardware plus 800 lb. additional vertical load at the tip of each arm to account for two maintenance men and equipment.
10. Load Case 4 shall be for wind on structure only with no wires attached. Structure shall be analyzed with the wind in a transverse direction, at a 45° yawed angle and with a longitudinal wind.
11. Insulators will be designed for the following overload factors and strength reduction factors (reference RUS Bulletin 1724E-200 Paragraph 8.9.1)
    a. Case 1: Overload Factor = 1.0, Strength Reduction Factor = 0.4
    b. Cases 2, 3: Overload Factor = 1.0, Strength Reduction Factor = 0.5 for non-ceramic, 0.65 for ceramic and glass
12. All lattice structural members shall be able to hold a 350 lb load, applied vertically at their midpoint, conventionally combined with the stresses derived from Load Case 5.

Loading Conditions For Deadend Structures

Case	Description	Weather Case	Ref	Cable Condition	Vert. Load Factor	Wind Load Factor	Tension Load Factor	Strength Reduction Factor
1	NESC HEAVY ALL WIRES INTACT (STEEL & CONCRETE)	0°F, 0.5” ICE, 4 PSF	NESC 253-1 / 261-1A	Initial	1.5	2.5	1.65	1
2	EXTREME WIND ALL WIRES INTACT (STEEL & CONCRETE)	60°F 97 MPH (100 YR RP) ASSUME 200’ STR WITH 500’ SPAN 24.3 PSF ON WIRE 26.3 PSF ON STR	NESC 253-1 / 261-1A	Initial	1.0	1.0	1.0	1
3	NESC EXTREME ICE WITH CONCURRENT WIND ALL WIRES INTACT (STEEL & CONCRETE)	15°F 1.25” ICE (100 YR) 4.1 PSF WIND	NESC 253-1 / 261-1A	Initial	1.0	1.0	1.0	1
4	F2 TORNADIC WIND ON STRUCTURE WITH NO WIRES	60°F, 157 MPH (63.1 PSF)	ASCE #74 2.7.1	Not Applicable	1.0	1.0	1.0	1
5	EVERYDAY LOADS	60°F		Initial	1.0	1.0	1.0	1
6	NESC HEAVY DEADEND ALL WIRES REMOVED FROM ONE SPAN (STEEL & CONCRETE)	0°F, 0.5” ICE, 4 PSF	NESC 253-1 / 261-1A	Initial	1.5	2.5	1.65	1
7	EXTREME WIND DEADEND ALL WIRES REMOVED FROM ONE SPAN (STEEL & CONCRETE)	60°F 97 MPH (100 YR RP) ASSUME 200’ STR WITH 500’ SPAN 24.3 PSF ON WIRE 26.3 PSF ON STR	NESC 253-1 / 261-1A	Initial	1.0	1.0	1.0	1
8	NESC EXTREME ICE WITH CONCURRENT WIND; DEADEND; ALL WIRES REMOVED FROM ONE SPAN; (STEEL & CONCRETE)	15°F 1.25” ICE (100 YR) 4.1 PSF WIND	NESC 253-1 / 261-1A	Initial	1.0	1.0	1.0	1

Notes:

1. Load cases 1 through 4 shall be analyzed assuming a foundation rotation of 1.72° (3%) when used with pole structures.
2. Load case 2 is a maximum deflection case when used with pole structures. Deflection at the pole tip shall be limited to 9% of the above ground structure height under this load condition. The total of 9% includes 1.72° (3%) due to foundation rotation.
3. Load case 5 is for deflection control of pole structures under every day conditions. The maximum deflection for tangent structures is one pole tip diameter. The maximum deflection for angle structures at the pole tip is 1 ½ % of the above ground height. Angle structures not meeting this requirement shall be cambered.
4. For structure load calculations, the vertical span will be approximately 1.5 times the horizontal span unless actual span conditions are worse.
5. Load Cases 6, 7, 8 shall be used to verify all deadend structures are designed to carry all wires deadended on one side of the structure.
6. Load Case 2 shall be analyzed with the wind in a transverse direction, at a 45° yawed angle and with a longitudinal wind.
7. All load cases shall include the weight of the insulators and hardware plus 800 lb. additional vertical load at the tip of each arm to account for two maintenance men and equipment.
8. Load Case 4 shall be for wind on structure only with no wires attached. Load Case 4 shall be analyzed with the wind in a transverse direction, at a 45° yawed angle and with a longitudinal wind.
9. Insulators will be designed for the following overload factors and strength reduction factors (reference RUS Bulletin 1724E-200 Paragraph 8.9.1):
    a. Case 1, 6: Overload Factor = 1.0, Strength Reduction Factor = 0.4
    b. Cases 2, 3, 7, 8: Overload Factor = 1.0, Strength Reduction Factor = 0.5 for non-ceramic, 0.65 for ceramic and glass.
10. All lattice structural members shall be able to hold a 350 lb load, applied vertically at their midpoint, conventionally combined with the stresses derived from Load Case 5.

WIRE

Transmission Conductor	
Size (kcmil/AWG):	2156 kCMIL
Composition (ACSR, AAC, etc.):	ACSR
Code Word:	Bluebird
Diameter:	1.762 inches
Weight:	2.511 lbs/ft
Rated Breaking Strength:	60,300 lbs
Design Voltage:	600 kV HVDC
Typical Operating Voltage:	600 kV HVDC
Maximum Operating Voltage:	632 KV HVDC
Maximum Conductor Temperature (Temperatures calculated using IEEE 738 methodology for predicted line loadings under normal and emergency conditions):	Normal Regime: 64 Deg C (148 Deg F) Emergency Regime: 71 Deg C (160 Deg F)

For additional information, see Appendix E-Sag & Tension File, Appendix F-Ampacity Calculations, and Appendix J-Preliminary Conductors Comparison.

OPGW
There will be two OPGW, one to protect each pole.

See Appendix B-OPGW Detailed Specification, Appendix C- Lightning Algorithm: Expected Charge Calculation at Line Location, and Appendix D-OPGW Outer Layer's Wire Diameter Calculation based on Expected Lightning Charge at Line Location.

Size (kcmil/AWG):	49AY85ACS-2C
Composition (EHS, AW, etc.):	12 Aluminum Clad Steel Wires ACS20.3% IACS 2 Aluminum Alloy Wires AY6201-T81 2 Stainless Steel Tubes 304 containing 6-24 fibers each and gel
Diameter:	0.591 inches
Weight:	0.473 lbs/ft
Rated Breaking Strength:	25,369 lbs
Number of Fibers:	12-48, depending on final project requirements

Shield Wire

Size (kcmil/AWG):	Not Applicable for this Project
Composition (EHS, AW, etc.):	Not Applicable for this Project
Diameter:	Not Applicable for this Project
Weight:	Not Applicable for this Project
Rated Breaking Strength:	Not Applicable for this Project

CONDUCTOR RATING CRITERIA

The following table summarizes conductor ampacity calculated using IEEE 738 methodology under normal and emergency loading conditions, using the following assumptions:

Ambient air temperature = 40 deg C (104 deg F), Wind Speed=2 ft/s, Emissivity factor = 0.5; and Solar absorptivity factor = 0.5.

See Appendix F-Ampacity Calculations, for other parameters used in these calculations, and the resulting maximum operating temperatures for the conductors analyzed.

Circuit	Conductor	Voltage (kV)	Normal Ratings				Emergency Ratings (20% over Normal Ratings)			
			Winter		Summer		Winter		Summer	
			MW	Amps	MW	Amps	MW	Amps	MW	Amps
Grain Belt Express	ACSR Bluebird 3 sub-conductors per pole	Nominal: 600 Maximum: 632	3720 At rectifier	3100 Per pole 1033.3 Per sub-conductor	3720 At rectifier	3100 Per pole 1033.3 Per sub-conductor	4464 At rectifier	3720 Per pole 1240 Per sub-conductor	4464 At rectifier	3720 Per pole 1240 Per sub-conductor

WIRE SAG/TENSION LIMITS

Conductor Sag-Tension Limits

The following table summarizes all sag-tension limits considered. The most stringent limit will be utilized to control the sag-tension in each span, or an agreed upon control tension will be used that will also meet the requirements below. See Appendix E-Sag & Tension Files.

Weather Case				Sag or Tension Limit		
Wind (psf)	**Ice (inches)**	**Temp (°F)**	**Cond.**	**NESC Limit**	**Southwire Sag10 Program Limit**	**Project Specific Limit**
4	1/2	0	I	60% RBS	50% RBS	50% RBS
24.3	0	60	I	--	--	75% RBS
4.1	1.25	15	I			75% RBS
0	0	60	I	35% RBS	--	--
0	0	60	F	25% RBS	--	-
0	0	0	I	--	33.3% RBS	33.3% RBS
0	0	0	F	--	25% RBS	25% RBS
0	0	-20	I	--	--	Uplift Condition
4	1/2	0	I	--	--	Slack Tension Into Substation D.E. Frame. 5000 lbs maximum per sub-conductor. Max per HVDC pole = 5000 lbs x no. of sub-conductors.
24.3	0	60	I	--	--	
4.1	1.25	15	I	--	--	

OPGW Sag-Tension Limits

The following table summarizes all sag-tension limits considered. The most stringent limit will be utilized to control the sag-tension in each span, or an agreed upon control tension will be used that will also meet the requirements below. See Appendix E-Sag & Tension Files.

Weather Case				Sag or Tension Limit		
Wind (psf)	**Ice (inches)**	**Temp (°F)**	**Cond.**	**NESC Limit**	**Southwire Sag10 Program Limit**	**Project Specific Limit**
4	1/2	0	I	60% RBS	50% RBS	50% RBS
24.3	0	60	I	--	--	60% RBS
4.1	1.25	15	I			60% RBS
0	0	60	I	35% RBS	--	--
0	0	60	F	25% RBS	--	<= 85% of the Conductor Sag at the Same Loading Condition
0	0	0	I	--	33.3% RBS	33.3% RBS
0	0	0	F	--	25% RBS	15% RBS
0	0	-20	I	--	--	Uplift Condition
4	1/2	0	I	--	--	Slack Tension Into Substation D.E. Frame. 3000 lbs maximum per OPGW
24.3	0	60	I	--	--	
4.1	1.25	15	I	--	--	

OPGW to Conductor Sag Ratios Requirements (to ensure shielding angles are maintained):

OPGW Sag @ 60 F, No Wind, No Ice, Final <= 85% Conductor Sag @ 60 F, No Wind, No Ice, Final

OPGW Sag @ 32 F, No Wind, **0.5" Ice**, Final <= 95% Conductor Sag @ 32 F, No Wind, No Ice, Final

Creep-Stretch Criteria

Condition for Final Sag after Load (Common Point):	NESC Heavy Rule 250 B: 0 Deg F, 4 PSF Wind, 0.5" Ice
Condition for Final Sag after Creep:	60 Deg F

Galloping

Double-loop galloping will be assumed for spans greater than 600 feet. Single-loop galloping will be assumed for spans less than 600 feet. Galloping ellipses will be allowed to overlap up to 10% of the elliptical major axis.

The weather case used to calculate swing angle used during galloping analyses will be 2 psf wind, 1/2" ice, 32°F final. The weather case used to calculate the ellipse size will be 0 psf wind, 1/2" ice, 32°F final.

Aluminum in Compression

It will be assumed that outer aluminum strands can go into compression under high temperature.
The maximum virtual compressive stress for ACSR Bluebird conductor will be assumed to be 1.5 ksi, and for ACCR/TW Pecos conductor (used in Mississippi River Crossing Span) will be assumed to be 1.25 ksi.

STRUCTURES

Circuits

No. Circuits (Single or Double):	2-Pole Horizontal HVDC with Earth Return (preferred) 2-Pole Horizontal HVDC with Dedicated Metallic Ground Returns (potential option to be reviewed)
Bundled:	3 conductors per bundle (pole)
Guyed or Self-Supporting:	Potential both guyed and self-supporting structures

Material

Wood (DF, WRC, preservative):	Do not consider wood
Steel (self-weathering, painted, galv.):	Potential weathering steel and galvanized steel
Concrete:	Potential concrete
Other:	

Configuration

Single Pole:	Potential single pole structure types: • Self-supporting Steel Tubular • Self-supporting Concrete
H-Frame	No
3-Pole:	No
Lattice:	Consider the following lattice tower types • Self-supporting Steel Lattice, • Guyed Single Mast or Vee

Other: Consider the following additional structure types:
- Cross Rope Suspension, Guyed Steel Lattice (with two foundations)
- Cross Rope Suspension, Guyed Steel Lattice (Vee Configuration with a single foundation)
- Guyed Single Mast or Vee Tubular Steel

Are Transposition Structures Required: YES ☐ NO ☑

Foundations

Type: Drilled Pier

Geotechnical Data Available: YES ☐ NO ☑

Geotechnical Study Required: YES ☑ NO ☐
Desktop geotechnical study will be performed to determine soil types that may be encountered along the line and to classify them into several primary groups with typical soil design parameters to allow for estimated designs for budgetary purposes.

Design Criteria for Foundations subject to Lateral Loads: Drilled piers and direct embed poles subject to lateral loads will be designed per POWER standard as shown in Appendix K.

Design Criteria for Foundations subject to Uplift/Compression Loads: Drilled piers and direct embed poles subject to uplift/compression loads will be designed per POWER standard as shown in Appendix K.

Calculated Lightning Outages

Calculated outages from lightning will not exceed 1 outage per 100 miles per year per HVDC pole.

Distance Between Deadends

A deadend structure will be placed approximately every 5 miles.

Other

Shield Angle (If Required): Inside: Maximum 15 degrees Outside: Maximum 15 degrees

Raptor Protection: YES ☐ NO ☐ Distance: TBD

Maximum or Minimum Pole Height Limitations (specify): TBD

Annodes Required: YES ☐ NO ☐ TBD

GUYS AND ANCHORS

Guys

Guy Strand (size, material): TBD

Guy to Pole Attachment:

Pole Eye Plate: TBD

Pole Band: TBD

Guy Hook: TBD

Other:

Guy Connection

Pole Attachment:

Preformed: TBD

3-Bolt: TBD
Automatic: TBD
Other:
@ Anchor:
Preformed: TBD
3-Bolt: TBD
Automatic: TBD
Other:

Guy Strain Insulators
Type: TBD

Guy Guards
Locations Required: TBD
Plastic: TBD Metal: TBD
Color: TBD Cattle Stub: TBD
Other (describe):

Anchors
Type:
Plate: N/A Size: N/A
Screw: TBD Size: TBD
Log: N/A Size: N/A
Concrete (describe): TBD
Other (describe): TBD
Rod: Length: TBD Diameter: TBD
Anodes Required: YES ☐ NO ☐ TBD

HARDWARE

Deadend Attachment

Description	Bolted	Compression	Other (describe)
Transmission Conductor [1]		X	
Shield Wire		N/A	
OPGW	X		Preformed

[1]Corona free hardware required: YES ☑ NO ☐

Suspension Attachment

Description	Formed Tie	Trunion Clamp	Suspension Clamp	Armor Rod	Line Guard	AGS	Other (Describe
Transmission Conductor [1]	N/A	N/A	TBD	TBD	N/A	TBD	
Shield Wire	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OPGW	N/A	N/A	TBD	TBD	N/A	TBD	

[1]Corona free hardware required: YES ☑ NO ☐

Bracing
Transmission:

Wood: N/A Steel: TBD
Other (describe): ____

Vibration Analysis
For preliminary cost estimating, vibration analysis will be performed using Vibrec software. For final design, vibration analysis would be performed by the damper supplier.

Spacer Requirements
Spacer dampers will be utilized on conductors and will be installed such that:

- The spacer dampers will be spaced symmetrically in each span with a maximum spacing of 200 ft, or asymmetrically, with 10-15% detuning, with maximum spacing of 272 ft, per CIGRE rules.
- Number of spacer dampers that will be installed in jumper strings: three (if 2 jumper strings are used-rectangle cross arm) or two (if 1 jumper string is used-triangle cross arm); two spacer dampers will be used in the jumper loop. The spacer dampers will be equally spaced between the deadends.

INSULATION

Type-Transmission

I-String:	To Be Considered
V-String:	To Be Considered; Currently Preferred Configuration.
Horizontal Post:	N/A
Horizontal Vee:	N/A
Horizontal Jumper Post:	N/A
Vertical Jumper Post:	N/A

Material Transmission

Porcelain:	To Be Considered
Glass:	To Be Considered; Currently Preferred Material
Polymer:	To Be Considered
Other (fog, etc.):	To Be Considered
Corona Rings:	To Be Considered
End Fittings:	To Be Considered

Ratings-Transmission

					Electrical Characteristics *				
Structure Type	Impact Strength (in*lbs)	No. Bells/Sheds & Size	Insulator Weight (lbs) with hardware	Total Minimum Length (ft)	DC Withstand Voltage* Dry one minute (kV)	DC Withstand Voltage* Wet One minute (kV)	Dry lightning impulse withstand (kV)	Structure Type	Impact Strength (in*lbs)
Light Suspension Line Angle= 0-2 deg V-String Angles: 45 deg (L) 45 deg (R)	400 in.lbs	Single V-String: Each String: (41) 6-3/4"x13"	Each String: 1150 lbs Single V-String: 2x 1150= 2300 lbs	Each String: 23' (w/o hardware) 25' (with hardware)	150	65	140	225	1x50=50 kips
Basic Suspension Line Angle= 0-2 deg V-String Angles: 45 deg (L) 45 deg (R)	400 in.lbs	Single V-String: Each String: (37) 7-5/8"x 14-1/8"	Each String: 1450 lbs Single V-String: 2x 1450= 2900 lbs	Each String: 23' (w/o hardware) 25' (with hardware)	170	75	150	255	1x66=66 kips
Medium Suspension Line Angle= 0-2 deg V-String Angles: 45 deg (L) 45 deg (R)	400 in.lbs	Double V-String: Each String: (41) 6-3/4"x13"	Each String: 1150 lbs Double V-String: 4x 1150= 4600 lbs	Each String: 23' (w/o hardware) 25' (with hardware)	150	65	140	225	2x50=100 kips
Heavy Suspension Line Angle= 0-2 deg V-String Angles: 45 deg (L) 45 deg (R)	400 in.lbs	Double V-String: Each String: (37) 7-5/8"x 14-1/8"	Each String: 1450 lbs Double V-String: 4x 1450= 5800 lbs	Each String: 23' (w/o hardware) 25' (with hardware)	170	75	150	255	2x66=132 kips
River Crossing Heavy Suspension Line Angle= 0-2 deg V-String	400 in.lbs	Double V-String: Each String: (37) 7-5/8"x 14-1/8"	Each String: 1450 lbs Double V-String: 4x 1450= 5800 lbs	Each String: 23' (w/o hardware) 25' (with	170	75	150	255	2x66=132 kips

Angles: 45 deg (L) 45 deg (R)				hardware)					
Small Angle Suspension Line Angle= 2-10 deg V-String Angles: 20 deg (L) 35 deg (R)	400 in.lbs	Double V-String: Each String: (37) 7-5/8"x 14-1/8"	Each String: 1450 lbs Double V-String: 4x 1450= 5800 lbs	Each String: 23' (w/o hardware) 25' (with hardware)	170	75	150	255	2x66=132 kips
Medium Angle Suspension Line Angle= 10-30 deg V-String Angles: 12 deg (L) 65 deg (R)	400 in.lbs	Triple V-String: Each String: (41) 6-3/4"x13"	Each String: 1150 lbs Triple V-String: 6x 1150= 6900 lbs	Each String: 23' (w/o hardware) 25' (with hardware)	150	65	140	225	3x50=150 kips
Deadend Line Angle= 0-45 deg & Deadend Line Angle= 45-90 deg	400 in.lbs	Quadruple DE String: Each String: (50) 6-3/4"x13" 1 Jumper String: Single I-String (41) 6-3/4"x13"	Each String: 1455 lbs 1 Jumper: 1150 lbs Quadruple DE String: 4x 1455 =5820 lbs Both sides of structure: 2x 5820+ 1x1150= 12790 lbs	Dead end Insulator: 28' (w/o hardware) 33' (with hardware) Jumper: 23' (w/o hardware) 25' (with hardware)	150	65	140	225	4x50=200 kips (each side of structure) 2x200=400 kips (both sides of structure)

Data based on toughened glass, ball & socket coupling, Sediver's DC fog type: 50 kips (N220P/C-171DR) and 66 kips (F300PU/C-195DR).
*Electrical characteristics in accordance with IEC 61325.

RIGHT-OF-WAY

Description
Location of Line in ROW: Assumed center
ROW Width: Assumed 175' based on 1500' typical spans.

Right-of-Way Width Calculations for Blowout

Load Case 1: 0 PSF, No Ice, All Temperatures, Final (NESC 234 A.1)
Load Case 2: 6 PSF, No Ice, 60°F, Final (NESC 234 A.2)
Load Case 3: Extreme Wind 24.3 psf, No Ice, 60°F, Final

Minimum clearances to be maintained from the blown out conductor to the edge of right-of way shall be as follows. Load Cases 1 and 2 are based on maintaining NESC clearance to buildings. See NESC 234 B. Clearances for Load Case 3 are not governed by NESC. This case is a criteria designed to keep the

conductors on the right-of-way under an extreme wind. These clearances include a 3' buffer to accommodate survey and construction tolerances.
For clearances to the ROW, see also Appendix A- Clearances Calculation Tables.

	Clearance for ±600 kV nominal & ±632 kV maximum
Load Case 1	25 ft*
Load Case 2	22 ft*
Load Case 3	0 ft – May vary by location

*See Appendix A- Clearances Calculation Tables.

The maximum structure deflection, including foundation rotation, for single shaft steel structures will be assumed at 9% of structure above ground height for Load Case 3 and 5% for Load Case 2. For lattice towers the maximum structure deflection will be assumed at 1% of the structure above ground height.

Electric Field Affects

Electric field calculations will be prepared using the Corona and Field Affects Program (CAFEP) developed by the Bonneville Power Administration. The calculations will be based on a maximum line to line voltage of the nominal 600 kV plus 5% (or 632 kV) at the sending end. Typical approximate structure configurations will be used along with a sample of the possible conductor bundling scenarios. Calculated values will be compared to the limits listed below as a reference. Note that Kansas and Missouri do not have any published limits.

IEEE Standard C95.6-2002 Limits

- Maximum E-field at edge of right-of-way: 5 kV/m
- Maximum E-field on the right-of-way: 20 kV/m

Corona

POWER will prepare corona effects calculations using the CAFEP software and the same scenarios as the electric field calculations. Clean Line Energy will provide the audible noise (AN) and AM radio interference (RI) limits to be maintained at the edge of right-of-way. If no values are provided, the typical industry guidance of 40 dB μV/m will be used for RI and the EPA recommendation of no greater than 55 dBA will be used for AN. All values are calculated at the edge of the right-of-way.

In addition, the corona losses along the line will be calculated manually for the same scenarios as above. The calculations will assume a line length of 800 miles as the specific line length is yet to be determined.

CLEARANCES

All clearances will be determined using 600 kV DC, nominal, pole-to-ground, and 632 kV DC, maximum, pole-to-ground.
Also, for comparison purposes, clearances were calculated using an "AC equivalent" voltage (600 kV DC = 735 kV AC).
See Appendix A-Clearances Calculation Tables.

Voltage System

All systems are considered effectively grounded or systems where ground faults are cleared by promptly de-energizing the faulted section, both initially and following subsequent breaker operations. The maximum operating voltage is the normal voltage plus 5%.

Clearance to Structure/Insulator Swing

The maximum and minimum insulator swings will be limited by minimum clearances required to the structure. This clearance will be to the arm, tower body, or to the pole. The load cases considered for insulator swing as it relates to clearance to structure will be as follows:

Load Case 1:	0 PSF Wind, No Ice, All Temperatures, Final
Load Case 2:	6 PSF, No Ice, 60°F, Final (NESC 235 E.2)
Load Case 3:	Extreme Wind, No Ice, 60°F, Final

Minimum clearances to be maintained from the closest line conductor or other hot element to the face of the metal structures shall be as follows:

	Clearance for ±600 kV nominal & ±632 kV maximum
Load Case 1	17.33 ft
Load Case 2	17.33 ft
Load Case 3	5 ft

Load Case 1 required clearance based on air gap equivalent (dry arc distance) of tangent insulator. Load Case 2 clearance based on NESC Table 235-6. Load Case 1 and 2 minimum clearances increased to 17.33’ to meet IEEE 516-2009 MAD (Minimum Approach Distance) for tools (12.33’) and the Working Space (4.5’).

Load Case 3 based on EPRI T/L Reference Book +/ -600 KV HVDC Lines where the mechanical case Extreme Wind corresponds to the electrical case Steady State , normal regime, Figure 10-3 page 145 and Fig.10-4, Page 146: 4.1’, to which it was added a buffer of 0.9’.

See Appendix A-Clearances Calculation Tables.

Ground Clearance

NESC:	34’ (w/3’ buffer) (See Appendix A-Clearances Calculation Tables).
REA:	N/A
Other:	N/A

Water Clearance for River Crossing Spans

NESC:	55’ (w/3’ buffer) (See Appendix A- Water Clearances Calculation Tables).
REA:	N/A
Other:	N/A

The water clearance was determined based on NESC Rule 232D, Table 232-3, f (DC Calculation) and NESC Rule 232, Table 232-1, 7 (AC Equivalent Calculation). It might change, based future requirements from the Corps of Engineers, or other regulators.

5 milli Amp Rule

This rule, NESC Rule 232.C.1.c, does not apply to HVDC lines because a DC line will not create a steady-state current as occurs with AC lines.

Clearance Between Wires on Different Supporting Structures

NESC: Horizontal: 35 ft (w/3 ft buffer); Vertical: 28 ft(w/ 3 ft buffer) (Reference NESC Rule 233)

REA: N/A
Other: N/A

Clearance to Structures of Another Line
NESC: 22 ft (w/3 ft buffer) (Reference NESC Rule 234B)
REA: N/A
Other: N/A

Horizontal Clearance Between Line Conductors at Fixed Supports
CASE 1: The Horizontal clearance at the structure, of the same or different circuits, shall be per NESC 235B.3.a Alternate Clearance: Pole-to-Pole (horizontal configuration): 34.8' (w/3 ' buffer).

CASE 2: The Horizontal clearance at the supports, of the same or different circuits, shall also meet requirements according to sags per NESC 235B.1.b(2) :Pole-to-Pole (horizontal configuration): 27' (w/3' buffer).

CASE 3: Galloping

Refer to section titled "Galloping".

Vertical Clearance Between Line Conductors
Note: the poles (conductors) of the DC lines will be located horizontally, so these vertical clearances are just theoretical. Only the distance pole (conductor) to OPGW will be a vertical clearance.

CASE 1: Pole-to-Pole (if they are located in vertical configuration): 30 ft (w/3 ' buffer).
Pole-to-OPGW: 19 ft (w/3' buffer).The Vertical clearance at the structure shall be per NESC 235C. Reference NESC Table 235-5.

CASE 2: Pole-to-Pole (if they are located in vertical configuration): 30 ft (w/3' buffer).
Pole-to-OPGW: 19 ft (w/ 3' buffer). Vertical clearances at the structure shall be adjusted to provide sag-related clearances at any point in the span per NESC 235C.2.b. The sag-related clearances in the span are considered as diagonal clearances.

CASE 3: Galloping

Refer to section titled "Galloping".

Radial Clearance from Line Conductors to Supports, and to Vertical or Lateral Conductors, Span or Guy Wires Attached to the Same Support
NESC: To supports: 17.33' (MAD for Tools"12.33 per IEEE 516-2009+Working Space: 4.5' per NESC Rule 236&237)
To anchor guys: 19.4' (w/3 ft buffer) per NESC235E, 4 b., where 600 kV, dc equivalent to 735 kV ac.
The NESC Rule 235E3b (Alternative Clerances-600 kV DC): 16' and Rule 235E, 4b (600 kV dc equivalent to 735 KV ac): 16' do not control, it is the MAD for tools+WS:17.33' that controls this clearance case.
REA: N/A
Other: N/A

MISCELLANEOUS

Grounding Requirements (type and frequency of grounding required)
Ground Type:

Butt Plate:	N/A
Butt Wrap:	N/A
Ground Rod:	To be used.
Other:	

Frequency of Grounding:

All Structures:	Yes
No. Per Mile:	TBD
Maximum Resistance per Structure (ohms):	10
Other:	

Special Equipment
Describe any special equipment requirements (switches, fiber optic materials, distribution underbuild, reclosers, etc.):
Splice boxes for the OPGW fibers will be used at the splice structures where an OPGW reel will finish, and at certain dead-end structures. Underground loose tube (LT) type fiber optic cable will be used from the last structure to the substation. The fibers from this underground fiber optic cable will be spliced to the fibers from the OPGW inside the splice box located on the last structure before the substation.

Material
Describe Owner supplied material (attach additional sheets if necessary):

Does the utility have a standard material list it uses: YES ☐ NO ☐

Describe Contractor supplied material (attach additional sheets if necessary) :

Environmental Protection
State any measures required or agencies to be contacted for wildlife protection requirements:

Describe any known industrial, salt-water contamination or other environment that may impact or has been known to impact electrical insulation:

State any measures required for airborne contamination protection (dust control):

____

____

____

Describe any known caustic or corrosive soil conditions:

____

____

____

DRAWINGS AND MAPS

Maps

Existing facility maps, P&P's available: YES ☐ NO ☐

List foreign utilities to be considered for project, if maps are available:

Power:	____________	Gas:	____________
Phone:	____________	TV:	____________
Sewer:	____________	Water:	____________
Highways:	____________	Railroad:	____________
Other:	____________		

Separate access road maps required: YES ☐ NO ☐

Describe ROW/Environmental or Easement Maps required, if any:

____

____

____

Drawing Requirements

Map and Plan and Profile Scales:

Key Map Scale: ____________ **horiz.**

Plan Scale: ____________ horiz.

Profile Scale: ____________ vert. Size: ____________ horiz.

Plan Type:

Planimetric: ____________

Topographic: ____________

Other: ____________

Title Block:

POWER Standard: ____________

Other: ____________

Drawing Numbers:

POWER Generated: ____________

Owner Generated (describe): ____________

Final Drawings: ____________

Describe structure numbering sequence:

Describe any controlling mapping specifications:
All coordinates will be based on various State Plane systems, as required. Vertical datum is based on NAVD 88.

SUSTATION/SWITCHYARD INTERFACE

Terminate at existing substation entry structure: YES ☐ NO
Comments:

Maximum allowable tensions for substation deadend:
Conductor: 5000 lbs (assumed, no station data available)
OPGW/OHGW: 3000 lbs (assumed, no station data available)
Attachment height above ground substation deadend:
Conductor: TBD (no station data available)
OPGW/OHGW: TBD (no station data available)

Are substation drawings available? YES ☐ NO ☐, (if so, include)

OTHER

Describe any other items the engineer/designer may need to know to complete this project (attach additional sheets if necessary):

Appendix A- Comparison of Clearances for Clean Line +/- 600 kV Project Grain Belt Express

Case	**NESC- DC** V nom=600 KV peak, pole-ground V max=632 KV (5% over V nom)	**NESC- AC Equivalent** V nom=735 KV rms, phase-to-phase 735=600*sqrt(3)/sqrt(2) Rule 230 H V max=772 KV (5% over V nom)	**EPRI** T/L Reference Book HVDC Lines	**MAD* for Tools** (IEEE 516-2009) + **Working Space** (NESC Rule 236& 237)	**Conclusion**: Minimum possible value that can be used
Conductor to Ground:	Rule 232 D.3:	Rule 232 B and 232 C:	Not addressed.	N/A	
a. Track rails of railroads	38.68’ (bare) 39’ (rounded) 42’ (w/3’ buffer)	40.6’ (bare) 41’ (rounded) 44’ (w/3’ buffer)			**42’**
b. Streets, Alleys, roads, driveways, and parking lots	30.68’ (bare) 31’ (rounded) 34’ (w/3’ buffer)	32.6’ (bare) 33’ (rounded) 36’ (w/3’ buffer)			**34’**
c. Spaces and ways subject to pedestrians or restricted traffic:	26.68’ (bare) 27’ (rounded) 30’ (w/3’ buffer)	28.6’ (bare) 29’ (rounded) 32’ (w/3’ buffer)			**30’**
d. Vehicular areas	30.68’ (bare) 31’ (rounded) 34’ (w/3’ buffer)	32.6’ (bare) 33’ (rounded) 36’ (w/3’ buffer)			**34’**
Conductor to Water:	Rule 232 D, Table 232-3:	Rule 232, Table 232-1:	Not addressed.	N/A	
e. Water areas not suitable for sail boating or where sail boating is prohibited	28.46’ (bare) 29’ (rounded) 32’ (w/3’ buffer)	31.1’ (bare) 32’ (rounded) 35’ (w/3’ buffer)			**32’**
f. Water areas suitable for sail boating, including rivers, lakes, ponds, canals with unobstructed surface area:					
1) less than 0.08 km^2 (20 acres)	31.96’ (bare) 32’ (rounded) 35’ (w/3’ buffer)	34.6’ (bare) 35’ (rounded) 38’ (w/3’ buffer)			**35’**
(2) over 0.08 to 0.8 km^2 (20 to 200 acres)	39.96’ (bare) 40’ (rounded) 43’ (w/3’ buffer)	42.6’ (bare) 43’ (rounded) 46’ (w/3’ buffer)			**43’**
3) over 0.8 to 8 km^2 (200 to 2000 acres)	45.96’ (bare) 46’ (rounded) 49’ (w/3’ buffer)	48.6’ (bare) 49’ (rounded) 52’ (w/3’ buffer)			**49’**
(4) over 8 km^2 (2000 acres) Mississippi River Crossing	51.96’ (bare) 52’ (rounded) 55’ (w/3’ buffer)	54.6’ (bare) 55’ (rounded) 58’ (w/3’ buffer)			**55’**

Case	**NESC- DC** V nom=600 KV peak, pole-ground V max=632 KV (5% over V nom)	**NESC- AC Equivalent** V nom=735 KV rms, phase-to-phase 735=600*sqrt(3)/sqrt(2) Rule 230 H V max=772 KV (5% over V nom)	**EPRI** T/L Reference Book HVDC Lines	**MAD* for Tools** (IEEE 516-2009) + **Working Space** (NESC Rule 236& 237)	**Conclusion**: Minimum possible value that can be used
Conductor to Structure No Wind	12.96' (bare) 13' (rounded) 16' (w/3 ' buffer) Rule 235 E.3b	12.95' (bare) 13' (rounded) 16' (w/3' buffer) Rule 235E, Table 235-6, item 4b	16.4' No Wind Case corresponds to Lightning Impulse, required clearance from Figure 10-13, page 150. Lightning Surge will be at least 30% higher than Switching Surge: 1080*1.3=1404 kV Surge Factor: Ti=1.8	12.83'+4.5'=17.33' MAD+WS	**17.33'**
Conductor to Structure Medium Wind 6 psf	12.96' (bare) 13' (rounded) 16' (w/3' buffer) Rule 235 E.3b	12.95' (bare) 13' (rounded) 16' (w/3' buffer) Rule 235E, Table 235-6, item 4b	9.8 ' Medium Wind Case corresponds to Switching Impulse, required clearance from Figure 10-13, page 150 Switching Surge=1.8*600 =1080 kV Surge Factor: Ti=1.8	12.83'+4.5'=17.33' MAD+WS	**17.33'**
Conductor to Structure Extreme Wind 24.3 psf	Not addressed	Not addressed	4.1' (no buffer) 5' (w/0.9' buffer) Extreme Wind corresponds to Steady State required clearance from Fig.10-3 , Page 145 and Fig.10-4, Page 146.	Not addressed	**5'**

*MAD=Minimum Approach Distance.

NESC-Clearance Conductor to Ground calculation:

<table>
<tr>
<td>NESC- DC:
V nom=600 KV
peak, pole-ground

V max=632 KV
(5% over V nom)</td>
<td>NESC- AC Equiv
V nom=735 KV
rms, phase-to-phase
735=600*sqrt(3)/sqrt(2)
Rule 230 H
V max=772 KV
(5% over V nom)</td>
</tr>
<tr>
<td>Rule 232D, table 232-3:

a. Track rails of railroads: H ref=22’
b. Streets, Alleys, roads, driveways, and parking lots: H ref=14’
c. Spaces and ways subject to pedestrians or restricted traffic: H ref=10’
d. Vehicular areas: H ref=14’

For Ref Altitude < 1500 ft:
V max=1.05*V nom=632 kV
C ref=3.28*(632*1.8*1.15/(500*1.15)^1.667*1.03*1.2=15.96’
For assumed maximum altitude for this line (worst case scenario): 3000 ft:
Altitude Adder: (3000’-1500’)/1000’*3%=4.5%
C alt=C ref*1.045=15.96’*1.045=16.68’

a. Track rails of railroads:

C total=H ref + C alt=22’ + 16.68’=38.68’ (bare)
39’ (rounded)
42’ (w/3’ buffer)
CHOSEN

b. Streets, Alleys, roads, driveways, and parking lots:

C total=H ref + C alt=14’ + 16.68’=30.68’ (bare)
31’ (rounded)
34’ (w/3’ buffer)
CHOSEN

c. Spaces and ways subject to pedestrians or restricted traffic:

C total=H ref + C alt=10’ + 16.68’=26.68’ (bare)
27’ (rounded)
30’ (w/3’ buffer)
CHOSEN

d. Vehicular Areas:

C total=H ref + C alt=14’ + 16.68’=30.68’ (bare)
31’ (rounded)
34’ (w/3’ buffer)
CHOSEN</td>
<td>Equivalent max ac system voltage=735*1.05=772 KV
Equivalent max ac system voltage, phase-to-ground=772/sqrt(3)=446 kV
NESC Rule 232, Table 232-1, open supply conductor up to 22 kv:

a. Track rails of railroads: H basic=26.5’
b. Streets, Alleys, roads, driveways, and parking lots: H basic=18.5’
c. Spaces and ways subject to pedestrians or restricted traffic: H basic=14.5’
d. Vehicular areas: H basic=18.5’

Voltage Adder: C adder=(446-22)*0.4”/12=14.1’

Altitude adder : zero

a. Track rails of railroads:

C total=H basic + C adder= 26.5’ + 14.1’=40.6’ (bare)
41’ (rounded)
44’ (w/3’ buffer)

b. Streets, Alleys, roads, driveways, and parking lots:

C total=H basic + C adder= 18.5’ + 14.1’=32.6’ (bare)
33’ (rounded)
36’ (w/3’ buffer)

c. Spaces and ways subject to pedestrians or restricted traffic :

C total=H basic + C adder= 14.5’ + 14.1’=28.6’ (bare)
29’ (rounded)
32’ (w/3’ buffer)

d. Vehicular Areas:

C total=H basic + C adder= 18.5’ + 14.1’=32.6’ (bare)
33’ (rounded)
36’ (w/3’ buffer)</td>
</tr>
</table>

NESC- Clearance Conductor-to-Structure calculation
for Cases: Medium Wind (6 psf) and No Wind:

NESC- DC: V nom=600 KV peak, pole-ground V max=632 KV (5% over V nom)	**NESC- AC Equiv** V nom=735 KV rms, phase-to-phase 735=600*sqrt(3)/sqrt(2) Rule 230H V max=772 KV (5% over V nom)
Rule 235E3b For Ref Altitude < 1500 ft: V max=1.05*V nom=632 kV C ref=39.37*(632*1.8*1.15/(500*1.2)^1.667*1.03=148.7"=12.4' For assumed maximum altitude for this line (worst case scenario): 3000 ft: Altitude Adder: (3000'-1500')/1000'*3%=4.5% C alt=C ref*1.045=12.4'*1.045=12.96' C alt=**12.96' (bare)** **13' (rounded)** **16' (w/3' buffer)** **CHOSEN**	Equivalent max ac system voltage=735*1.05=772 KV Equivalent max ac system voltage, phase-to-ground=772/sqrt(3)=446 kV NESC Rule 235 E, 4b, open supply conductor up to 50 kv: H basic=11"=0.917' Voltage Adder: C adder=(772-50)*0.2"/12=12.033' Altitude adder : zero C total=H basic + C adder= 0.917' + 12.033'=**12.95' (bare)** **13' (rounded)** **16' (w/3' buffer)**

NESC- Clearance to Anchor Guys calculation:
for Cases: Medium Wind (6 psf) and No Wind:

NESC- AC Equiv V nom=735 KV rms, phase-to-phase 735=600*sqrt(3)/sqrt(2) Rule 230H V max=772 KV (5% over V nom)
Equivalent max ac system voltage=735*1.05=772 KV Equivalent max ac system voltage, phase-to-ground=772/sqrt(3)=446 kV NESC Rule 235 E, 4b, open supply conductor up to 50 kv: H basic=16"=1.333' Voltage Adder: C adder=(772-50)*0.25"/12=15.041' Altitude adder : zero C total=H basic + C adder= 1.333' + 15.041'=**16.374' (bare)** **16.4' (rounded)** **19.4 ' (w/3' buffer)** **CHOSEN**

NESC-Clearance to Right –of-Way (Blowout):
for Cases: Medium Wind (6 psf) and No Wind:

NESC- AC Equiv V nom=735 KV rms, phase-to-phase 735=600*sqrt(3)/sqrt(2) Rule 230H V max=772 KV (5% over V nom)
Equivalent max ac system voltage=735*1.05=772 KV Equivalent max ac system voltage, phase-to-ground=772/sqrt(3)=446 kV NESC Rule 234B, clearance to buildings, open supply conductor up to 22 kv: H basic=4.5' (**with 6 psf wind**) H basic=7.5' (**with no wind**) Voltage Adder: C adder=(446-22)*0.4"/12=14.133' Altitude adder : zero **Medium Wind (6 psf):** C total=H basic + C adder= 4.5' + 14.133'=**18.633' (bare)** **19' (rounded)** **22' (w/3' buffer)** **CHOSEN** **No Wind (0 psf):** C total=H basic + C adder= 7.5' + 14.133'=**21.633' (bare)** **22' (rounded)** **25' (w/3' buffer)** **CHOSEN**

NESC- Clearance Conductor-to-Water calculation

NESC- DC: V nom=600 KV peak, pole-ground V max=632 KV (5% over V nom)	**NESC- AC Equiv** V nom=735 KV rms, phase-to-phase 735=600*sqrt(3)/sqrt(2) Rule 230H V max=772 KV (5% over V nom)
Rule 232D, Table 232-3 item: e. Water areas not suitable for sail boating or where sail boating is prohibited: H ref=12.5’ f. Water areas suitable for sail boating, including rivers, lakes, ponds, canals with unobstructed surface area: (1) less than 0.08 km^2 (20 acres): H ref=16’ (2) over 0.08 to 0.8 km^2 (20 to 200 acres): H ref=24’ (3) over 0.8 to 8 km^2 (200 to 2000 acres): H ref=30’ (4) over 8 km^2 (2000 acres): Mississippi River Crossing: H ref=36’ For Ref Altitude < 1500 ft: V max=1.05*V nom=632 kV C ref=3.28*(632*1.8*1.15/(500*1.15)^1.667*1.03*1.2=15.96’ PU=1.8-maximum switching surge factor for +/- 600 kV DC Altitude at Mississippi River Crossing location: Alt=300’ from PLS-CADD Model 300’ < 1500’ results: Altitude Adder=0, results: C alt=C ref=15.96’ e. Water areas not suitable for sail boating or where sail boating is prohibited: C total=H ref+C alt=12.5’+15.96’=**28.46’ (bare)** **C total=29’ (rounded)** **C total=32’ (w/3’ buffer)** **CHOSEN** f. Water areas suitable for sail boating, including rivers, lakes, ponds, canals with unobstructed surface area: (1) less than 0.08 km^2 (20 acres): C total=H ref+C alt=16’+15.96’=**31.96’ (bare)** **C total=32’ (rounded)** **C total=35’ (w/3’ buffer)** **CHOSEN** (2) over 0.08 to 0.8 km^2 (20 to 200 acres): C total=H ref+C alt=24’+15.96’=**39.96’ (bare)** **C total=40’ (rounded)** **43’ (w/3’ buffer)** **CHOSEN** (3) over 0.8 to 8 km^2 (200 to 2000 acres): C total=H ref+C alt=30’+15.96’=**45.96’ (bare)** **C total=46’ (rounded)** **49’ (w/3’ buffer)** **CHOSEN** (4) over 8 km^2 (2000 acres): Mississippi River Crossing: C total=H ref+C alt=36’+15.96’=**51.96’ (bare)**	Equivalent max ac system voltage=735*1.05=772 KV Equivalent max ac system voltage, phase-to-ground=772/sqrt(3)=446 kV NESC Rule 232, Table 232-1, open supply conductor up to 22 kV: 6. Water areas not suitable for sail boating or where sail boating is prohibited: H basic=17’ 7. Water areas suitable for sail boating, including rivers, lakes, ponds, canals with unobstructed surface area: (1) less than 0.08 km^2 (20 acres): H basic=20.5’ (2) over 0.08 to 0.8 km^2 (20 to 200 acres): H basic=28.5’ (3) over 0.8 to 8 km^2 (200 to 2000 acres): H ref=34.5’ (4) over 8 km^2 (2000 acres): Mississippi River Crossing: H ref=40.5’ Voltage Adder: C adder=(446-22)*0.4”/12=14.1’ Altitude at Mississippi River Crossing location: Alt=300’ from PLS-CADD Model 00’ < 1500’ results: Altitude Adder=0, results: C alt=C adder=14.1’ e. Water areas not suitable for sail boating or where sail boating is prohibited: C total=H basic + C adder= 17’ + 14.1’=**31.1’ (bare)** **C total=32’ (rounded)** **C total=35’ (w/3’ buffer)** f. Water areas suitable for sail boating, including rivers, lakes, ponds, canals with unobstructed surface area: (1) less than 0.08 km^2 (20 acres): C total=H basic + C adder= 20.5’ + 14.1’=**34.6’ (bare)** **C total=35’ (rounded)** **C total=38’ (w/3’ buffer)** (2) over 0.08 to 0.8 km^2 (20 to 200 acres): C total=H basic + C adder= 28.5’ + 14.1’=**42.6’ (bare)** **C total=43’ (rounded)** **C total=46’ (w/3’ buffer)** (3) over 0.8 to 8 km^2 (200 to 2000 acres): C total=H basic + C adder= 34.5’ + 14.1’=**48.6’ (bare)** **C total=49’ (rounded)** **C total=52’ (w/3’ buffer)** 4) over 8 km^2 (2000 acres): Mississippi River Crossing: C total=H basic + C adder= 40.5’ + 14.1’=**54.6’ (bare)**

C total=52' (rounded) 55' (w/3' buffer) CHOSEN	C total=55' (rounded) C total=58' (w/3' buffer)

Appendix B-OPGW Detailed Specification:

This +/-600 kV DC line will go through Kansas and Missouri, and according to the Visalia public domain Ground Flash Density (GFD) Map (http://www.weather.gov/os/lightning/images/Vaisala_96-05_Flash_Map.gif), the expected average maximum GFD in these regions is about GFD max= 6 [strokes/sqkm/year]. This is a significant value, enough to require a lower maximum allowable shielding angle. For this project, we have selected 15 degrees.

For an GFD=6 [strokes/sqkm/year], and considering, at this preliminary design criteria stage, an average tower height of 42 m=140 ft, and a distance between the 2 OPGWs of about 8.8 m = 29 ft, and assuming the average ruling span at 460 m=1500 ft, for an exposure interval of 30 years, and assuming 95% of the lightning strikes are negative and 5% are positive (which is a typical case) results the worst lightning charge to be **Q=121 Coulombs (negative polarity**), using IEEE 1243 method.

That will require the OPGW to have in the outer layer a wire diameter of minimum **3.1 mm (ACS 20.3%IACS wire material).** Calculations of required outer wire diameter based on formulas developed empirically from test data developed by AFL.

This minimum size of wire in the outer layer: **3.1 mm** is necessary to ensure that after lightning strike, the remaining strength in the OPGW will be at least 75% of the original OPGW RBS, per IEEE 1138 OPGW lightning test method.

See attached calculations prepared by Power Engineers in "Lightning Algorithm-Clean Line-Expected Charge .xlsx" Spreadsheet, that is attached as Appendix C to this Preliminary Design Criteria.

Also, because this line will be in a region with 1.25" ice with concurrent wind of 4.1 psf (NESC), a good assumption is that the OPGW maximum working tension will be at about 60%RBS under 1.25" ice+4.1 psf wind, in order for the OPGW sag to be at 85% of the conductor sag at 60 F, Final, bare cable.

Therefore, the OPGW must have **Cable Tension for Zero Fiber Strain (CTZFS) of at least 85%RBS**. Due to this requirement any OPGW with central tube design (i.e. fibers in central stainless steel tube, or fibers in central stainless steel tube inside an aluminum pipe), are not recommended.

These types of designs do not meet CTZFS=85%RBS.
At this level of high tension, in this type of design, there will be some allowable fiber strain, about 0.20%-0.33%, which can result in fiber attenuation [dB/km].

The only OPGW design that will meet Cable Tension for Zero Fiber Strain (CTZFS)=85%RBS is a stranded stainless steel tube design, where the fibers are located inside stranded stainless steel tubes.
The fibers need to be in an element that has a lay length (pitch), because the EFL (Excess Fiber Length) itself inside the tube is not sufficient to provide CTZFS=85%RBS.

Minimum EFL (Excess Fiber Length) in the stainless steel tube must be 0.5%, and the lay length (pitch) of the inner layer, containing the stainless steel tubes, must be tight enough to obtain enough fiber free elongation in tension to reach CTZFS=85%RBS.

Therefore, it is recommended that the inner layer lay ratio be in the range of 10-13.
This means that the inner layer lay length (pitch) must be 10 to 13 times the diameter over the inner layer.

The preferred design, for maximum 48 fibers, will be a design with 2 stainless steel tubes in the inner layer, each with a maximum of 24 fibers.

If more than 12 fibers per tube are used, the fibers will be grouped in 12 fibers, each group of 12 fibers should be differentiated using stripes, not string binders.

Note that while an OPGW design with fibers inside stranded plastic buffer tubes inside an AL Pipe will also meet the requirement of CTZFS = 85%RBS. However, an OPGW designed in this manner will be much larger (with a resulting increase in structure loads) than an equivalent design using stranded stainless steel tubes designs.

The OPGW Rated breaking Strength (RBS) will be calculated as 90% of the OPGW UTS (Ultimate Tensile Strength), as defined in IEEE 1138 standard for OPGW.

The hollow stainless steel tubes will not be considered in the calculation of the OPGW RBS, only the wires.

The type of fiber to be used, due to the line length: 800 miles, must be G.655C (NZDSF=Non-Zero Dispersion Shifted Fiber, large Core Area), and not SMF G.652D (Low Water Peak).

Using G.655C type of fibers allows an increased spacing between repeaters (amplifiers) to reduce the non-linear effects, which determines fiber losses (fiber attenuation, in dB/km).

The G.655 fibers attenuation limits should be:

- 0.22 db/km @ 1550 nm
- 0.25 dB/km @ 1625 nm

Important Note: these will be the "cabled" fiber maximum allowed attenuation values, not the "uncabled" fibers value (incoming fiber from fiber's manufacturer).

Based on the above, the preliminary OPGW design characteristics/specifications are as follows: Maximum Cable Diameter: D c=0.591 inches

- Minimum Wire Diameter in the Outer Layer: D wire=3.00 mm
- Maximum Weight: W=0.475 lbs/ft
- Minimum Rated Breaking Strength: RBS=25369 lbs
- Minimum Cable Tension for Zero Fiber Strain=85%RBS
- Minimum Total Cross-Sectional Area: A=0.19 sq in
- Minimum Fault Current Rating: I^2*t=98 kA^2*sec; which corresponds to the following assumed fault magnitude and clearing time scenarios:
    - I=14.0 kA; t=0.50 sec (worst case scenario: longest fault current duration: 30 cycles)
    - I=31.3 kA; t=0.10 sec (best case scenario: shortest fault current duration: 10 cycles)
      (fault current: initial temperature=40 C; final temperature=210 C)

- Maximum DC Resistance at 20 deg C: R dc=0.7945 Ohm/mile
- Outer Layer of Wire Lay Direction: Left
- Fiber Type: G.655C: fiber attenuation limits: 0.22 dB/km @ 1550 nm; 0.25 dB/km @ 1625 nm.
- Fiber Count: Minimum: 12; Maximum 48
- PLS-CADD .wir file: polynomial coefficients from SAG10 chart 1-1427

Algorithm To Establish Calculated Lightning Charge Levels at Customer Location:

This spreadsheet to be used ONLY when customer DID NOT provide lightning charge level in his technical specifications, and that lightning charge level must be established at customer location.

Line Geometry Input:

1. Tower Height: h_t **42** [m] **Note**: **"h_t" should be provided by customer.**

ONLY if the customer does not know the tower height: h t , it can be assumed:

for Distribution Lines, 0 kV < V <= 69 kV:	h_t =	25	[m]
for Transmission Lines, 69 kV < V <= 115 kV:	h_t =	30	[m]
for Transmission Lines, 115 kV < V <= 230 kV:	h_t =	35	[m]
for Transmission Lines, 230 kV < V <= 345 kV:	h_t =	40	[m]
for Transmission Lines, 345 kV < V <= 1000 kV:	h_t =	45	[m]

2. Number of Groundwires: N_{GW} **2** [-] **Note**: **"N_{GW}" should be provided by customer.**

3. Groundwires Spacing: b **8.8** [m] **Note**: **"b" should be provided by customer.**
if 2 groundwires: N_{GW} = 2, then "b" has a value
if 1 groundwire: N_{GW} = 1, then "b" = 0

ONLY if the customer does not know the spacing between the 2 groundwires: b, it can be assumed:

for Distribution Lines, 0 kV < V <= 69 kV:	b =	2	[m]
for Transmission Lines, 69 kV < V <= 115 kV:	b =	3	[m]
for Transmission Lines, 115 kV < V <= 230 kV:	b =	4	[m]
for Transmission Lines, 230 kV < V <= 345 kV:	b =	5	[m]
for Transmission Lines, 345 kV < V <= 1000 kV:	b =	6	[m]

4. Average Span: S **457** [m] **Note**: **"S" should be provided by customer.**

ONLY if the customer does not know the average span: S, of that line, it can be assumed:

for Distribution Lines, 0 kV < V <= 69 kV:	S =	100	[m]
for Transmission Lines, 69 kV < V <= 115 kV:	S =	225	[m]
for Transmission Lines, 115 kV < V <= 230 kV:	S =	275	[m]
for Transmission Lines, 230 kV < V <= 345 kV:	S =	300	[m]
for Transmission Lines, 345 kV < V <= 1000 kV:	S =	325	[m]

5. Line Length: L **30** [km] **Note**: **"L" should be provided by customer.**

Meteorological Input:

1. Ground Flash Density: N_g 1.15 **[strokes/km^2/year] (also called : GFD) ; GFDline=GFD^0.078=6^0.078=1.15**

Notes:
1. For USA: use the GFD map from spreadsheets: "Vidalia" **OR "USA GFD Map- Global Atmospherics" (this one is more detailed)**
2. For Canada: use the GFD map from spreadsheet "**Canada GFD Map-CEA"**.
3. For South Africa: use the GFD map from spreadsheet "**South Africa GFD Map-CSIR"**.
4. For the rest of the world: use 10% of the total OTD data from the the web site provided in the spreadsheet **"Rest of the World".**

Reason:
OTD data: only 10% are flashes cloud -to- ground (the one you are interested in: GFD)
the rest 90% are flashes cloud-to-cloud or intracloud (you are not interested in these data)

2. Precent Negative Flashes (PNF) in the total number of flashes:

PNF= 0.95 **[probability, absolute value]**

Note: if not known from OTD data, it can be used as default: PNF= 0.95 (95%).

3. Precent Positive Flashes (PPF) in the total number of flashes:

PPF= 0.05 **[probability, absolute value]**

Note: if not known from OTD data, it can be used as default: PNF= 0.05 (5%).

Probability Input:

Exposure Interval: **Y** 30 **[years]**

Important Check: $Y \cdot L \cdot N_g$ **1035 [strokes/km]** **O.K.**

Note: The product: "Y*L*Ng" MUST be MAXIMUM 4000 [strokes/km]

Reason for the product "Y*L*Ng" limitation: for long lines cases, to avoid level of charges too high, resulting in OPGW design cost prohibitive.

Calculations (Output Data):

1. **Total Number of Flashes to the Line: N_{Line} :**

Ericsson's formula: $N_{Line} = 0.10 \cdot N_g \cdot \left(28 \cdot h_t^{0.6} + b\right)$ **[strikes/100 km/year]**

where: R $R_a = 14 \cdot h_t^{0.6}$ **$_a$ = attractive radius [m]**

$N_{Line} =$ **31** **[strikes/100 km/year]**

2. **Total Number of Flashes to the Tower: N $_{tower}$:**

IEEE proposed formula: $N_{tower} = \frac{b}{S} \cdot N_{Line}$ **[strikes/100 km/year]**

$N_{tower} =$ **0** **[strikes/100 km/year]**

3. **Total Number of Flashes to the OPGW: N $_{OPGW}$:**

IEEE proposed formula: $N_{OPGW} = \frac{N_{Line} - N_{tower}}{N_{GW}}$ **[strikes/100 km/year]**

$N_{OPGW} =$ **15** **[strikes/100 km/year]**

4. **Basic Probability Level for stroke current, rate of rise and total flash charge:** **P:**

IEEE proposed formula: $P = \frac{100}{Y \cdot L \cdot N_{OPGW}}$ **[probability, absolute value]**

$P =$ **0.0074** **[probability, absolute value]**

0.74 **[probability,precent]**

5. Probability Design Level for Negative First Stroke Flashes: P_{first}^{neg}

IEEE proposed formula: $P_{first}^{neg} = \frac{P}{PNF}$ **[probability, absolute value]**

$P_{first}^{neg} =$ **0.0078** **[probability, absolute value]**

0.78 **[probability, precent]**

6. Corresponding Number of Negative Flashes to this Probability Design Level: **NNF:**

IEEE proposed formula: $NNF = \frac{1}{P_{first}^{neg}}$ **128** **[negative flashes]**

5. Probability Design Level for Positive First Stroke Flashes: P_{first}^{pos}

IEEE proposed formula: $P_{first}^{pos} = \frac{P}{PPF}$ **[probability, absolute value]**

$P_{first}^{pos} =$ **0.1481** **[probability, absolute value]**

14.81 **[probability, precent]**

6. Corresponding Number of Positive Flashes to this Probability Design Level: **NPF:**

IEEE proposed formula: $NPF = \frac{1}{P_{first}^{pos}}$ **7** **[positive flashes]**

7. Negative First Stroke Peak Amplitude: $I_{first}^{neg\,*}$

probabilistic function: **log normal:**

IEEE formula: $P_{(I > I^*)} = \frac{1}{1 + \left(\frac{I^*}{31}\right)^{2.6}}$ **where:** $I_m = 31 \quad [kA]$ **median current for negative first stroke**

$$I_{first}^{neg*} = 31 \cdot \left(\left(P_{first}^{neg}\right)^{-1} - 1\right)^{\frac{1}{2.6}}$$ [kA]

$I_{first}^{neg\,*} =$ **200** [kA]

8. Positive First Stroke Peak Amplitude: $I_{first}^{pos}\,{}^{*}$

probabilistic function: **log normal:**

IEEE formula: $P_{(I>I^{*})} = \dfrac{1}{1+\left(\dfrac{I^{*}}{31}\right)^{2.6}}$ **where:** $I_m = 31 \quad [kA]$ **median current for positive first stroke**

$$I_{first}^{pos*} = 31\cdot\left(\left(P_{first}^{pos}\right)^{-1}-1\right)^{\frac{1}{2.6}}$$ [kA]

$I_{first}^{pos\,*} =$ **61** [kA]

9. Negative Subsequent Strokes Probability: P_{subs}^{neg}

Typically: 2 subsequent strokes for every first stroke:

IEEE formula: $P_{subs}^{neg} = \dfrac{P_{first}^{neg}}{2}$ **[probability, absolute value]**

$P_{subs}^{neg} =$ **0.0039** **[probability, absolute value]**

0.39 **[probability, precent]**

10. Negative Subsequent Strokes Peak Amplitude: $I_{subs}^{neg}\,{}^{*}$

IEEE formula:

$P_{(I>I^{*})} = \dfrac{1}{1+\left(\dfrac{I^{*}}{12}\right)^{2.7}}$ **where:** $I_m = 12 \quad [kA]$ **median current for negative subsequent strokes**

$$I_{subs}^{neg*} = 12\cdot\left(\left(P_{subs}^{neg}\right)^{-1}-1\right)^{\frac{1}{2.7}}$$ [kA]

$I_{subs}^{neg\,*} =$ **93** [kA]

11. Positive Subsequent Strokes Probability: P_{subs}^{pos}

Typically: 2 subsequent strokes for every first stroke:

IEEE formula: $$P_{subs}^{pos} = \frac{P_{first}^{pos}}{2}$$ **[probability, absolute value]**

$P_{subs}^{pos} =$ **0.0741** **[probability, absolute value]**

7.41 **[probability, precent]**

12. Positive Subsequent Strokes Peak Amplitude: $I_{subs}^{pos\,*}$

IEEE formula:

$$P_{(I>I^*)} = \frac{1}{1+\left(\frac{I^*}{12}\right)^{2.7}}$$

where: $I_m = 12 \quad [kA]$ **median current for for positive subsequent strokes**

$$I_{subs}^{pos*} = 12 \cdot \left(\left(P_{subs}^{pos}\right)^{-1} - 1\right)^{\frac{1}{2.7}}$$ [kA]

$I_{subs}^{pos\,*} =$ **31** [kA]

13. Negative Flash Total Charge: $Q_{negative}$

probabilistic function: log-normal:

Berger's curve for negative flashes:

$$P_{(Qnegative)} = \frac{1}{1+\left(\frac{Q_{negative}}{7}\right)^{1.7}}$$

where: $Q_{negative\ med} = 7 \quad [C]$ **median charge value for negative flashes in Berger's curve**

$$Q_{negative} = 7 \cdot \left(\left(P_{first}^{neg}\right)^{-1} - 1\right)^{\frac{1}{1.7}}$$

$Q_{negative} =$ **121** [C]

14. Positive Flash Total Charge: $Q_{positive}$

probabilistic function: log-normal:

Berger's curve for positive flashes:

$$P_{(Q_{positive})} = \frac{1}{1 + \left(\frac{Q_{positive}}{85}\right)^{2.0}}$$

where: $Q_{positive\ \ med} = 85\ [C]$ **median charge value for positive flashes in Berger's curve**

$$Q_{positive} = 85 \cdot \left(\left(P_{first}^{pos}\right)^{-1} - 1\right)^{\frac{1}{2.0}}$$

$Q_{positive} =$ **204** [C]

Note: **Qpositive<2*Qnegative, TEST WILL BE DONE ONLY FOR Qnegative**

Theoretical Requirements:

Total Negative Charge:

$Qnegative$ 121 [C]

First Stroke:

Peak Amplitude: $I^{neg*}_{first} =$ 200 [kA] **Rise Time:** $t_r =$ 1.2 [μsec] **Pulse Duration:** **(Time to a half of the Amplitude)** $t_d =$ 50 [μsec]

2 Subsequent Strokes:

Peak Amplitude: $I^{neg*}_{subs} =$ 93 [kA] **Rise Time:** $t_r =$ 0.1 [μsec] **Pulse Duration:** **(Time to a half of the Amplitude)** $t_d =$ 10 [μsec]

Note:
Between first stroke and the 2 subsequent strokes, there could be any combination of intermediate current component "B" and continuing current component "C", as long as the total charge remains:

$Q_{negative} =$ 121 [C]

Test Variables:

Total Negative Charge: $Q_{negative} =$ 121 [C]

If Test done ONLY with the intermediate component "B" and the continuing component "C":

intermediate component "B":			continuous component "C":		
charge:	$Q_B =$	10 [C]	charge:	$Q_C =$	111 [C]
mean current:	$I_{B\,mean} =$	2000 [A]	current:	$I_C =$	250 [A]
time:	$t_B =$	0.005 [sec]	time:	$t =$	0.444 [sec]

Theoretical Requirements:

Total Positive Charge:

$Q_{positive} =$ **204** [C]

First Stroke:

Peak Amplitude: $I^{pos*}_{first} =$ **61** [kA]

Rise Time: $t_r =$ **1.2** [μsec]

Pulse Duration: (Time to a half of the Amplitude) $t_d =$ **50** [μsec]

2 Subsequent Strokes:

Peak Amplitude: $I^{pos*}_{subs} =$ **31** [kA]

Rise Time: $t_r =$ **0.1** [μsec]

Pulse Duration: (Time to a half of the Amplitude) $t_d =$ **10** [μsec]

Note:
Between first stroke and the 2 subsequent strokes, there could be any combination of intermediate current component "B" and continuing current component "C", as long as the total charge remains:

$Q_{positive} =$ **204** [C]

Test Variables:

Total Positive Charge: $Q_{positive} =$ **204** [C]

If Test done ONLY with the intermediate component "B" and the continuing component "C":

intermediate component "B":			continuous component "C":		
charge:	$Q_B =$	10 [C]	charge:	$Q_C =$	194 [C]
mean current:	$I_{B\ mean} =$	2000 [A]	current:	$I_C =$	250 [A]
time:	$t_B =$	0.005 [sec]	time:	$t =$	0.775 [sec]

Wire Type: AW20.3% (all wires) **Tensile Strength: TS:** 195 [kpsi] **Conductivity: λ:** 20.3 [%]

Gap: 5 [cm] **Tolerance:** + / - 1 cm

Input below Total Charge from Customer Technical Specifications.

If is not provided, please follow the algorithm from spreadsheet "Calculated Charge" to determine the total charge at customer location, and then input below.

Note: only if positive charge is twice as large as the negative charge, there will be a test also for the positive charge, and you input the positive charge below.

Otherwise, positive charge does not matter.

Remnant Strength: 75 [%] RBS

Negative polarity: Q 121 [C] **Positive polarity: Q** 242 [C]

Wire Diameter: D 3.12 [mm] **Wire Diameter: D** 3.12 [mm]

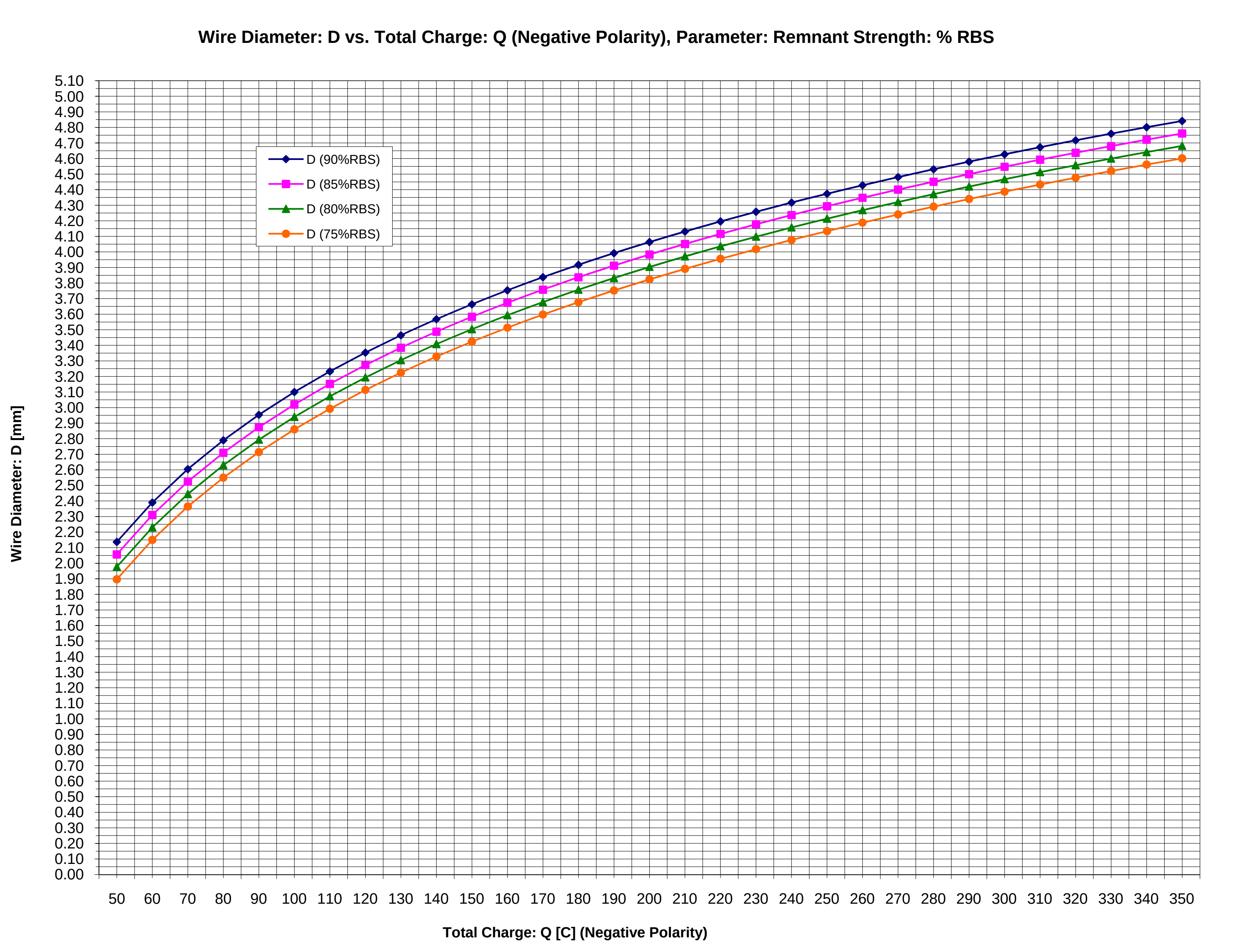
RBS= Rated Breaking Strength of the cable, NOT of the individual wire

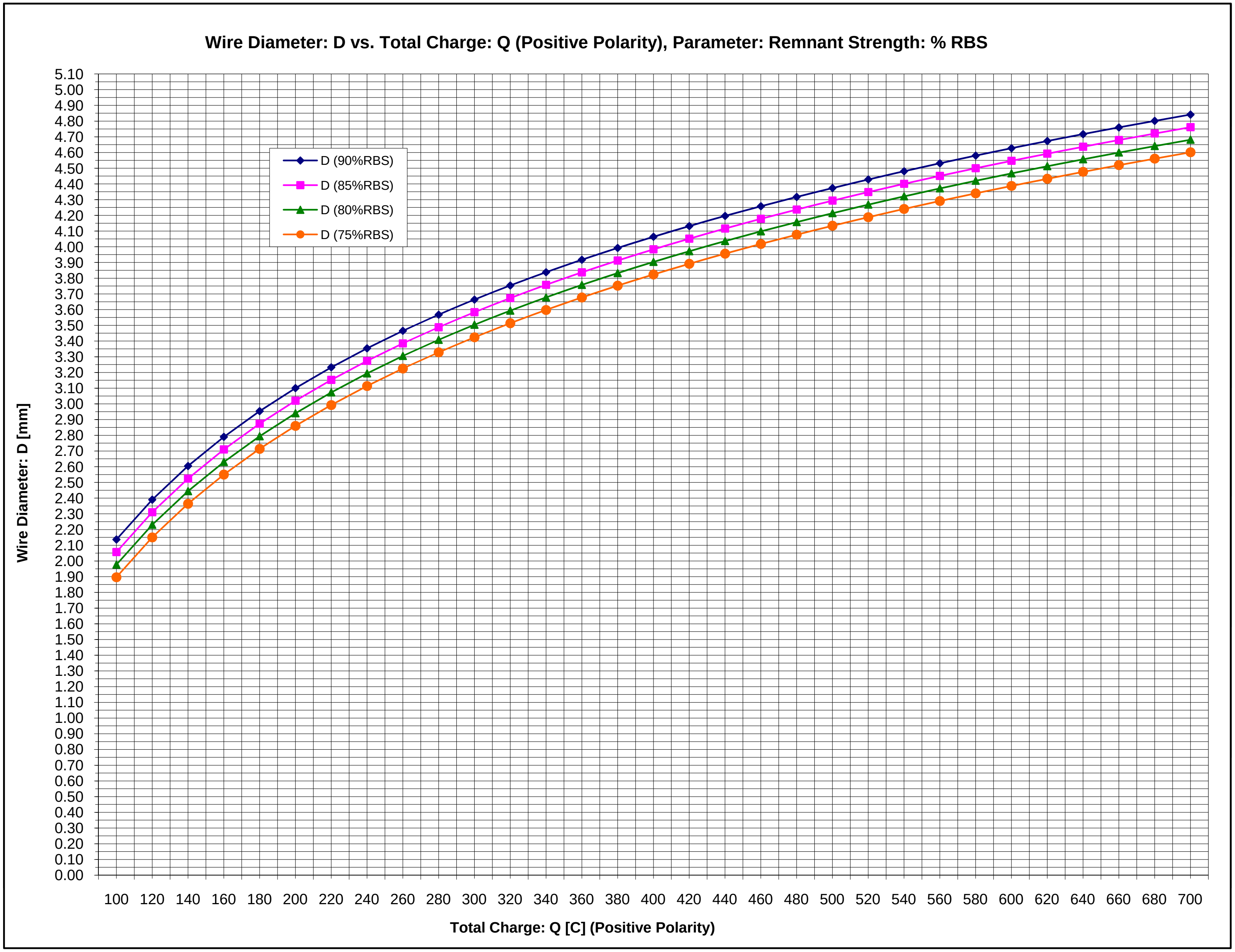
Negative Polarity:

Q [C]	D (90%RBS) [mm]	D (85%RBS) [mm]	D (80%RBS) [mm]	D (75%RBS) [mm]
50	2.14	2.06	1.98	1.90
60	2.39	2.31	2.23	2.15
70	2.60	2.52	2.44	2.36
80	2.79	2.71	2.63	2.55
90	2.95	2.87	2.79	2.71
100	3.10	3.02	2.94	2.86
110	3.23	3.15	3.07	2.99
120	3.35	3.27	3.19	3.11
130	3.46	3.38	3.30	3.22
140	3.57	3.49	3.41	3.33
150	3.66	3.58	3.50	3.42
160	3.75	3.67	3.59	3.51
170	3.84	3.76	3.68	3.60
180	3.92	3.84	3.76	3.68
190	3.99	3.91	3.83	3.75
200	4.06	3.98	3.90	3.82
210	4.13	4.05	3.97	3.89
220	4.20	4.12	4.04	3.96
230	4.26	4.18	4.10	4.02
240	4.32	4.24	4.16	4.08
250	4.37	4.29	4.21	4.13
260	4.43	4.35	4.27	4.19
270	4.48	4.40	4.32	4.24
280	4.53	4.45	4.37	4.29
290	4.58	4.50	4.42	4.34
300	4.63	4.55	4.47	4.39
310	4.67	4.59	4.51	4.43
320	4.72	4.64	4.56	4.48
330	4.76	4.68	4.60	4.52
340	4.80	4.72	4.64	4.56
350	4.84	4.76	4.68	4.60

Positive Polarity:

Q [C]	D (90%RBS) [mm]	D (85%RBS) [mm]	D (80%RBS) [mm]	D (75%RBS) [mm]
100	2.14	2.06	1.98	1.90
120	2.39	2.31	2.23	2.15
140	2.60	2.52	2.44	2.36
160	2.79	2.71	2.63	2.55
180	2.95	2.87	2.79	2.71
200	3.10	3.02	2.94	2.86
220	3.23	3.15	3.07	2.99
240	3.35	3.27	3.19	3.11
260	3.46	3.38	3.30	3.22
280	3.57	3.49	3.41	3.33
300	3.66	3.58	3.50	3.42
320	3.75	3.67	3.59	3.51
340	3.84	3.76	3.68	3.60
360	3.92	3.84	3.76	3.68
380	3.99	3.91	3.83	3.75
400	4.06	3.98	3.90	3.82
420	4.13	4.05	3.97	3.89
440	4.20	4.12	4.04	3.96
460	4.26	4.18	4.10	4.02
480	4.32	4.24	4.16	4.08
500	4.37	4.29	4.21	4.13
520	4.43	4.35	4.27	4.19
540	4.48	4.40	4.32	4.24
560	4.53	4.45	4.37	4.29
580	4.58	4.50	4.42	4.34
600	4.63	4.55	4.47	4.39
620	4.67	4.59	4.51	4.43
640	4.72	4.64	4.56	4.48
660	4.76	4.68	4.60	4.52
680	4.80	4.72	4.64	4.56
700	4.84	4.76	4.68	4.60


Wire Diameter: D vs. Total Charge: Q (Negative Polarity), Parameter: Remnant Strength: % RBS
D (90%RBS)
D (85%RBS)
D (80%RBS)
D (75%RBS)
Wire Diameter: D [mm]
5.10
5.00
4.90
4.80
4.70
4.60
4.50
4.40
4.30
4.20
4.10
4.00
3.90
3.80
3.70
3.60
3.50
3.40
3.30
3.20
3.10
3.00
2.90
2.80
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350
Total Charge: Q [C] (Negative Polarity)


Wire Diameter: D vs. Total Charge: Q (Positive Polarity), Parameter: Remnant Strength: % RBS
Wire Diameter: D [mm]
Total Charge: Q [C] (Positive Polarity)
D (90%RBS)
D (85%RBS)
D (80%RBS)
D (75%RBS)

Formulas:

RBS= Rated Breaking Strength of the cable, NOT of the individual wire

Negative Polarity:

For Remanent Strength=90% RBS:

$$D = 0.144702564\frac{TS}{\lambda}\cdot\ln\left(0.001041026\frac{TS}{\lambda}\cdot Q\right)+3.10$$

$$D = 1.39\ln(0.01\cdot Q)+3.10$$

For Remanent Strength=85% RBS:

$$D = 0.144702564\frac{TS}{\lambda}\cdot\ln\left(0.001041026\frac{TS}{\lambda}\cdot Q\right)+3.02$$

$$D = 1.39\ln(0.01\cdot Q)+3.02$$

For Remanent Strength=80% RBS:

$$D = 0.144702564\frac{TS}{\lambda}\cdot\ln\left(0.001041026\frac{TS}{\lambda}\cdot Q\right)+2.94$$

$$D = 1.39\ln(0.01\cdot Q)+2.94$$

For Remanent Strength=75% RBS:

$$D = 0.144702564\frac{TS}{\lambda}\cdot\ln\left(0.001041026\frac{TS}{\lambda}\cdot Q\right)+2.86$$

$$D = 1.39\ln(0.01\cdot Q)+2.86$$

Positive Polarity:

For Remanent Strength=90% RBS:

$$D = 0.144702564\frac{TS}{\lambda}\cdot\ln\left(0.001041026\frac{TS}{\lambda}\cdot Q/2\right)+3.10$$

$$D = 1.39\ln(0.01\cdot Q/2)+3.10$$

For Remanent Strength=85% RBS:

$$D = 0.144702564\frac{TS}{\lambda}\cdot\ln\left(0.001041026\frac{TS}{\lambda}\cdot Q/2\right)+3.02$$

$$D = 1.39\ln(0.01\cdot Q/2)+3.02$$

For Remanent Strength=80% RBS:

$$D = 0.144702564\frac{TS}{\lambda}\cdot\ln\left(0.001041026\frac{TS}{\lambda}\cdot Q/2\right)+2.94$$

$$D = 1.39\ln(0.01\cdot Q/2)+2.94$$

For Remanent Strength=75% RBS:

$$D = 0.144702564\frac{TS}{\lambda}\cdot\ln\left(0.001041026\frac{TS}{\lambda}\cdot Q/2\right)+2.86$$

$$D = 1.39\ln(0.01\cdot Q/2)+2.86$$

		4
1	90	
2	85	
3	80	
4	75	

PLS-CADD Version 10.64x64   3:38:35 PM Friday, November 19, 2010
Power Engineers
Project Name: 'r:\pls\pls_cadd\projects\119990 clean line\clean line_span comparison_bluebird_1500 ft.LOA'

Criteria notes:
Clean Line Structure Load Trees
NESC Heavy Common Point
HS=VS=1500ft
0° Final After Load @25% Controls (Conductor)
0° Final After Creep @15% Controls OPGW

Section #6 '3:1:Ahead'
Cable 'r:\pls\pls_cadd\projects\119990 clean line\cables\bluebird_acsr.wir', Ruling span (ft) 1500
Sagging data: Catenary (ft) 5542.19, Horiz. Tension (lbs) 13916.4 Condition I Temperature (deg F) 60.0001
Note: Temperature and condition above are program supplied defaults used for automatic sagging.
Weather case for final after creep 60, Equivalent to 78.9 (deg F) temperature increase
Weather case for final after load NESC Heavy-Rule 250B, Equivalent to 24.1 (deg F) temperature increase

Ruling Span Sag Tension Report

Weather Case		Cable Load			R.S. Initial Cond.					R.S. Final Cond. After Creep					R.S. Final Cond. After Load				
#	Description	Hor. Load (lbs/ft)	Vert Load (lbs/ft)	Res. Load (lbs/ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)
1	NESC Heavy-Rule 250B	0.92	3.92	4.32	23767	23344	39	5399	52.18	22085	21630	37	5002	56.33	23767	23344	39	5399	52.18
2	NESC Rule 250D	1.46	7.19	7.34	34530	33551	57	4572	61.66	33973	32977	56	4494	62.74	34530	33551	57	4572	61.66
3	32deg, .5", 0psf	0.00	3.92	3.92	21258	20796	35	5309	53.07	19576	19074	32	4869	57.88	21010	20542	35	5244	53.73
4	60deg, 0", 97mph	3.57	2.51	4.36	22217	21874	37	5013	56.20	20618	20248	34	4641	60.74	22010	21664	37	4965	56.75
5	60deg, 0", 157mph	9.27	2.51	9.60	39677	38961	66	4059	69.49	39677	38961	66	4059	69.49	39677	38961	66	4059	69.49
6	60deg, 0", 12.2 psf	1.79	2.51	3.08	16823	16530	28	5359	52.57	15232	14907	25	4833	58.31	16367	16065	27	5208	54.09
7	0deg, 0", 4psf	0.59	2.51	2.58	15940	15681	26	6081	46.31	14117	13825	23	5361	52.55	15414	15147	26	5874	47.95
8	60deg, 0", 6psf	0.88	2.51	2.66	14901	14616	25	5493	51.28	13370	13051	22	4905	57.46	14402	14107	24	5301	53.14
9	0	0.00	2.51	2.51	15607	15349	26	6113	46.07	13795	13503	23	5378	52.39	15073	14806	25	5896	47.76
10	32	0.00	2.51	2.51	14815	14544	25	5792	48.63	13179	12872	22	5126	54.96	14295	14013	24	5580	50.47
11	60	0.00	2.51	2.51	14200	13916	24	5542	50.83	12700	12382	21	4931	57.15	13694	13399	23	5336	52.79
12	90	0.00	2.51	2.51	13605	13309	23	5300	53.15	12236	11905	20	4741	59.45	13126	12819	22	5105	55.19
13	120	0.00	2.51	2.51	13076	12767	22	5084	55.42	11817	11474	20	4570	61.69	12621	12300	21	4899	57.53
14	148	0.00	2.51	2.51	12625	12305	21	4900	57.51	11461	11107	19	4423	63.73	12194	11862	20	4724	59.66
15	160	0.00	2.51	2.51	12446	12121	21	4827	58.38	11319	10960	19	4365	64.59	12024	11688	20	4655	60.55
16	284	0.00	2.51	2.51	10929	10558	18	4205	67.07	10110	9707	17	3866	72.98	10598	10214	18	4068	69.34

PLS-CADD Version 10.60   11:52:49 AM Tuesday, October 05, 2010
Power Engineers
Project Name: 'r:\pls\pls_cadd\projects\119990 clean line\clean line str. analysis_bluebird_sag.LOA'

Criteria notes:
  Clean Line Structure Load Trees
  NESC Heavy Common Point
  HS=VS=1500ft
  0° Final After Load @25% Controls (Cond.)
  0° Final After Creep @15% Controls (opgw)

Section #1 '1:1:Back'
Cable 'r:\pls\pls_cadd\projects\119990 clean line\cables\49ay85acs-2c 1-1427.wir', Ruling span (ft) 1500
Sagging data: Catenary (ft) 7672.59, Horiz. Tension (lbs) 3629.14 Condition I Temperature (deg F) 60.0001
Note: Temperature and condition above are program supplied defaults used for automatic sagging.
Weather case for final after creep 60, Equivalent to 37.8 (deg F) temperature increase
Weather case for final after load NESC Heavy-Rule 250B, Equivalent to 46.6 (deg F) temperature increase

Ruling Span Sag Tension Report

------Weather Case-----		--Cable Load--			-----R.S. Initial Cond.----					------R.S. Final Cond.----- --------After Creep--------					------R.S. Final Cond.----- ---------After Load--------				
#	Description	Hor. -----Load----- ---(lbs/ft)---	Vert	Res.	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)
1	NESC Heavy-Rule 250B	0.53	1.15	1.57	8826	8774	35	5597	50.32	8826	8774	35	5597	50.32	8826	8774	35	5597	50.32
2	NESC Rule 250D	1.06	3.33	3.50	14652	14415	58	4121	68.44	14652	14415	58	4121	68.44	14652	14415	58	4121	68.44
3	32deg, .5", 0psf	0.00	1.15	1.15	7020	6967	28	6051	46.54	6935	6881	27	5977	47.12	6871	6817	27	5921	47.57
4	60deg, 0", 97mph	1.20	0.47	1.29	7366	7302	29	5674	49.64	7310	7246	29	5631	50.02	7248	7184	29	5582	50.46
5	60deg, 0", 12.2 psf	0.60	0.47	0.76	5133	5101	20	6671	42.21	4946	4912	19	6424	43.83	4889	4856	19	6350	44.34
6	0deg, 0", 4psf	0.20	0.47	0.51	4305	4288	17	8368	33.63	4032	4014	16	7833	35.93	3969	3950	16	7710	36.51
7	60deg, 0", 6psf	0.30	0.47	0.56	4105	4083	16	7322	38.45	3878	3855	15	6913	40.73	3826	3803	15	6819	41.29
8	0	0.00	0.47	0.47	4089	4074	16	8613	32.67	3804	3788	15	8008	35.15	3743	3726	15	7877	35.73
9	32	0.00	0.47	0.47	3839	3823	15	8082	34.82	3581	3563	14	7533	37.36	3526	3508	14	7417	37.95
10	60	0.00	0.47	0.47	3646	3629	14	7673	36.69	3408	3389	13	7165	39.29	3358	3339	13	7060	39.88
11	90	0.00	0.47	0.47	3460	3442	14	7277	38.68	3243	3224	13	6816	41.31	3199	3179	13	6722	41.89
12	120	0.00	0.47	0.47	3295	3276	13	6926	40.65	3096	3076	12	6503	43.30	3057	3037	12	6420	43.86
13	284	0.00	0.47	0.47	2646	2622	10	5544	50.81	2522	2497	10	5278	53.38	2499	2474	10	5231	53.86

PLS-CADD Version 10.64x64   3:03:14 PM Friday, December 10, 2010
Power Engineers
Project Name: 'r:\pls\pls_cadd\projects\119990 clean line\clean line_river crossing=4000 ft-accr_tw cumberland.LOA'

Criteria notes:
River Crossing Span=4000 ft
0 deg F Final @25% Controls (Conductor ACCR/TW Cumberland)

Section #1 '1:Back'
Cable 'r:\pls\pls_cadd\projects\119990 clean line\cables\cumberland_accr_tw_dc.wir', Ruling span (ft) 4000
Sagging data: Catenary (ft) 7437.05, Horiz. Tension (lbs) 15655 Condition I Temperature (deg F) 60.0001
Weather case for final after creep 60, Equivalent to 47.3 (deg F) temperature increase
Weather case for final after load NESC Heavy-Rule 250B, Equivalent to 40.3 (deg F) temperature increase

Ruling Span Sag Tension Report

Weather Case		Cable Load (lbs/ft)			R.S. Initial Cond.					R.S. Final Cond. After Creep					R.S. Final Cond. After Load					
#	Description	Hor.	Vert	Res.	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	
1	NESC Heavy-Rule 250B	0.85	3.38	3.78	28649	27607	44	7303	275.57	28579	27534	44	7284	276.30	28649	27607	44	7303	275.57	
2	NESC Rule 250D	1.38	6.45	6.59	47068	45128	72	6845	294.27	47068	45128	72	6845	294.27	47068	45128	72	6845	294.27	
3	32deg, .5", 0psf	0.00	3.38	3.38	25568	24637	39	7299	275.72	25386	24448	39	7243	277.88	25447	24511	39	7262	277.15	
4	60deg, 0", 97mph	3.12	2.11	3.77	28106	27049	43	7180	280.37	27929	26865	43	7131	282.31	27995	26935	43	7149	281.58	
5	60deg, 0", 12.2 psf	1.57	2.11	2.63	20025	19307	31	7354	273.63	19759	19030	30	7249	277.66	19807	19080	30	7268	276.92	
6	0deg, 0", 4psf	0.51	2.11	2.17	16991	16415	26	7575	265.55	16764	16180	26	7467	269.46	16805	16223	26	7487	268.74	
7	60deg, 0", 6psf	0.77	2.11	2.24	17232	16624	26	7415	271.36	16964	16345	26	7291	276.05	17004	16387	26	7309	275.33	
8	0	0.00	2.11	2.11	16528	15970	25	7587	265.15	16300	15733	25	7474	269.19	16341	15776	25	7494	268.45	
9	32	0.00	2.11	2.11	16365	15801	25	7506	268.03	16114	15541	25	7383	272.56	16156	15583	25	7403	271.81	
10	60	0.00	2.11	2.11	16224	15654	25	7437	270.56	15958	15379	24	7306	275.47	15998	15419	24	7325	274.73	
11	90	0.00	2.11	2.11	16077	15502	25	7364	273.25	15795	15208	24	7225	278.59	15832	15247	24	7243	277.88	
12	120	0.00	2.11	2.11	15933	15352	24	7293	275.95	15637	15044	24	7147	281.67	15676	15084	24	7166	280.92	
13	152	0.00	2.11	2.11	15783	15196	24	7219	278.82	15474	14874	24	7066	284.93	15509	14911	24	7084	284.22	MOT-Normal
14	166	0.00	2.11	2.11	15718	15128	24	7187	280.09	15403	14800	24	7031	286.39	15438	14837	24	7048	285.67	MOT-Emergency

PLS-CADD Version 10.64x64   8:42:50 AM Wednesday, December 15, 2010
Power Engineers
Project Name: 'r:\pls\pls_cadd\projects\119990 clean line\clean line_river crossing=4000 ft-opgw 161acs-2c.loa'

Criteria notes:
River Crossing Span=4000 ft
NESC -Rule 250D- Extreme ice with Concurrent Wind-Initial @75% Controls (OPGW)

Section #1 '1:Back'
Cable 'r:\pls\pls_cadd\projects\119990 clean line\cables\mississippi river crossing-conductor selection\brugg_161acs-2c 1-1140.wir', Ruling span (ft) 4000
Sagging data: Catenary (ft) 9262.54, Horiz. Tension (lbs) 6280 Condition I Temperature (deg F) 60.0001
Weather case for final after creep 60, Equivalent to 47.3 (deg F) temperature increase
Weather case for final after load NESC Heavy-Rule 250B, Equivalent to 26.5 (deg F) temperature increase

Ruling Span Sag Tension Report

------Weather Case-----		--Cable Load--			-----R.S. Initial Cond.-----					------R.S. Final Cond.------ ---------After Creep--------					------R.S. Final Cond.------ ---------After Load---------					
#	Description	Hor. -----Load----- ---(lbs/ft)---	Vert	Res.	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	Max. Tens. (lbs)	Hori. Tens. (lbs)	Max Ten %UL	C (ft)	R.S. Sag (ft)	
1	NESC Heavy-Rule 250B	0.55	1.39	1.79	15580	15153	41	8442	238.01	15480	15050	41	8385	239.66	15580	15153	41	8442	238.01	
2	NESC Rule 250D	1.07	3.63	3.78	28550	27504	75	7274	276.70	28550	27504	75	7274	276.70	28550	27504	75	7274	276.70	
3	32deg, .5", 0psf	0.00	1.39	1.39	12384	12062	33	8674	231.59	12248	11922	32	8574	234.34	12333	12010	32	8637	232.61	
4	60deg, 0", 97mph	1.31	0.68	1.47	12905	12558	34	8523	235.74	12775	12424	34	8432	238.31	12860	12511	34	8492	236.62	
5	60deg, 0", 12.2 psf	0.66	0.68	0.94	8694	8483	23	8987	223.47	8556	8341	22	8837	227.29	8621	8409	23	8908	225.46	
6	0deg, 0", 4psf	0.22	0.68	0.71	6887	6736	18	9469	211.99	6754	6600	18	9278	216.41	6812	6659	18	9361	214.46	
7	60deg, 0", 6psf	0.32	0.68	0.75	7062	6897	19	9184	218.63	6934	6766	18	9010	222.90	6990	6824	18	9086	221.01	
8	0	0.00	0.68	0.68	6591	6448	17	9510	211.08	6460	6314	17	9313	215.59	6516	6371	17	9397	213.63	
9	32	0.00	0.68	0.68	6502	6357	17	9376	214.13	6376	6228	17	9186	218.59	6430	6283	17	9268	216.64	
10	60	0.00	0.68	0.68	6427	6280	17	9262	216.77	6305	6155	17	9078	221.20	6357	6209	17	9157	219.27	
11	90	0.00	0.68	0.68	6350	6201	17	9146	219.55	6232	6080	16	8968	223.95	6282	6132	16	9044	222.05	
12	120	0.00	0.68	0.68	6275	6125	16	9033	222.31	6161	6007	16	8860	226.70	6209	6057	16	8933	224.83	MOT-OPGW
13	152	0.00	0.68	0.68	6198	6045	16	8916	225.26	6088	5932	16	8749	229.59	6135	5980	16	8820	227.72	MOT-Normal-Conductor
14	166	0.00	0.68	0.68	6165	6012	16	8867	226.52	6056	5900	16	8702	230.85	6102	5947	16	8772	229.00	MOT-Emergency-Conductor

(OPGW Sag @ 60 F, No Ice , No Wind, Final)/(Conductor ACCR/TW Cumberland Sag @ 60 F, No Ice, No Wind, Final)x100= 221.20/275.47x100=80.3% <=85%, OK

(OPGW Sag @ 32 F, 0.5" Ice, No Wind, Final)/(Conductor ACCR/TW Cumberland Sag @ 32 F, No Ice, No Wind, Final)x100= 234.34/272.56x100=85.9% <=95%, OK

APPENDIX

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PLS-CADD Version 10.64x64    3:16:39 PM Friday, November 19, 2010
Power Engineers
Project Name: 'r:\pls\pls_cadd\projects\119990 clean line\clean line_plains & eastern 600kv dc_segment 3.DON'

IEEE Std. 738-2006 method of calculation
NRMAL REGIME: I pole=3100 A; I conductor=I pole/3=1033.3 A

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -16 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 62 deg. and solar azimuth is -106 deg.)
Conductor latitude is 35.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.762 (in)
Conductor resistance is     0.0423 (Ohm/mile) at  68.0 (deg F)
                    and     0.0499 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is      7.088 (Watt/ft) (corresponds to Global Solar Radiation of   96.549 (Watt/ft^2) - which was
calculated)
Radiation cooling is     4.120 (Watt/ft)
Convective cooling is   12.764 (Watt/ft)

Given a constant ac current of 1033.3 amperes,
The conductor temperature is 148.2 (deg F)=64 (deg C)
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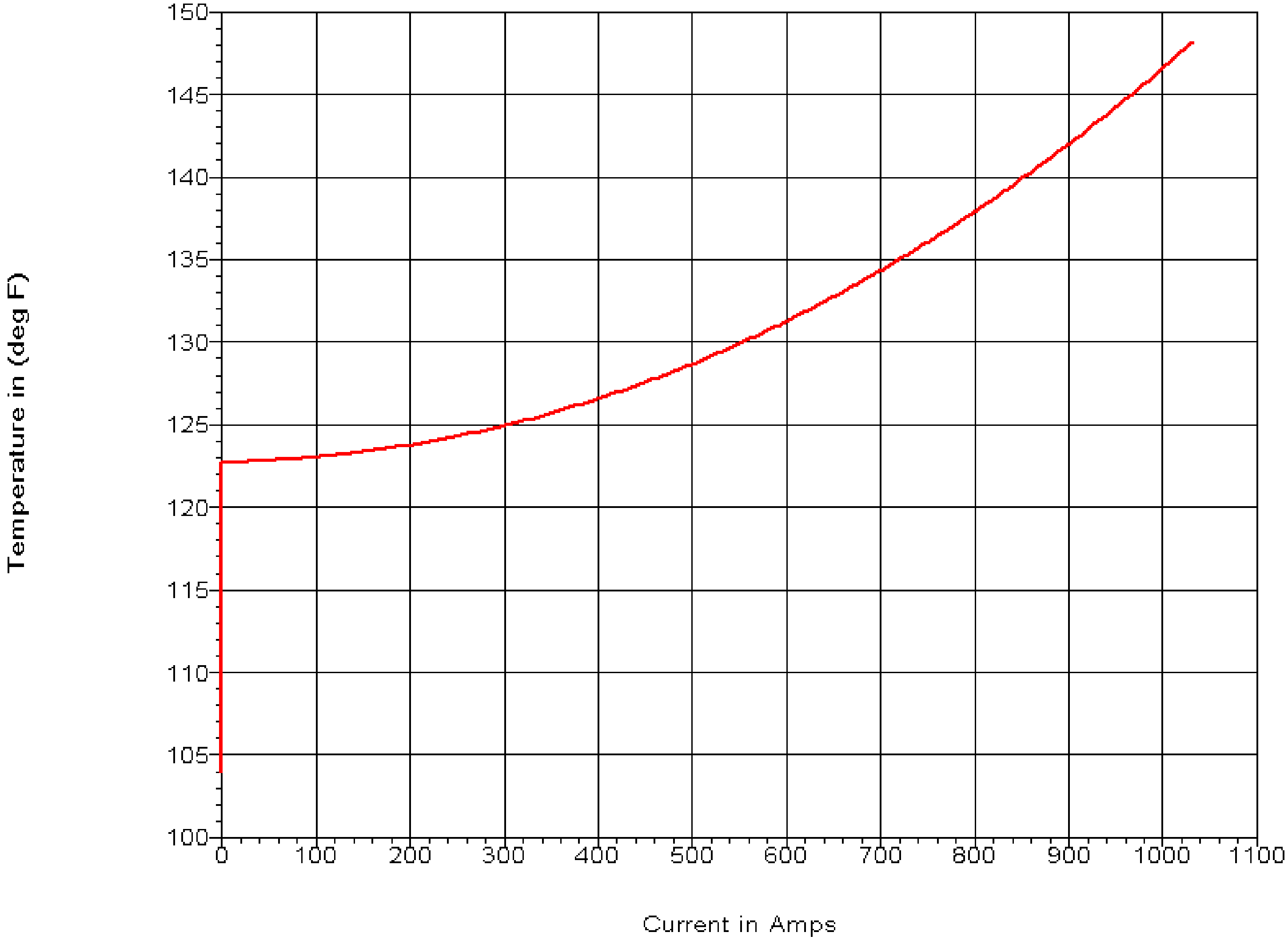


Temperature in (deg F)
150
145
140
135
130
125
120
115
110
105
100
0
100
200
300
400
500
600
700
800
900
1000
1100
Current in Amps

Project Name: 'r:\pls\pls_cadd\projects\119990 clean line\clean line_plains & eastern 600kv dc_segment 3.DON'

IEEE Std. 738-2006 method of calculation

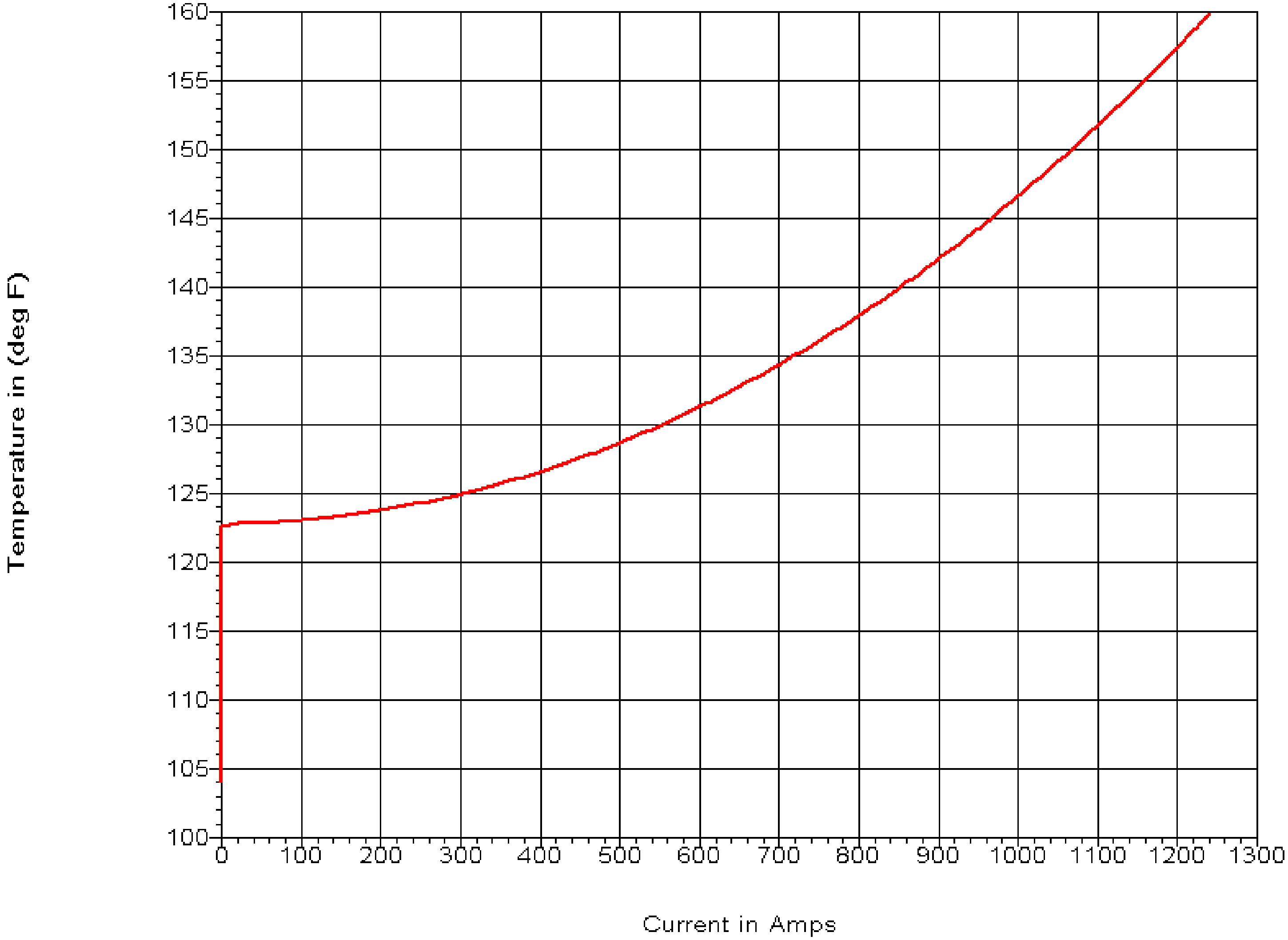
EMERGENCY REGIME: I pole=3720 A; I conductor=I pole/3=1240 A
(20% over Normal Regime: I pole=3100 A; I conductor=I pole/3=1033.3 A)

Air temperature is 104.00 (deg F)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -16 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 62 deg. and solar azimuth is -106 deg.)
Conductor latitude is 35.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.762 (in)
Conductor resistance is   0.0423 (Ohm/mile) at 68.0 (deg F)
                    and   0.0499 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is   7.088 (Watt/ft) (corresponds to Global Solar Radiation of   96.549 (Watt/ft^2) - which was calculated)
Radiation cooling is   5.359 (Watt/ft)
Convective cooling is   16.099 (Watt/ft)

Given a constant ac current of 1240.0 amperes,
The conductor temperature is 159.8 (deg F)=71 (deg C)



160
155
150
145
140
135
130
125
120
115
110
105
100
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Temperature in (deg F)
Current in Amps

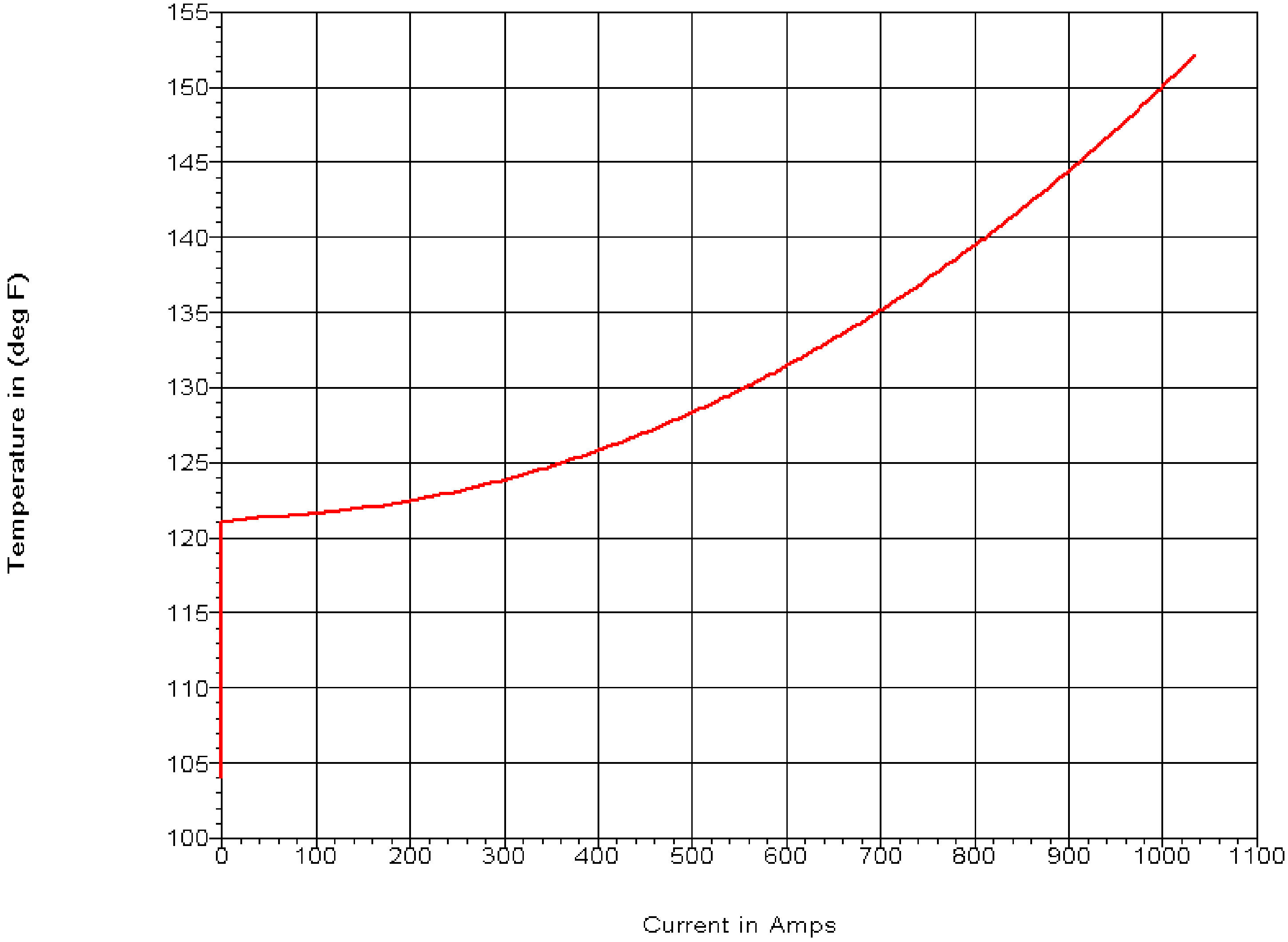
IEEE Std. 738-2006 method of calculation
NORMAL REGIME: I pole=3100 A; I conductor=I pole/3=1033.3 A

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 300 (ft)-at Mississippi River Crossing Span=4000 ft.
Conductor bearing is -16 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 62 deg. and solar azimuth is -106 deg.)
Conductor latitude is 35.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: ACCR-TW_1927-T13 Cumberland
Conductor diameter is 1.543 (in)
Conductor resistance is   0.0461 (Ohm/mile) at 68.0 (deg F)
                    and   0.0560 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is   6.066 (Watt/ft) (corresponds to Global Solar Radiation of   94.350 (Watt/ft^2) - which was calculated)
Radiation cooling is   3.961 (Watt/ft)
Convective cooling is   13.129 (Watt/ft)

Given a constant dc current of 1033.3 amperes,
The conductor temperature is 152.1 (deg F)=67 (deg C)


Temperature in (deg F)
155
150
145
140
135
130
125
120
115
110
105
100
0
100
200
300
400
500
600
700
800
900
1000
1100
Current in Amps

Project Name: 'r:\pls\pls_cadd\projects\119990 clean line\clean line_plains & eastern 600kv dc_segment 7.DON'

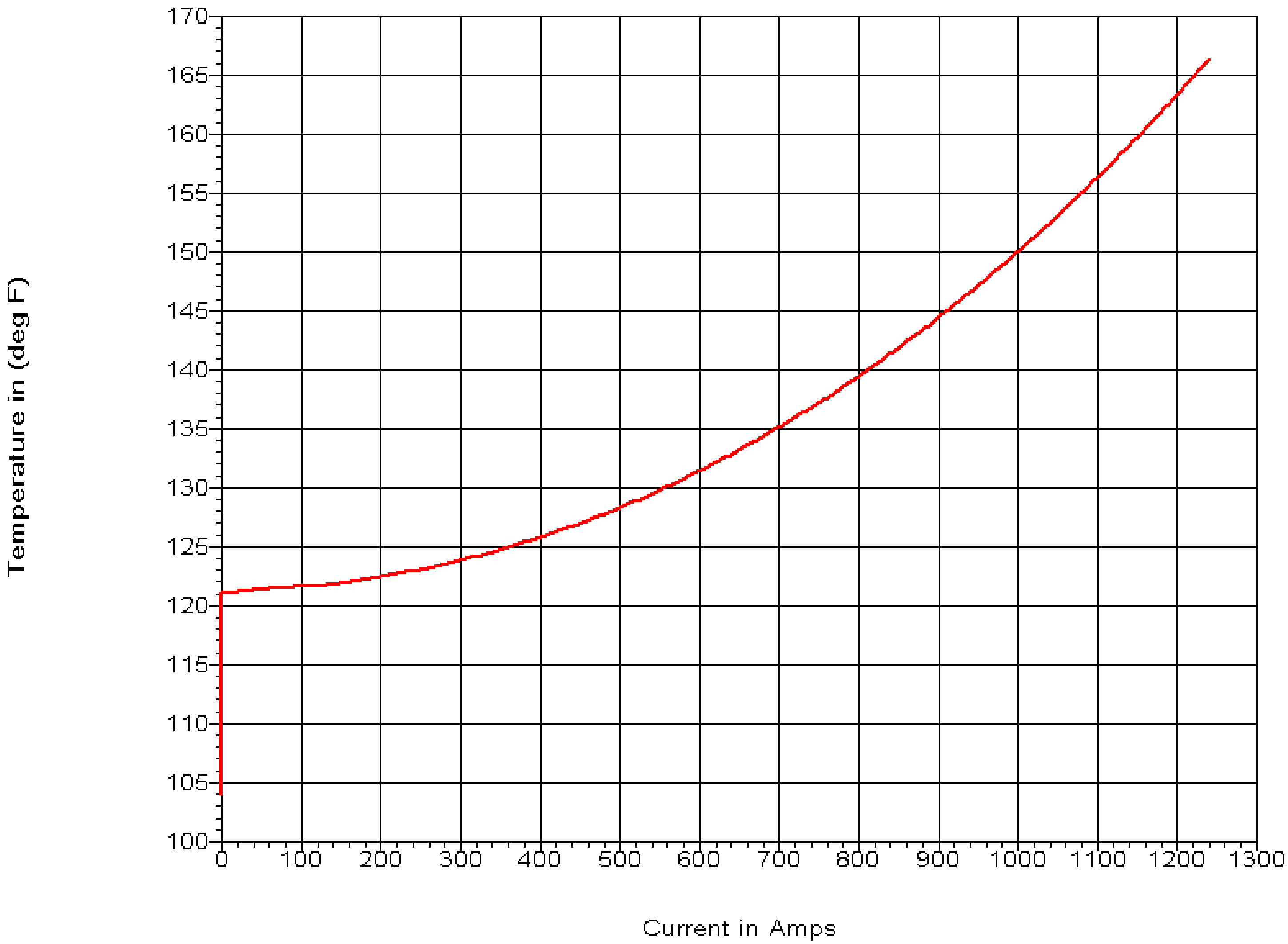
IEEE Std. 738-2006 method of calculation
EMERGENCY REGIME: I pole=3720 A; I conductor=I pole/3=1240 A
(20% over Normal Regime: I pole=3100 A; I condcutor=I pole/3=1033.3 A)

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 300 (ft)
Conductor bearing is -16 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 62 deg. and solar azimuth is -106 deg.)
Conductor latitude is 35.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: ACCR-TW_1927-T13 Cumberland
Conductor diameter is 1.543 (in)
Conductor resistance is   0.0461 (Ohm/mile) at 68.0 (deg F)
                    and   0.0560 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is   6.066 (Watt/ft) (corresponds to Global Solar Radiation of   94.350 (Watt/ft^2) - which was calculated)
Radiation cooling is   5.333 (Watt/ft)
Convective cooling is   17.021 (Watt/ft)

Given a constant dc current of 1240.0 amperes,
The conductor temperature is 166.4 (deg F)=74 (deg C)

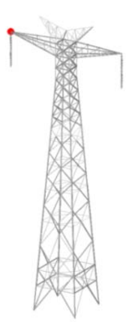

Temperature in (deg F)
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Current in Amps

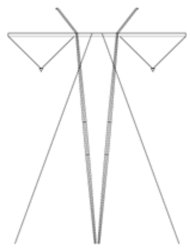
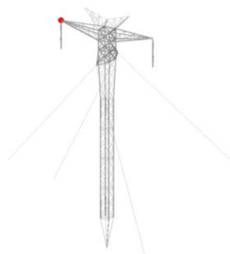
APPENDIX

600 kV DC Line –Clean Line Project # 119990

Horizontal Bipolar Line

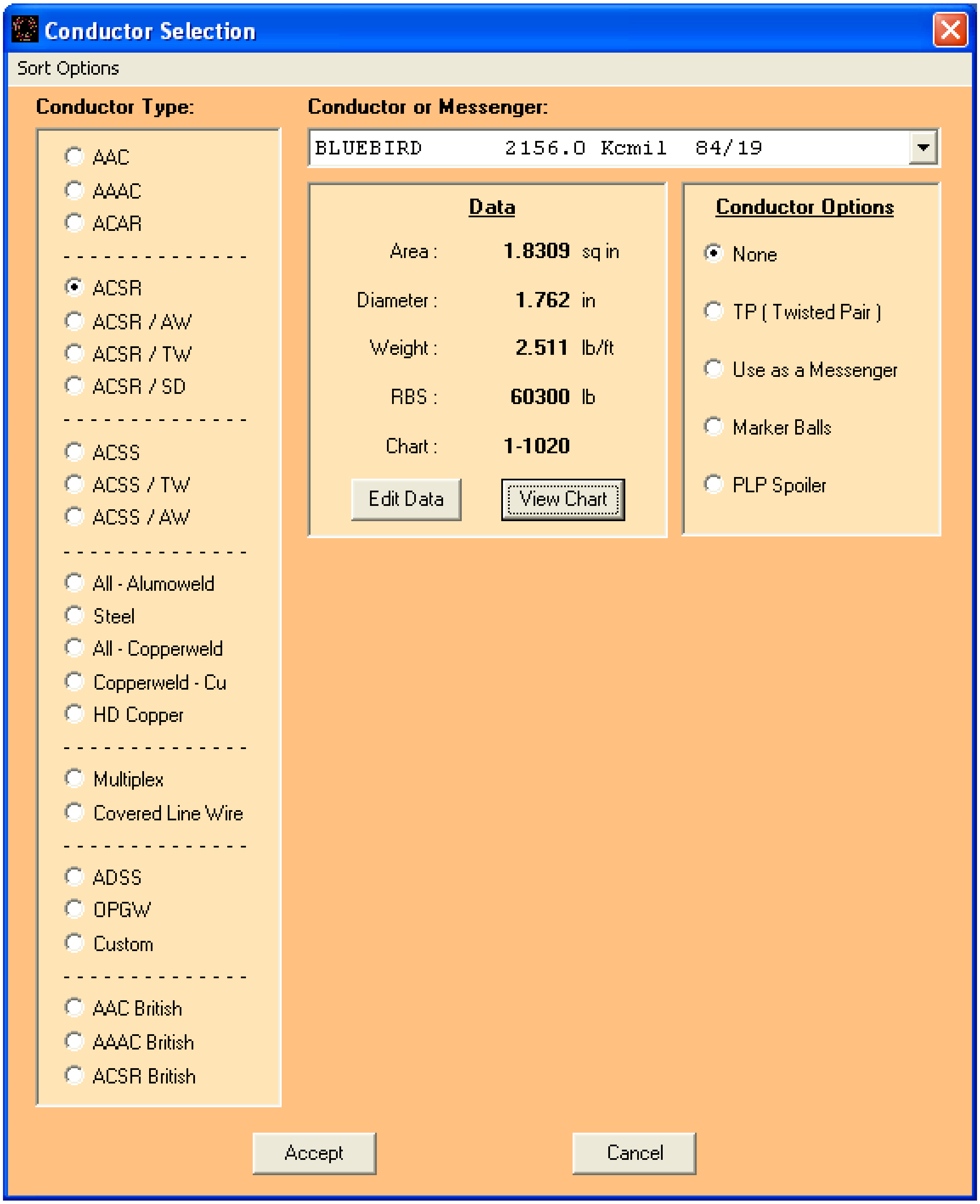
Comparison of Structure Types

Structure Type	Drawing	Advantages	Disadvantages	Conclusion
Self-Supported Steel Single Tubular		• reduced land use • line compaction • smaller footprint than any of the guyed types • shorter lead time vs. steel lattice • shorter construction time vs. steel lattice. • Needs less design time than steel lattice. • Does not use so many plates, gussets, fasteners and bolts as steel lattice • Does not need galvanizing as much as the steel lattice.	• cover shorter spans than steel lattice for same external extreme loading cases. • expensive foundation.	• Good for urban & sub-urban areas (farming land with irrigation) on the corridor of this Clean Line HVDC project. • Good for areas with restricted and/or reduced ROW • Not used too much in open country ROW, unless farm land with irrigation or special environment requirements.
Self-Supporting Steel Lattice		• Suitable for rugged terrain (mountains, valleys, river crossings, etc) • Smaller footprint than any of the guyed types. • Past experience with HVDC lines in USA and internationally, with very good reliability. • Use of different extension legs and extension bodies, makes it suitable for worst rough terrain.	• Requires 4 foundations (higher total foundation costs). • Highest weight (heaviest of all types). • Long lead times • Longer construction time • Needs more design time. • More exposed wind area (higher forces on structure). • Heavier equipment used during erection vs. CSR type.	• Best solution for rugged terrain (mountains) on the corridor of this Clean Line HVDC project, with very good reliability proved in many years of field presence, even for HVDC lines.

Guyed Mast Variant 1: Tubular Steel V-String Variant 2: Lattice Steel I-String	 	• Single foundation. • Very light. • In the tubular steel variant, less material than in the self-supported lattice steel (less expensive), for same height. • Some past experience with HVDC lines in USA and internationally.	• Difficult to use in the ROW of mountain zones • The 4 anchored guys take a lot of space from the ROW. • Possible rotational effect in case of slack guy or any minor anchor movement (it can be eliminated by attaching the guys with brackets to the front and back of the tower, instead of being attached to the tower on the opposite side of each anchor).	• A far less expensive solution for the open country zones of the corridor of this Clean Line HVDC project, as long as it does not have irrigation system.
Cross-Rope Suspension (CSR) with2 Masts Variant 1: Portal Formation 2 Foundations I-String Variant 2: V-Formation 1 Foundation V-String	 	• The most economical. • Lowest weight, for same height, from all types of structures. • High strength/weight ratio • Lower cost of erection. • Flexible suspension catenary (anti-cascading structure). • Claimed that it can sustain the loss of 1 guy w/o collapsing. • In the portal type, the masts can have different lengths, for use in irregular terrain. • Light equipment used during erection. • The strength of the tower can be increased by using larger or stronger steel	• Difficult to assembly in the ROW of mountain zones. • Very large base makes it incompatible with large irrigation systems. • Lack of previous experience with CSR tower in USA makes it difficult to obtain permit. • Small footing print, but it takes a lot from the ROW due to its large base. • It can collapse, if guys are lost. • The portal type requires a larger space than the guyed single mast type. • Maintenance Safety: access to the insulator string and conductor supports it is a concern to line field personnel.	• Due to its very large base that makes it incompatible with large irrigation systems and due to lack of previous experience with CSR tower in USA, making it difficult to obtain permit, plus the safety concern (access to insulator and conductors during maintenance work), the CSR type is not recommend to be used on this Clean Line HVDC project.

		cables. • Used extensively in international HVAC lines 400 kV- 800 KV (Brazil, Argentina, South Africa, Canada).		

APPENDIX H


Conductor Selection
Sort Options
Conductor Type:
AAC
AAAC
ACAR
ACSR
ACSR / AW
ACSR / TW
ACSR / SD
ACSS
ACSS / TW
ACSS / AW
All - Alumoweld
Steel
All - Copperweld
Copperweld - Cu
HD Copper
Multiplex
Covered Line Wire
ADSS
OPGW
Custom
AAC British
AAAC British
ACSR British
Conductor or Messenger:
BLUEBIRD 2156.0 Kcmil 84/19
Data
Area : 1.8309 sq in
Diameter : 1.762 in
Weight : 2.511 lb/ft
RBS : 60300 lb
Chart : 1-1020
Edit Data
View Chart
Conductor Options
None
TP (Twisted Pair)
Use as a Messenger
Marker Balls
PLP Spoiler
Accept
Cancel

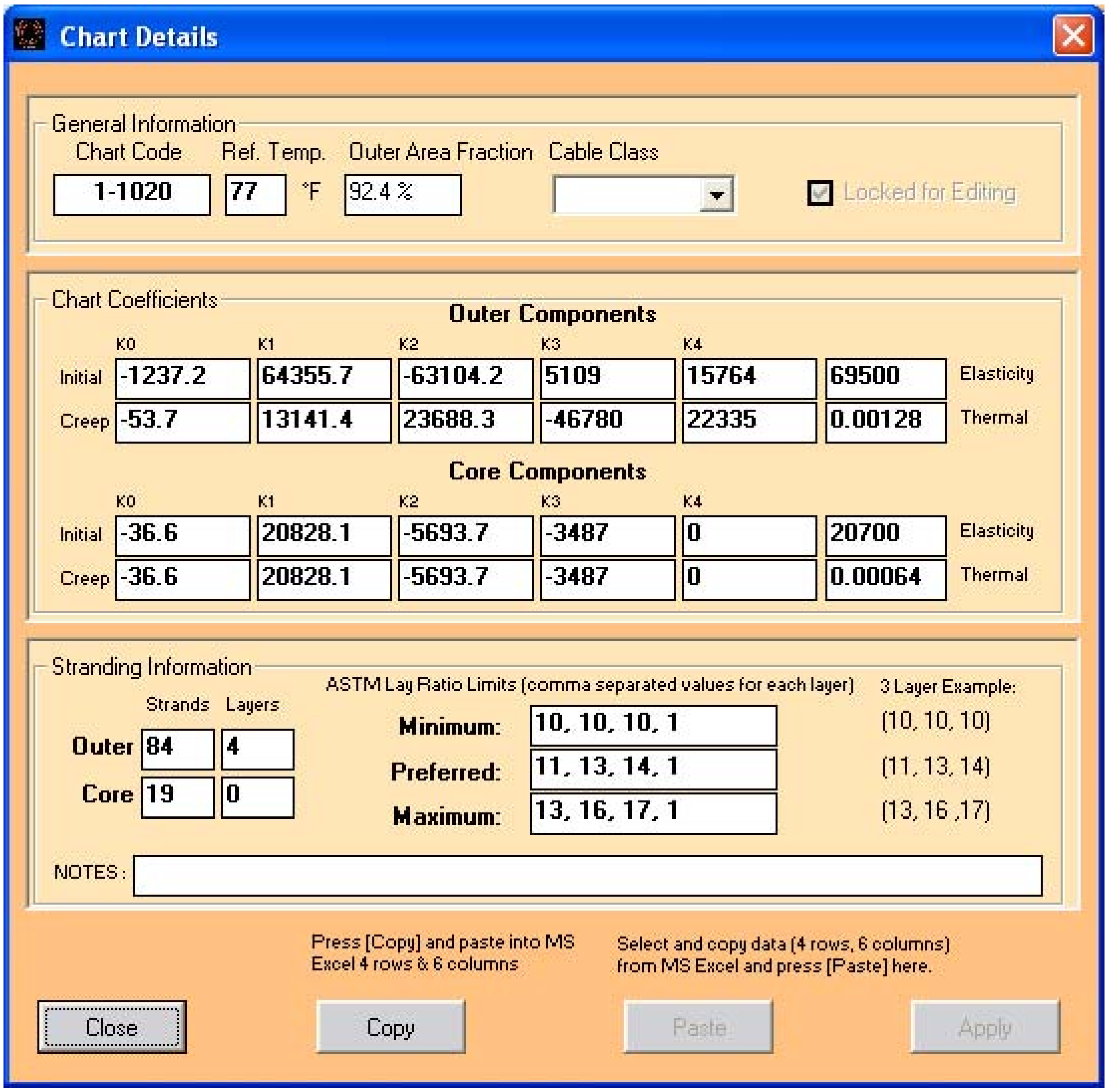
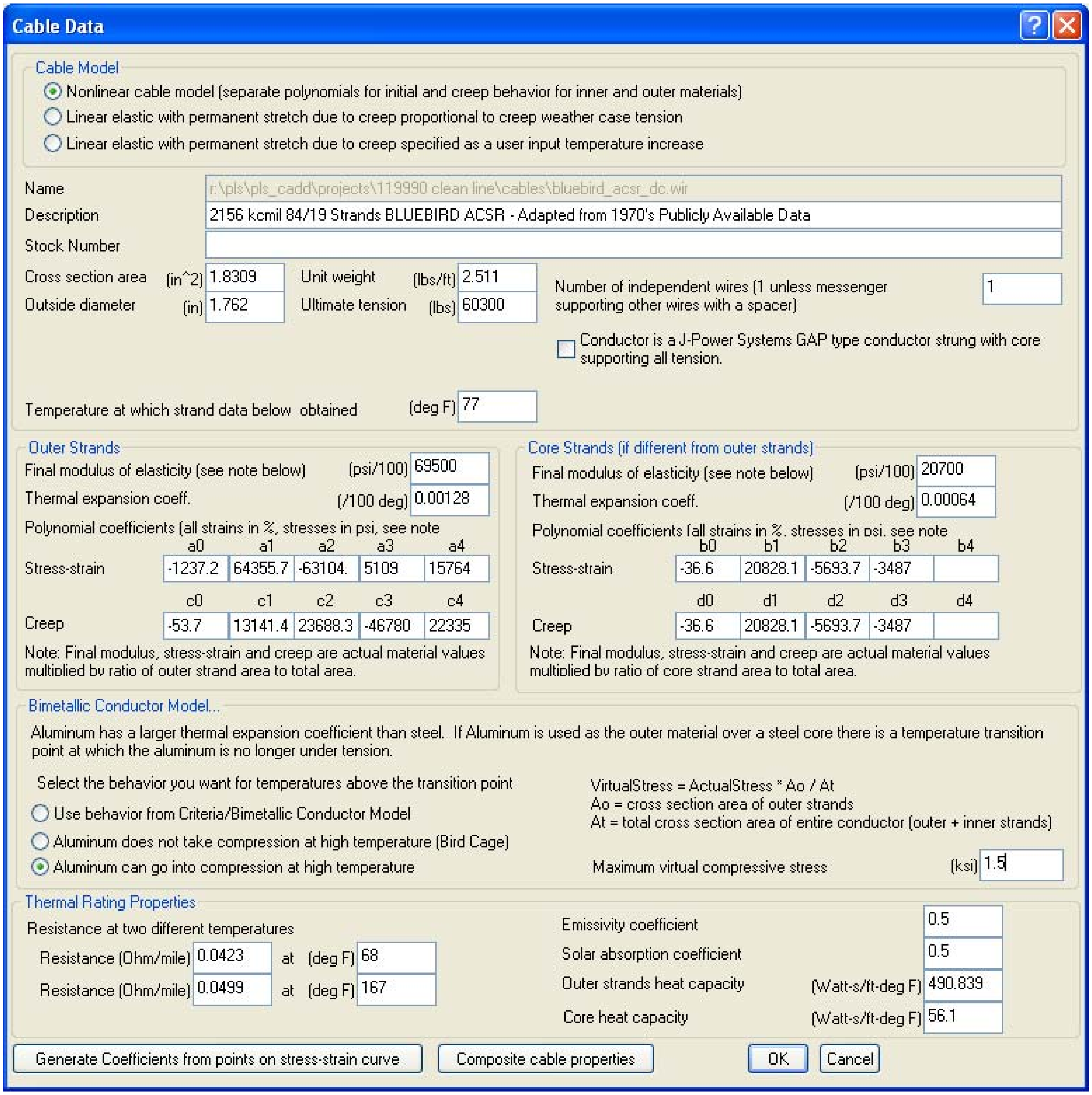


Chart Details
General Information
Chart Code
Ref. Temp.
Outer Area Fraction
Cable Class
1-1020
77
°F
92.4 %
Locked for Editing
Chart Coefficients
Outer Components
K0
K1
K2
K3
K4
Initial
-1237.2
64355.7
-63104.2
5109
15764
69500
Elasticity
Creep
-53.7
13141.4
23688.3
-46780
22335
0.00128
Thermal
Core Components
K0
K1
K2
K3
K4
Initial
-36.6
20828.1
-5693.7
-3487
0
20700
Elasticity
Creep
-36.6
20828.1
-5693.7
-3487
0
0.00064
Thermal
Stranding Information
ASTM Lay Ratio Limits (comma separated values for each layer)
3 Layer Example:
Strands
Layers
Outer
84
4
Core
19
0
Minimum:
10, 10, 10, 1
(10, 10, 10)
Preferred:
11, 13, 14, 1
(11, 13, 14)
Maximum:
13, 16, 17, 1
(13, 16 ,17)
NOTES :
Press [Copy] and paste into MS Excel 4 rows & 6 columns
Select and copy data (4 rows, 6 columns) from MS Excel and press [Paste] here.
Close
Copy
Paste
Apply

acsr_bluebird_dc.wir: the resistances values in this table are DC Resistances:


Cable Data

Cable Model

- (•) Nonlinear cable model (separate polynomials for initial and creep behavior for inner and outer materials)
- ( ) Linear elastic with permanent stretch due to creep proportional to creep weather case tension
- ( ) Linear elastic with permanent stretch due to creep specified as a user input temperature increase

Name: r:\pls\pls_cadd\projects\119990 clean line\cables\bluebird_acsr_dc.wir

Description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's Publicly Available Data

Stock Number:

Cross section area (in^2) 1.8309 | Unit weight (lbs/ft) 2.511

Outside diameter (in) 1.762 | Ultimate tension (lbs) 60300

Number of independent wires (1 unless messenger supporting other wires with a spacer) 1

[ ] Conductor is a J-Power Systems GAP type conductor strung with core supporting all tension.

Temperature at which strand data below obtained (deg F) 77

Outer Strands

Final modulus of elasticity (see note below) (psi/100) 69500

Thermal expansion coeff. (/100 deg) 0.00128

Polynomial coefficients (all strains in %, stresses in psi, see note

	a0	a1	a2	a3	a4
Stress-strain	-1237.2	64355.7	-63104.	5109	15764
	c0	c1	c2	c3	c4
Creep	-53.7	13141.4	23688.3	-46780	22335

Note: Final modulus, stress-strain and creep are actual material values multiplied by ratio of outer strand area to total area.

Core Strands (if different from outer strands)

Final modulus of elasticity (see note below) (psi/100) 20700

Thermal expansion coeff. (/100 deg) 0.00064

Polynomial coefficients (all strains in %, stresses in psi, see note

	b0	b1	b2	b3	b4
Stress-strain	-36.6	20828.1	-5693.7	-3487	
	d0	d1	d2	d3	d4
Creep	-36.6	20828.1	-5693.7	-3487	

Note: Final modulus, stress-strain and creep are actual material values multiplied by ratio of core strand area to total area.

Bimetallic Conductor Model...

Aluminum has a larger thermal expansion coefficient than steel. If Aluminum is used as the outer material over a steel core there is a temperature transition point at which the aluminum is no longer under tension.

Select the behavior you want for temperatures above the transition point

- ( ) Use behavior from Criteria/Bimetallic Conductor Model
- ( ) Aluminum does not take compression at high temperature (Bird Cage)
- (•) Aluminum can go into compression at high temperature

VirtualStress = ActualStress * Ao / At
Ao = cross section area of outer strands
At = total cross section area of entire conductor (outer + inner strands)

Maximum virtual compressive stress (ksi) 1.5

Thermal Rating Properties

Resistance at two different temperatures

Resistance (Ohm/mile) 0.0423 at (deg F) 68

Resistance (Ohm/mile) 0.0499 at (deg F) 167

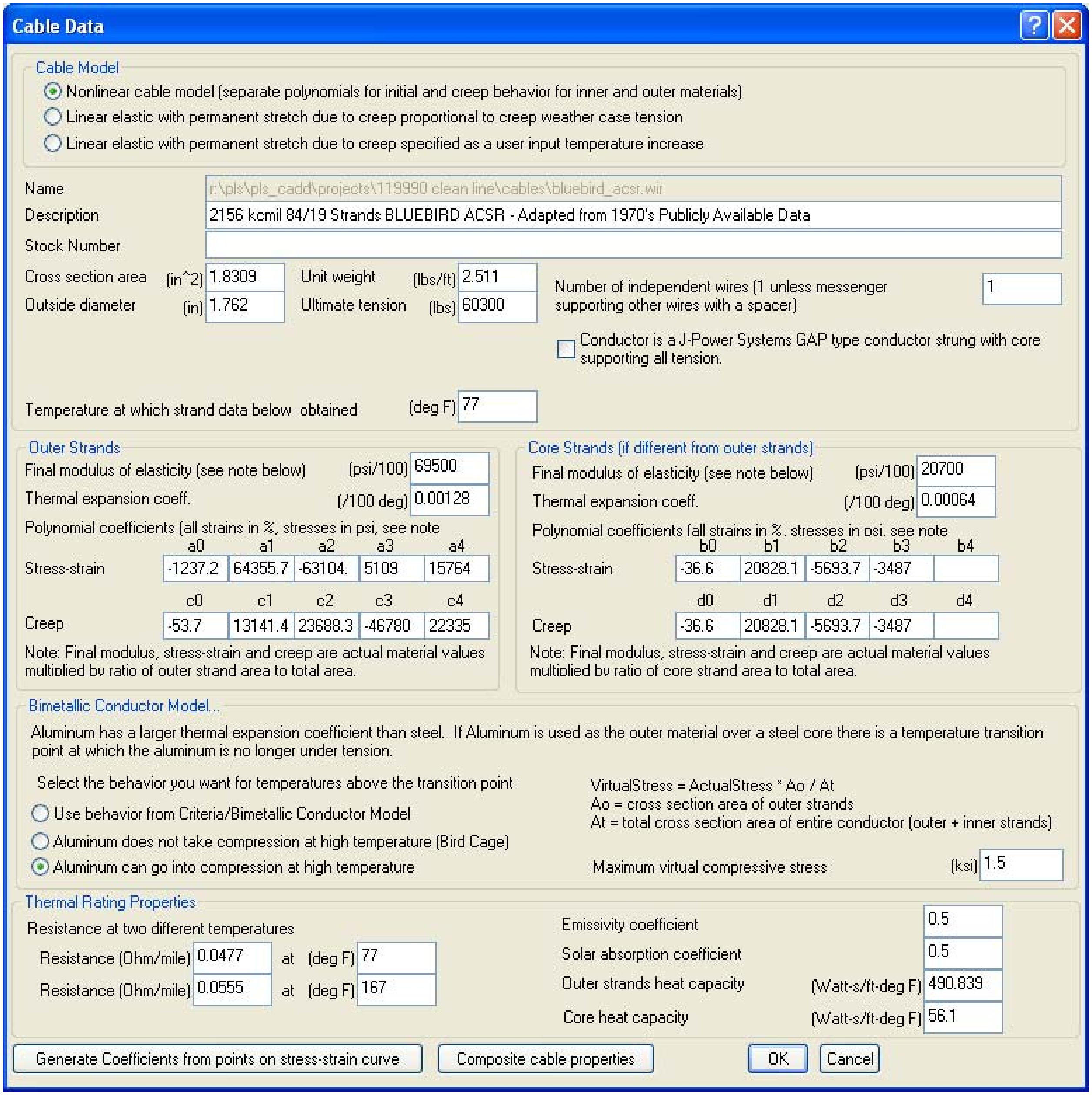
Emissivity coefficient 0.5

Solar absorption coefficient 0.5

Outer strands heat capacity (Watt-s/ft-deg F) 490.839

Core heat capacity (Watt-s/ft-deg F) 56.1

[Generate Coefficients from points on stress-strain curve] [Composite cable properties] [OK] [Cancel] acsr_bluebird.wir: the resistances values in this table are AC Resistances:



Cable Data

Cable Model

- (selected) Nonlinear cable model (separate polynomials for initial and creep behavior for inner and outer materials)
- Linear elastic with permanent stretch due to creep proportional to creep weather case tension
- Linear elastic with permanent stretch due to creep specified as a user input temperature increase

Name: r:\pls\pls_cadd\projects\119990 clean line\cables\bluebird_acsr.wir

Description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's Publicly Available Data

Stock Number:

Cross section area (in^2) 1.8309 | Unit weight (lbs/ft) 2.511

Outside diameter (in) 1.762 | Ultimate tension (lbs) 60300

Number of independent wires (1 unless messenger supporting other wires with a spacer) 1

Conductor is a J-Power Systems GAP type conductor strung with core supporting all tension. (unchecked)

Temperature at which strand data below obtained (deg F) 77

Outer Strands

Final modulus of elasticity (see note below) (psi/100) 69500

Thermal expansion coeff. (/100 deg) 0.00128

Polynomial coefficients (all strains in %, stresses in psi, see note

	a0	a1	a2	a3	a4
Stress-strain	-1237.2	64355.7	-63104.	5109	15764
	c0	c1	c2	c3	c4
Creep	-53.7	13141.4	23688.3	-46780	22335

Note: Final modulus, stress-strain and creep are actual material values multiplied by ratio of outer strand area to total area.

Core Strands (if different from outer strands)

Final modulus of elasticity (see note below) (psi/100) 20700

Thermal expansion coeff. (/100 deg) 0.00064

Polynomial coefficients (all strains in %, stresses in psi, see note

	b0	b1	b2	b3	b4
Stress-strain	-36.6	20828.1	-5693.7	-3487	
	d0	d1	d2	d3	d4
Creep	-36.6	20828.1	-5693.7	-3487	

Note: Final modulus, stress-strain and creep are actual material values multiplied by ratio of core strand area to total area.

Bimetallic Conductor Model...

Aluminum has a larger thermal expansion coefficient than steel. If Aluminum is used as the outer material over a steel core there is a temperature transition point at which the aluminum is no longer under tension.

Select the behavior you want for temperatures above the transition point

- Use behavior from Criteria/Bimetallic Conductor Model
- Aluminum does not take compression at high temperature (Bird Cage)
- (selected) Aluminum can go into compression at high temperature

VirtualStress = ActualStress * Ao / At
Ao = cross section area of outer strands
At = total cross section area of entire conductor (outer + inner strands)

Maximum virtual compressive stress (ksi) 1.5

Thermal Rating Properties

Resistance at two different temperatures

Resistance (Ohm/mile) 0.0477 at (deg F) 77

Resistance (Ohm/mile) 0.0555 at (deg F) 167

Emissivity coefficient 0.5

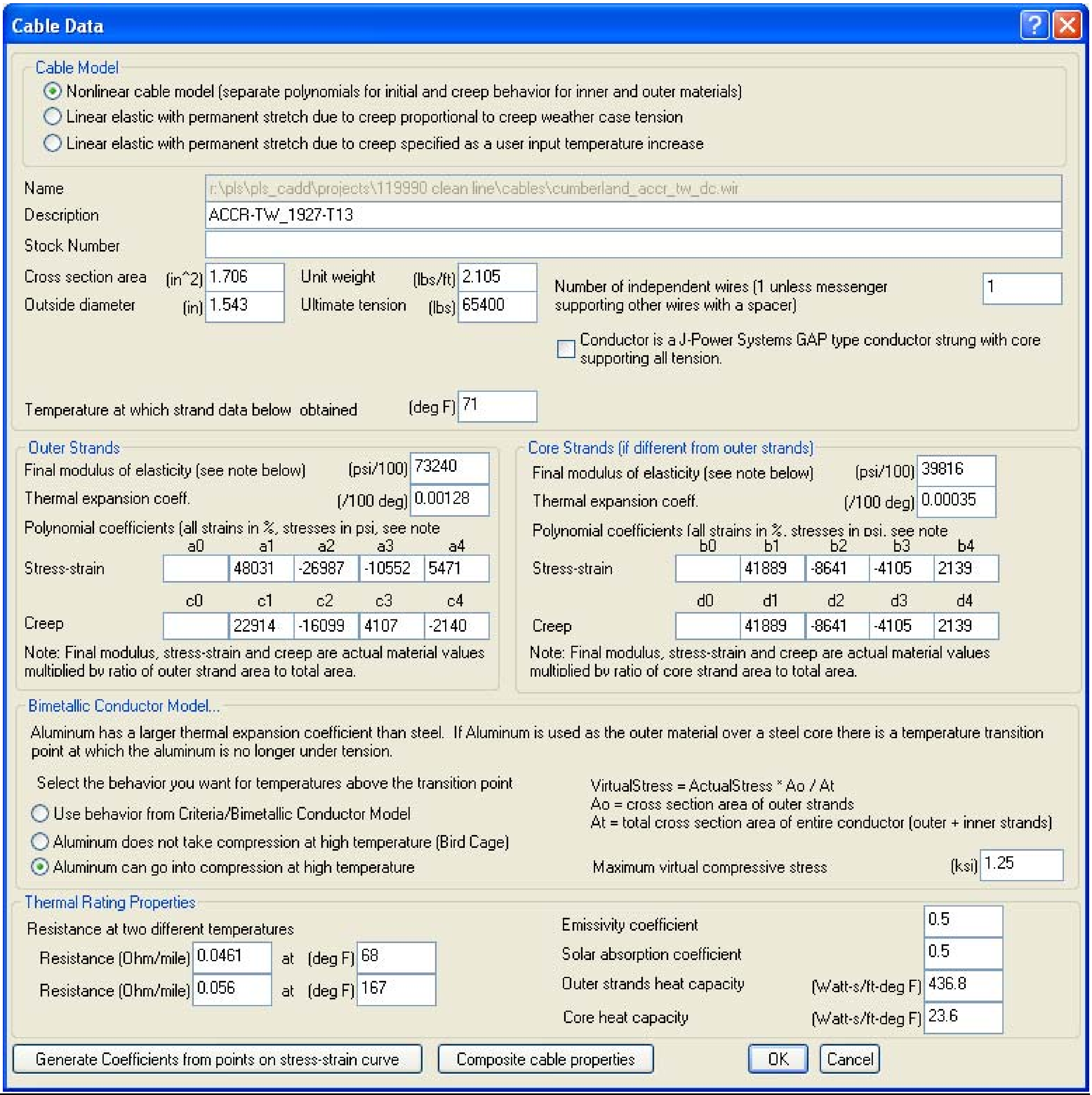
Solar absorption coefficient 0.5

Outer strands heat capacity (Watt-s/ft-deg F) 490.839

Core heat capacity (Watt-s/ft-deg F) 56.1

Generate Coefficients from points on stress-strain curve | Composite cable properties | OK | Cancel

ACCR/TW Cumberland- with DC Resistances:



Cable Data

Cable Model

- (•) Nonlinear cable model (separate polynomials for initial and creep behavior for inner and outer materials)
- ( ) Linear elastic with permanent stretch due to creep proportional to creep weather case tension
- ( ) Linear elastic with permanent stretch due to creep specified as a user input temperature increase

Name: r:\pls\pls_cadd\projects\119990 clean line\cables\cumberland_accr_tw_dc.wir

Description: ACCR-TW_1927-T13

Stock Number:

Cross section area (in^2) 1.706 | Unit weight (lbs/ft) 2.105

Outside diameter (in) 1.543 | Ultimate tension (lbs) 65400

Number of independent wires (1 unless messenger supporting other wires with a spacer): 1

[ ] Conductor is a J-Power Systems GAP type conductor strung with core supporting all tension.

Temperature at which strand data below obtained (deg F) 71

Outer Strands

Final modulus of elasticity (see note below) (psi/100) 73240

Thermal expansion coeff. (/100 deg) 0.00128

Polynomial coefficients (all strains in %, stresses in psi, see note

	a0	a1	a2	a3	a4
Stress-strain		48031	-26987	-10552	5471

	c0	c1	c2	c3	c4
Creep		22914	-16099	4107	-2140

Note: Final modulus, stress-strain and creep are actual material values multiplied by ratio of outer strand area to total area.

Core Strands (if different from outer strands)

Final modulus of elasticity (see note below) (psi/100) 39816

Thermal expansion coeff. (/100 deg) 0.00035

Polynomial coefficients (all strains in %, stresses in psi, see note

	b0	b1	b2	b3	b4
Stress-strain		41889	-8641	-4105	2139

	d0	d1	d2	d3	d4
Creep		41889	-8641	-4105	2139

Note: Final modulus, stress-strain and creep are actual material values multiplied by ratio of core strand area to total area.

Bimetallic Conductor Model...

Aluminum has a larger thermal expansion coefficient than steel. If Aluminum is used as the outer material over a steel core there is a temperature transition point at which the aluminum is no longer under tension.

Select the behavior you want for temperatures above the transition point

- ( ) Use behavior from Criteria/Bimetallic Conductor Model
- ( ) Aluminum does not take compression at high temperature (Bird Cage)
- (•) Aluminum can go into compression at high temperature

VirtualStress = ActualStress * Ao / At
Ao = cross section area of outer strands
At = total cross section area of entire conductor (outer + inner strands)

Maximum virtual compressive stress (ksi) 1.25

Thermal Rating Properties

Resistance at two different temperatures

Resistance (Ohm/mile) 0.0461 at (deg F) 68

Resistance (Ohm/mile) 0.056 at (deg F) 167

Emissivity coefficient 0.5

Solar absorption coefficient 0.5

Outer strands heat capacity (Watt-s/ft-deg F) 436.8

Core heat capacity (Watt-s/ft-deg F) 23.6

[Generate Coefficients from points on stress-strain curve] [Composite cable properties] [OK] [Cancel]

APPENDIX I- Preliminary Conductors Comparison Summary Table: MOT vs. Ampacity and Power

Conductor Type	Normal Regime; 2 ft/s wind Calculated Neccesary MOT for: P rectifier=3720 MW P pole=1860 MW I pole=3100 A I conductor=1033.3 A 2)	Emergency Regime 1); 2 ft/s wind Calculated Neccesary MOT for: P rectifier=4092 MW 1) P pole=2046 MW 1) I pole=3400 A 1) I conductor=1133.3 A 1), 2)	Normal Regime; 0 ft/s wind Calculated Neccesary MOT for: P rectifier=3720 MW P pole=1860 MW I pole=3100 A I conductor=1033.3 A 2)	Emergency Regime 1); 0 ft/s wind Calculated Neccesary MOT for: P rectifier=4092 MW 1) P pole=2046 MW 1) I pole=3400 A 1) I conductor=1133.3 A 1), 2)	Normal Regime; 2 ft/s wind Neccesary Power (Current) to reach: MOT=284 F=140 C (MAX.)
Biggest ACSR Bluebird 2156 kCMIL	MOT=148 F= 64 C Max. Sag=58.98 ft at MOT=148 F=64 C, Final in Ruling Span=1500 ft	MOT=154 F= 68 C	MOT=173 F= 78 C	MOT=180 F= 82 C	For Bluebird conductor to reach MOT=284 F= 140 C (MAX.) results it is neccesary: P rectifier=8914 MW (very high!) P pole=4457 MW I pole=7428 A I conductor=2476 A 2) Max. Sag=68.57 ft at MOT=284 F=140 C, Final in Ruling Span=1500 ft Difference in Max Sag=9.59 ft between Max MOT=140 C and Neccesary MOT=64 C
Smallest ACSR Bittern 1272 kCMIL	MOT=175 F= 79 C Max. Sag=64.08 ft at MOT=175 F=79 C, Final in Ruling Span=1500 ft	MOT=186 F= 86 C	MOT=214 F= 101 C	MOT=230 F= 110 C	For Bittern conductor to reach MOT=284 F= 140 C (MAX.) results it is neccesary: P rectifier=6170 MW (very high!) P pole=3085 MW I pole=5142 A I conductor=1714 A 2) Max. Sag=70.02 ft at MOT=284 F=140 C, Final in Ruling Span=1500 ft Difference in Max Sag=5.94 ft between Max MOT=140 C and Neccesary MOT=79 C

Notes: 1) Emergency Regime: 10% higher than Normal Regime. 2) Assumed 3 conductors/pole.

3.10.0v

Southwire SAG10™

8/11/2010

Power engineers

ACSR BlueBird @ MOT=148 F=64 C for Normal Regime, Ampacity=1033.3 A
Rling Span=1500 ft
Max Sag @ MOT=148 F=64 C, Final=58.98 ft

Conductor: 2156.0 Kcmil 84/19 Stranding ACSR "BLUEBIRD"

Area = 1.8309 Sq. in Diameter = 1.762 in Weight = 2.511 lb/ft RTS = 60300 lb
Data from Chart No. 1-1020
English Units
Limits and Outputs in Average Tensions.

Span = 1500.0 Feet Customary Heavy Load Zone
Creep IS a Factor Rolled Rod

Design Points					Final				Initial	
Temp	Ice	Wind	K	Weight	Sag	Tension	RTS	Sag	Tension	RTS
°F	in	psf	lb/ft	lb/ft	Ft	lb	%	Ft	lb	%
0.0	0.50	4.00	0.30	4.324	51.53	23714	39.3	47.16	25891	42.9
15.0	1.25	4.10	0.00	7.339	58.38	35571	59.0	57.72	35975	59.7
32.0	0.50	0.00	0.00	3.917	53.07	20866	34.6	47.84	23126	38.4
60.0	0.00	24.30	0.00	4.363	56.07	22008	36.5	51.19	24084	39.9
-20.0	0.00	0.00	0.00	2.511	45.27	15655	26.0	38.24	18515	30.7
0.0	0.00	0.00	0.00	2.511	47.03	15075	25.0*	39.89	17756	29.4
30.0	0.00	0.00	0.00	2.511	49.60	14301	23.7	42.36	16727	27.7
60.0	0.00	0.00	0.00	2.511	52.09	13623	22.6	44.82	15814	26.2
90.0	0.00	0.00	0.00	2.511	54.51	13025	21.6	47.25	15006	24.9
120.0	0.00	0.00	0.00	2.511	56.85	12494	20.7	49.65	14287	23.7
148.0	0.00	0.00	0.00	2.511	58.98	12049	20.0	51.85	13687	22.7

* Design Condition

3.10.0v

Southwire SAG10™

8/11/2010

Power engineers

ACSR Bittern @ MOT=284 F=140 C (Max Allowed for ACSR)
Ruling Span=1500 ft
Max Sag @ MOT=284 F=140 C, Final=70.02 ft

Conductor: 1272.0 Kcmil 45/ 7 Stranding ACSR "BITTERN"

Area = 1.0680 Sq. in Diameter = 1.345 in Weight = 1.434 lb/ft RTS = 34100 lb
Data from Chart No. 1-957
English Units
Limits and Outputs in Average Tensions.

Span = 1500.0 Feet Customary Heavy Load Zone
Creep is NOT a Factor Rolled Rod

Design Points					Final			Initial		
Temp °F	Ice in	Wind psf	K lb/ft	Weight lb/ft	Sag Ft	Tension lb	RTS %	Sag Ft	Tension lb	RTS %
0.0	0.50	4.00	0.30	2.997	55.96	15146	44.4	49.65	17050	50.0*
15.0	1.25	4.10	0.00	5.623	64.08	24862	72.9	64.08	24862	72.9
32.0	0.50	0.00	0.00	2.581	56.99	12812	37.6	49.25	14803	43.4
60.0	0.00	24.30	0.00	3.078	60.49	14404	42.2	53.69	16206	47.5
-20.0	0.00	0.00	0.00	1.434	48.54	8343	24.5	37.53	10773	31.6
0.0	0.00	0.00	0.00	1.434	50.29	8056	23.6	39.21	10313	30.2
30.0	0.00	0.00	0.00	1.434	52.83	7672	22.5	41.75	9690	28.4
60.0	0.00	0.00	0.00	1.434	55.30	7333	21.5	44.27	9141	26.8
90.0	0.00	0.00	0.00	1.434	57.69	7033	20.6	46.77	8658	25.4
120.0	0.00	0.00	0.00	1.434	60.00	6765	19.8	49.22	8230	24.1
284.0	0.00	0.00	0.00	1.434	70.02	5810	17.0	61.70	6581	19.3

* Design Condition

Southwire SAG10™

8/11/2010

Power engineers

ACSR Bittern @ MOT=175 F=79 C for Normal Regime, Ampacity=1033.3 A
Ruling Span=1500 ft
Max Sag @ MOT=175 F=79 C, Final=62.10 ft

Conductor: 1272.0 Kcmil 45/ 7 Stranding ACSR "BITTERN"

Area = 1.0680 Sq. in   Diameter = 1.345 in   Weight = 1.434 lb/ft   RTS = 34100 lb
Data from Chart No. 1-957
English Units
Limits and Outputs in Average Tensions.

Span = 1500.0 Feet   Customary Heavy Load Zone
Creep is NOT a Factor   Rolled Rod

Design Points					Final				Initial	
Temp °F	Ice in	Wind psf	K lb/ft	Weight lb/ft	Sag Ft	Tension lb	RTS %	Sag Ft	Tension lb	RTS %
0.0	0.50	4.00	0.30	2.997	55.96	15146	44.4	49.65	17050	50.0*
15.0	1.25	4.10	0.00	5.623	64.08	24862	72.9	64.08	24862	72.9
32.0	0.50	0.00	0.00	2.581	56.99	12812	37.6	49.25	14803	43.4
60.0	0.00	24.30	0.00	3.078	60.49	14404	42.2	53.69	16206	47.5
-20.0	0.00	0.00	0.00	1.434	48.54	8343	24.5	37.53	10773	31.6
0.0	0.00	0.00	0.00	1.434	50.29	8056	23.6	39.21	10313	30.2
30.0	0.00	0.00	0.00	1.434	52.83	7672	22.5	41.75	9690	28.4
60.0	0.00	0.00	0.00	1.434	55.30	7333	21.5	44.27	9141	26.8
90.0	0.00	0.00	0.00	1.434	57.69	7033	20.6	46.77	8658	25.4
120.0	0.00	0.00	0.00	1.434	60.00	6765	19.8	49.22	8230	24.1
148.0	0.00	0.00	0.00	1.434	62.10	6539	19.2	51.46	7874	23.1

* Design Condition

```
PLS-CADD Version 10.60x64    3:01:58 PM Tuesday, August 10, 2010
Power Engineers

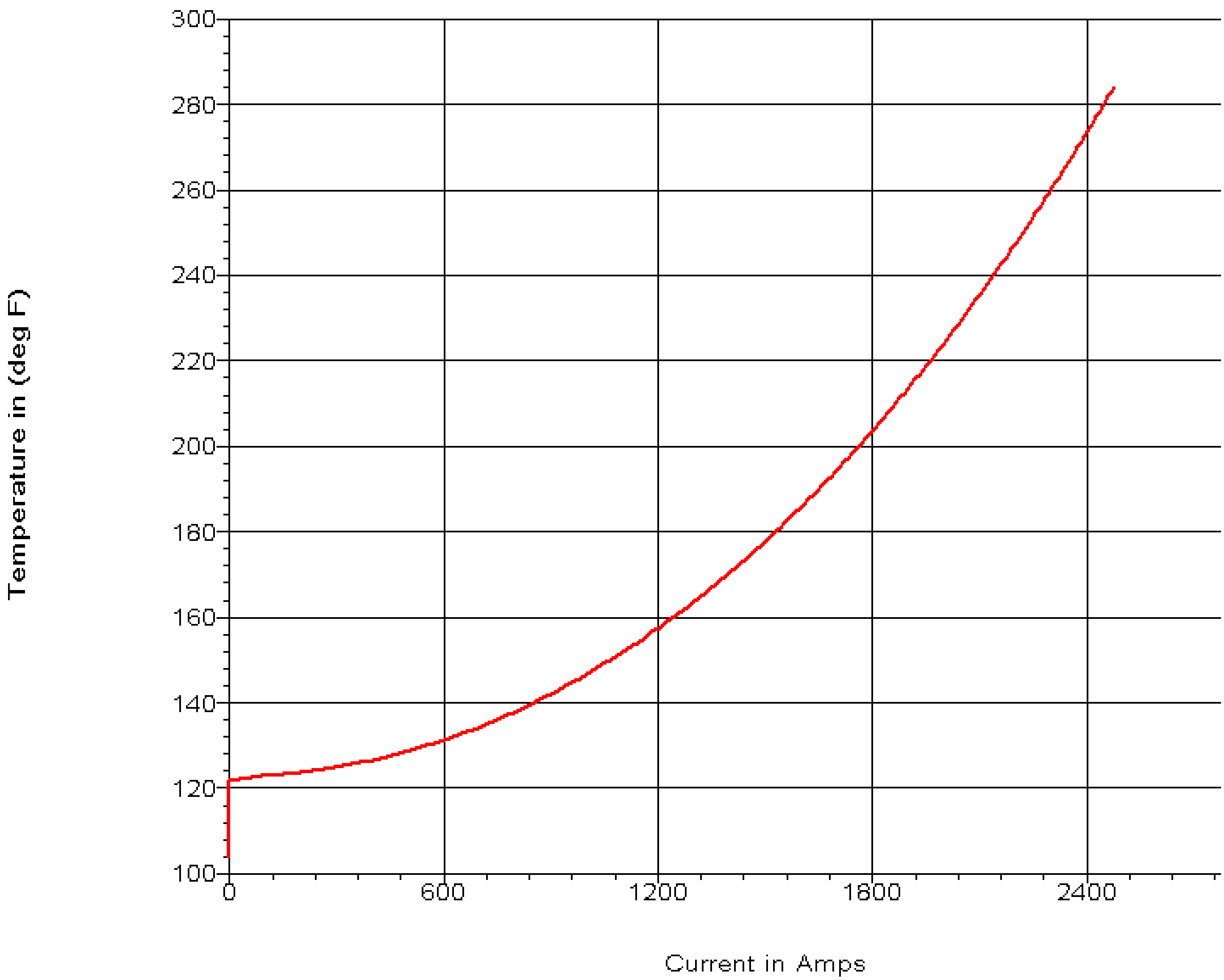
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar
heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with
most solar heating)

Conductor description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's
Publicly Available Data
Conductor diameter is 1.762 (in)
Conductor resistance is     0.0423 (Ohm/mile) at  68.0 (deg F)
                    and     0.0499 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is      7.105 (Watt/ft) (corresponds to Global Solar Radiation
of   96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is    23.703 (Watt/ft)
Convective cooling is   51.773 (Watt/ft)

Given a constant ac current of 2476.0 amperes,
The conductor temperature is 284.0 (deg F)=140 (deg C)
```


Temperature in (deg F)
300
280
260
240
220
200
180
160
140
120
100
0
600
1200
1800
2400
Current in Amps

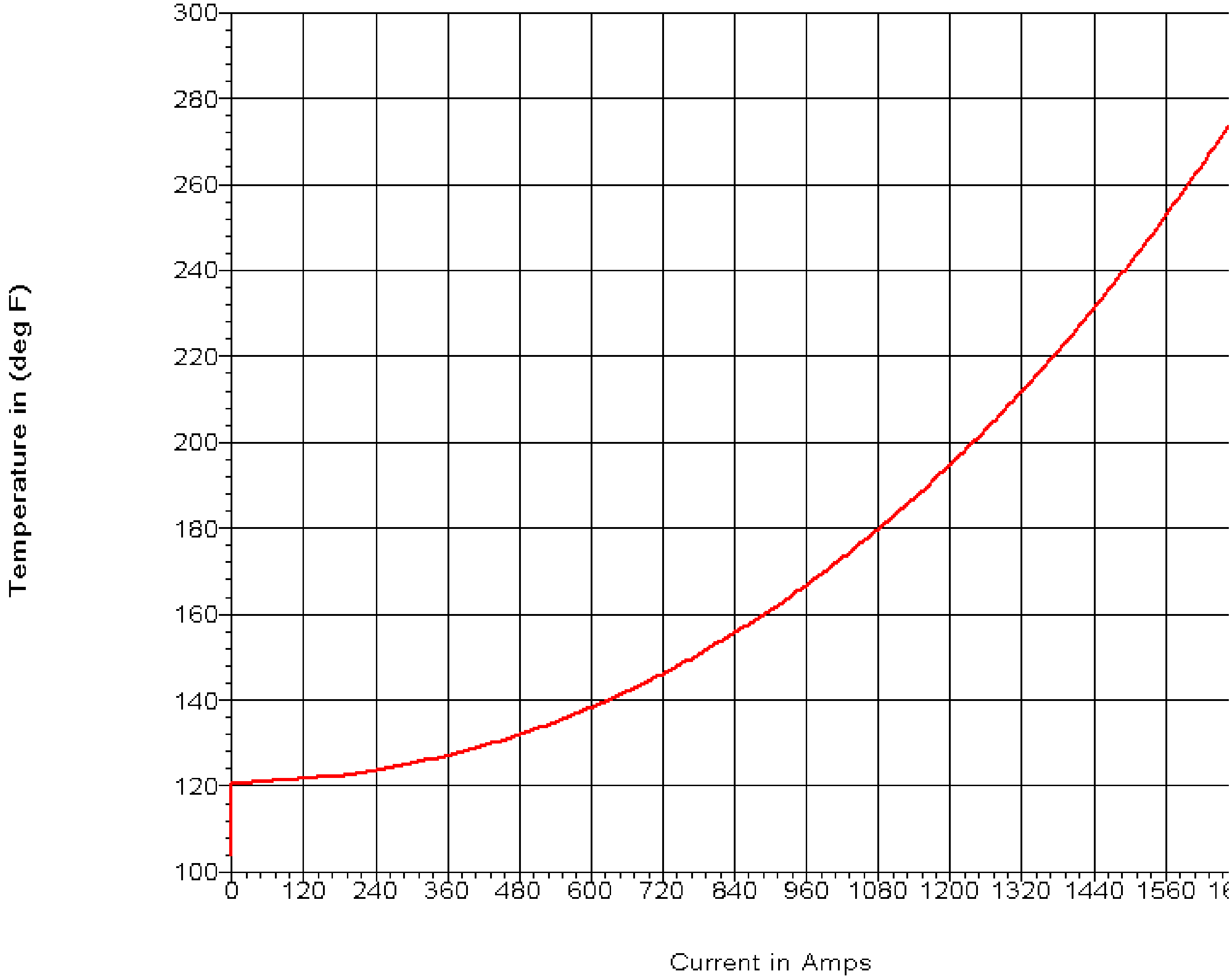
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 9deg C)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: 1272 kcmil 45/7 Strands BITTERN ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.345 (in)
Conductor dc resistance is   0.0714 (Ohm/mile) at 68.0 (deg F)
                       and   0.0863 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is   5.424 (Watt/ft) (corresponds to Global Solar Radiation of 96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is   18.109 (Watt/ft)
Convective cooling is   45.141 (Watt/ft)

Given a constant ac current of 1714.0 amperes,
The conductor temperature is 284.1 (deg F)=140 (deg C)


300
280
260
240
220
200
180
160
140
120
100
Temperature in (deg F)
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
Current in Amps

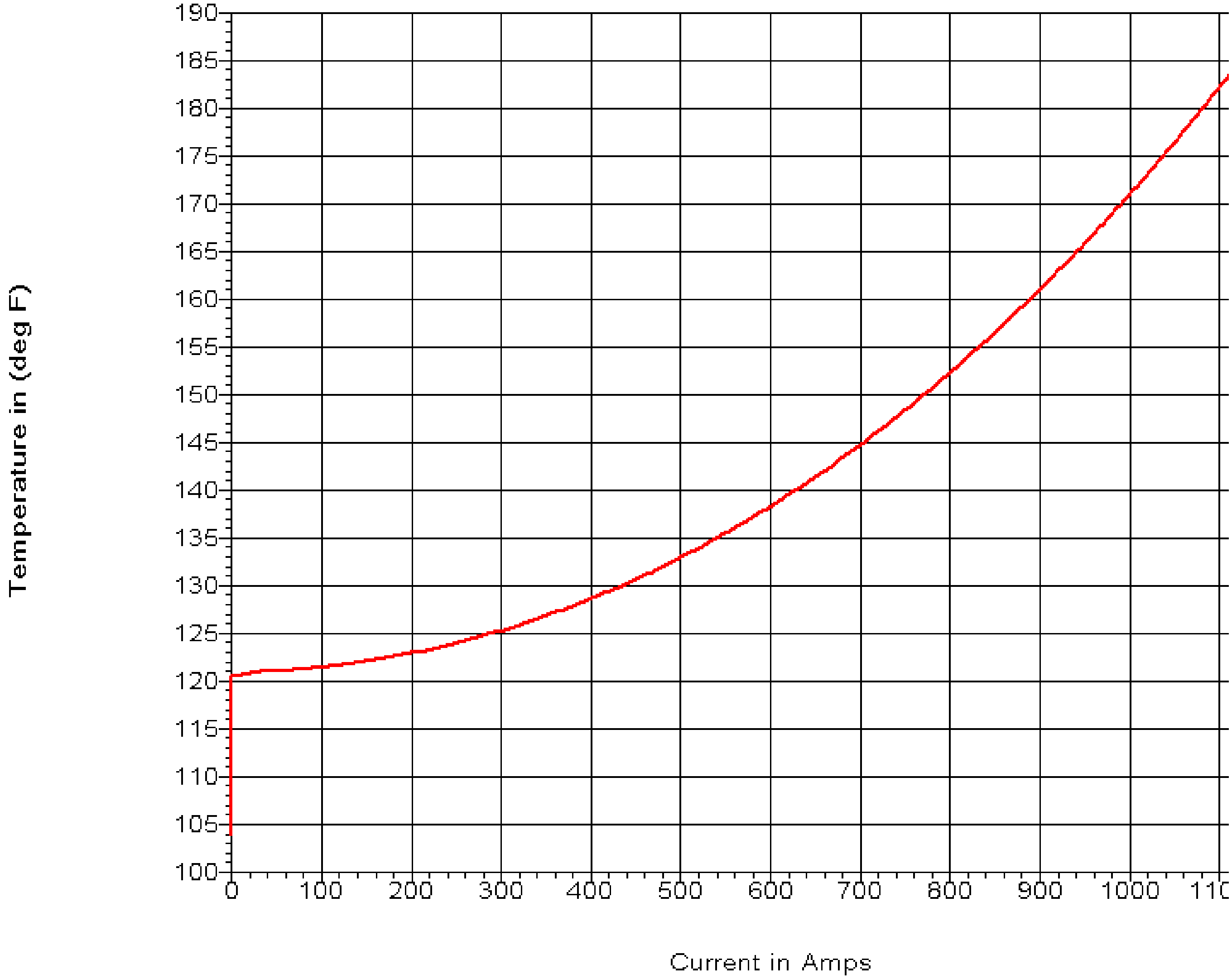
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: 1272 kcmil 45/7 Strands BITTERN ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.345 (in)
Conductor dc resistance is 0.0714 (Ohm/mile) at 68.0 (deg F)
and 0.0863 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is 5.424 (Watt/ft) (corresponds to Global Solar Radiation of 96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is 6.460 (Watt/ft)
Convective cooling is 20.662 (Watt/ft)

Given a constant ac current of 1133.3 amperes,
The conductor temperature is 186.3 (deg F)=86 (deg C)


Temperature in (deg F)
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
0
100
200
300
400
500
600
700
800
900
1000
110
Current in Amps

PLS-CADD Version 10.60x64   2:34:38 PM Tuesday, August 10, 2010
Power Engineers

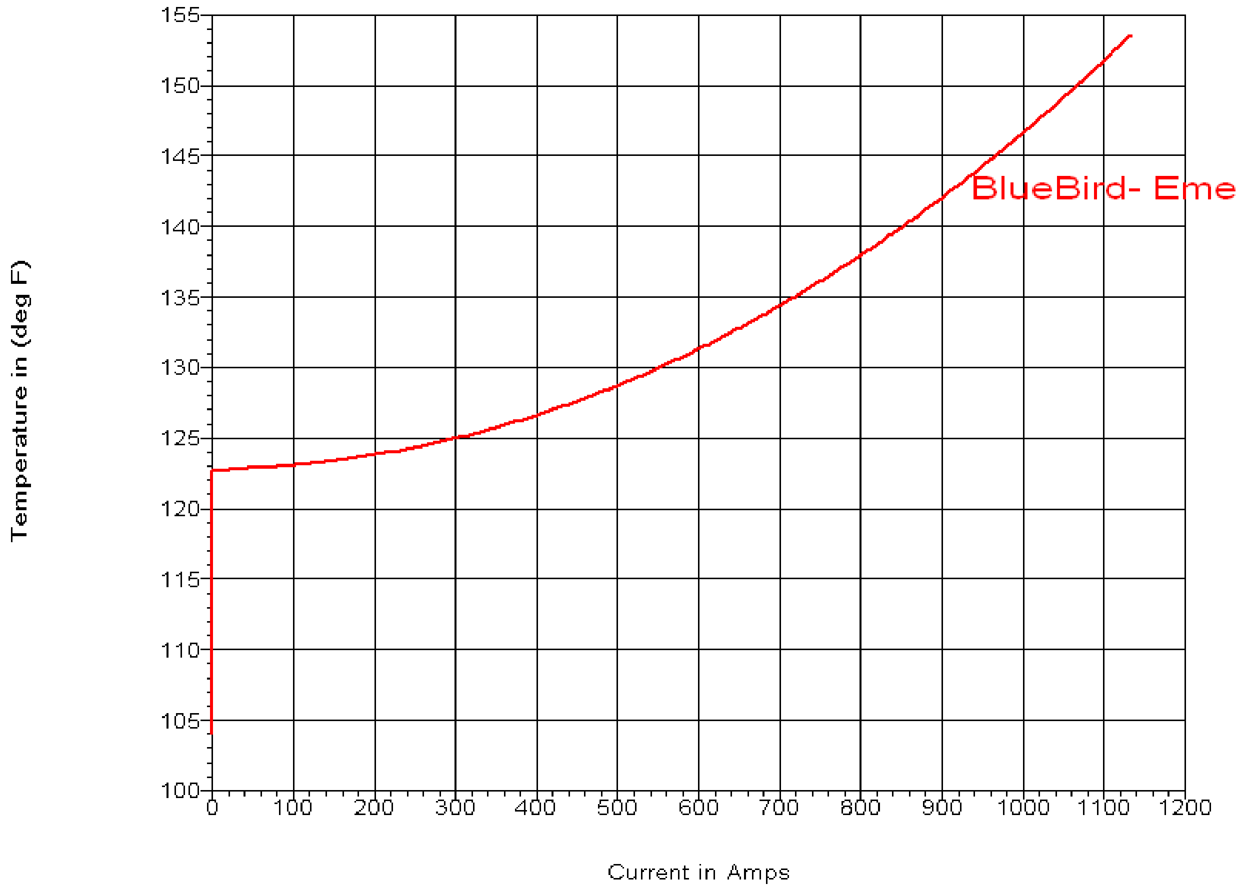
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.762 (in)
Conductor resistance is   0.0423 (Ohm/mile) at 68.0 (deg F)
                    and   0.0499 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is   7.105 (Watt/ft) (corresponds to Global Solar Radiation of   96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is   4.685 (Watt/ft)
Convective cooling is   14.307 (Watt/ft)

Given a constant ac current of 1133.3 amperes,
The conductor temperature is 153.6 (deg F)=68 (deg C)



155
150
145
140
135
130
125
120
115
110
105
100
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Temperature in (deg F)
Current in Amps
BlueBird- Eme

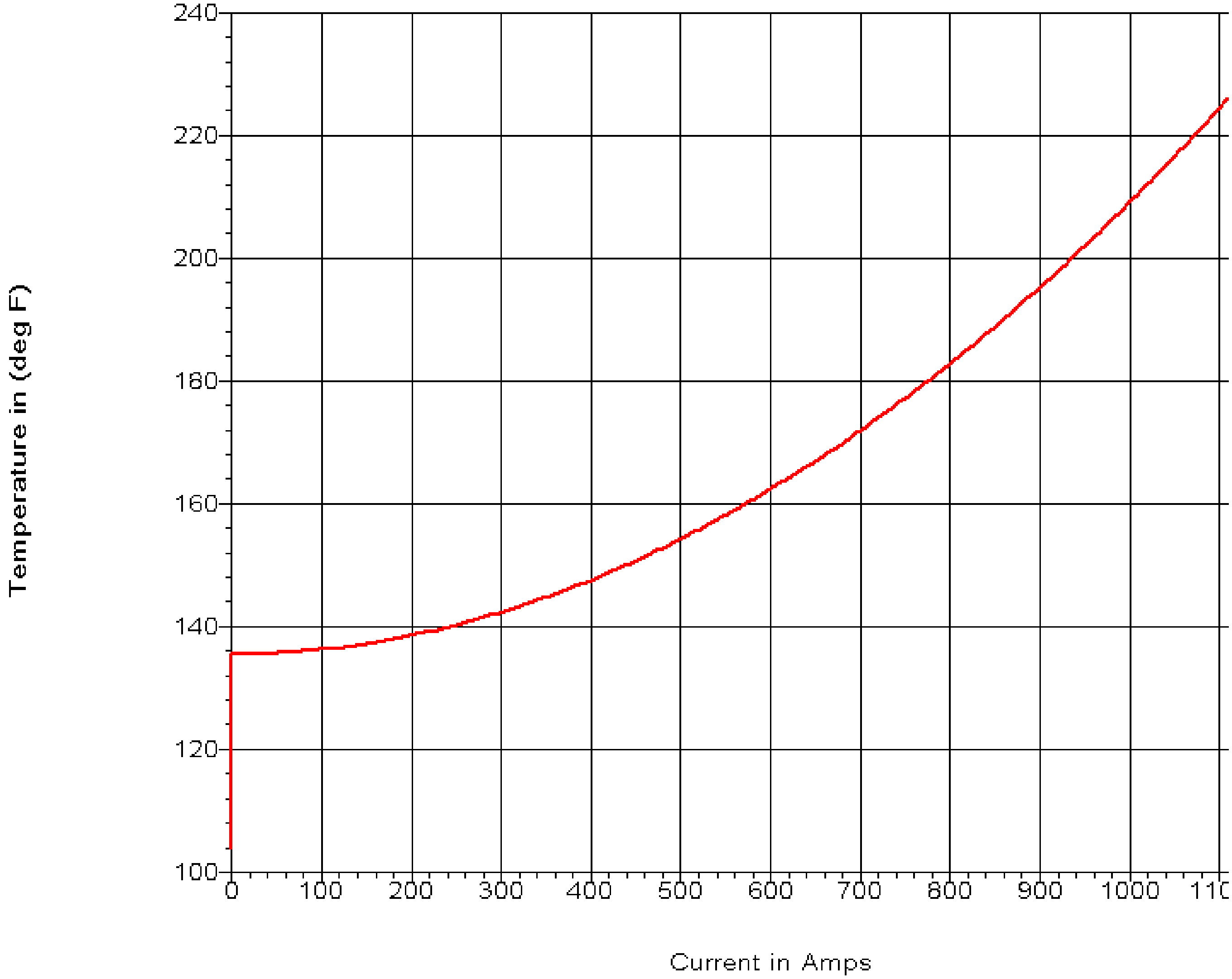
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 0.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: 1272 kcmil 45/7 Strands BITTERN ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.345 (in)
Conductor dc resistance is   0.0714 (Ohm/mile) at 68.0 (deg F)
and   0.0863 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is   5.424 (Watt/ft) (corresponds to Global Solar Radiation of 96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is   11.053 (Watt/ft)
Convective cooling is   17.666 (Watt/ft)

Given a constant ac current of 1133.3 amperes,
The conductor temperature is 229.9 (deg F)=110 (deg C)



240
220
200
180
160
140
120
100
0
100
200
300
400
500
600
700
800
900
1000
Current in Amps
Temperature in (deg F)

```
PLS-CADD Version 10.60x64    2:35:36 PM Tuesday, August 10, 2010
Power Engineers

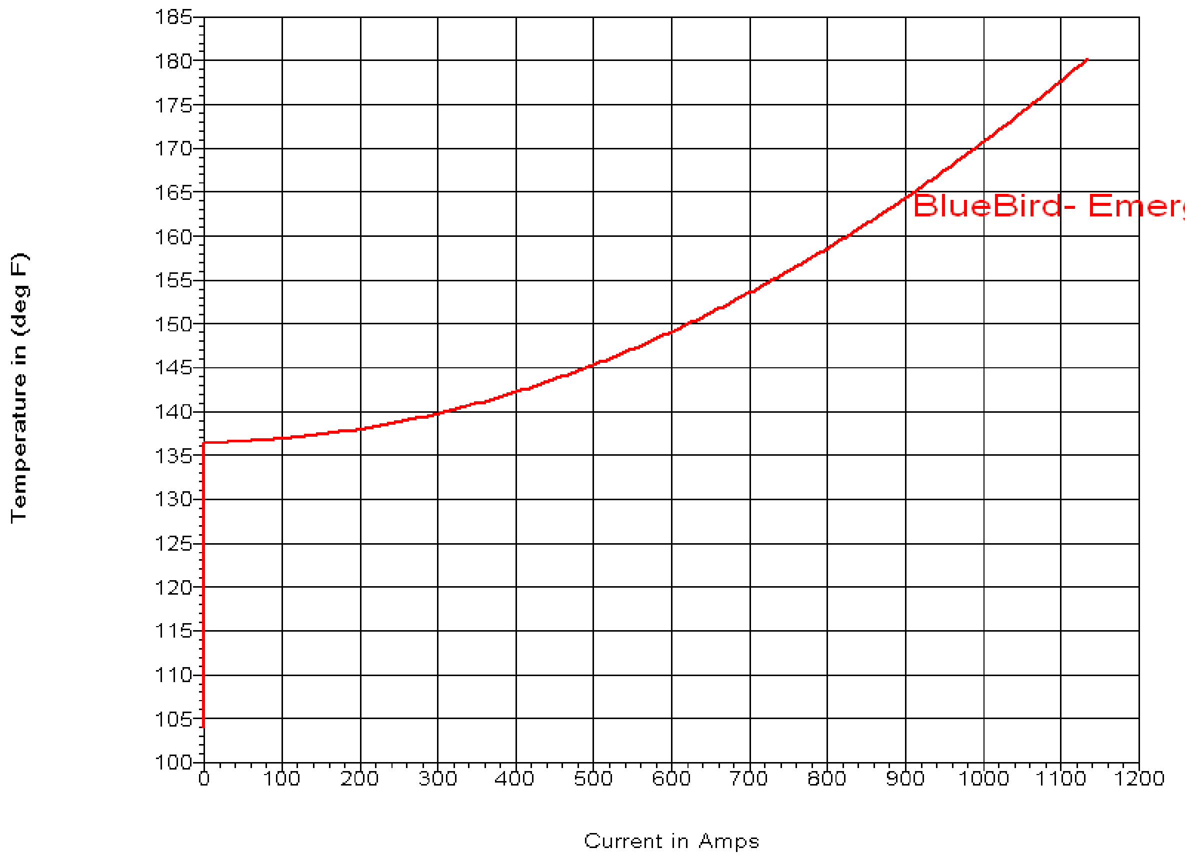
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 0.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar
heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with
most solar heating)

Conductor description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's
Publicly Available Data
Conductor diameter is 1.762 (in)
Conductor resistance is     0.0423 (Ohm/mile) at  68.0 (deg F)
                    and     0.0499 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is      7.105 (Watt/ft) (corresponds to Global Solar Radiation
of   96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is     7.711 (Watt/ft)
Convective cooling is   11.779 (Watt/ft)

Given a constant ac current of 1133.3 amperes,
The conductor temperature is 180.2 (deg F)=82 (deg C)
```


BlueBird- Emer
Temperature in (deg F)
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Current in Amps

3.10.0v

8/11/2010

Power engineers

ACSR Bittern @ MOT=175 F=79 C for Normal Regime, Ampacity=1033.3 A
Ruling Span=1500 ft
Max Sag @ MOT=175 F=79 C, Final=64.08 ft

Conductor: 1272.0 Kcmil 45/ 7 Stranding ACSR "BITTERN"

Area = 1.0680 Sq. in Diameter = 1.345 in Weight = 1.434 lb/ft RTS = 34100 lb
Data from Chart No. 1-957
English Units
Limits and Outputs in Average Tensions.

Span = 1500.0 Feet Special Load Zone
Creep is NOT a Factor Rolled Rod

Design Points					Final			Initial		
Temp °F	Ice in	Wind psf	K lb/ft	Weight lb/ft	Sag Ft	Tension lb	RTS %	Sag Ft	Tension lb	RTS %
0.0	0.50	4.00	0.30	2.997	55.96	15146	44.4	49.65	17050	50.0*
15.0	1.25	4.10	0.00	5.623	64.08	24862	72.9	64.08	24862	72.9
32.0	0.50	0.00	0.00	2.581	56.99	12812	37.6	49.25	14803	43.4
60.0	0.00	24.30	0.00	3.078	60.49	14404	42.2	53.69	16206	47.5
-20.0	0.00	0.00	0.00	1.434	48.54	8343	24.5	37.53	10773	31.6
0.0	0.00	0.00	0.00	1.434	50.29	8056	23.6	39.21	10313	30.2
30.0	0.00	0.00	0.00	1.434	52.83	7672	22.5	41.75	9690	28.4
60.0	0.00	0.00	0.00	1.434	55.30	7333	21.5	44.27	9141	26.8
90.0	0.00	0.00	0.00	1.434	57.69	7033	20.6	46.77	8658	25.4
120.0	0.00	0.00	0.00	1.434	60.00	6765	19.8	49.22	8230	24.1
175.0	0.00	0.00	0.00	1.434	64.08	6340	18.6	53.58	7566	22.2

* Design Condition

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PLS-CADD Version 10.60x64    2:16:15 PM Tuesday, August 10, 2010
Power Engineers

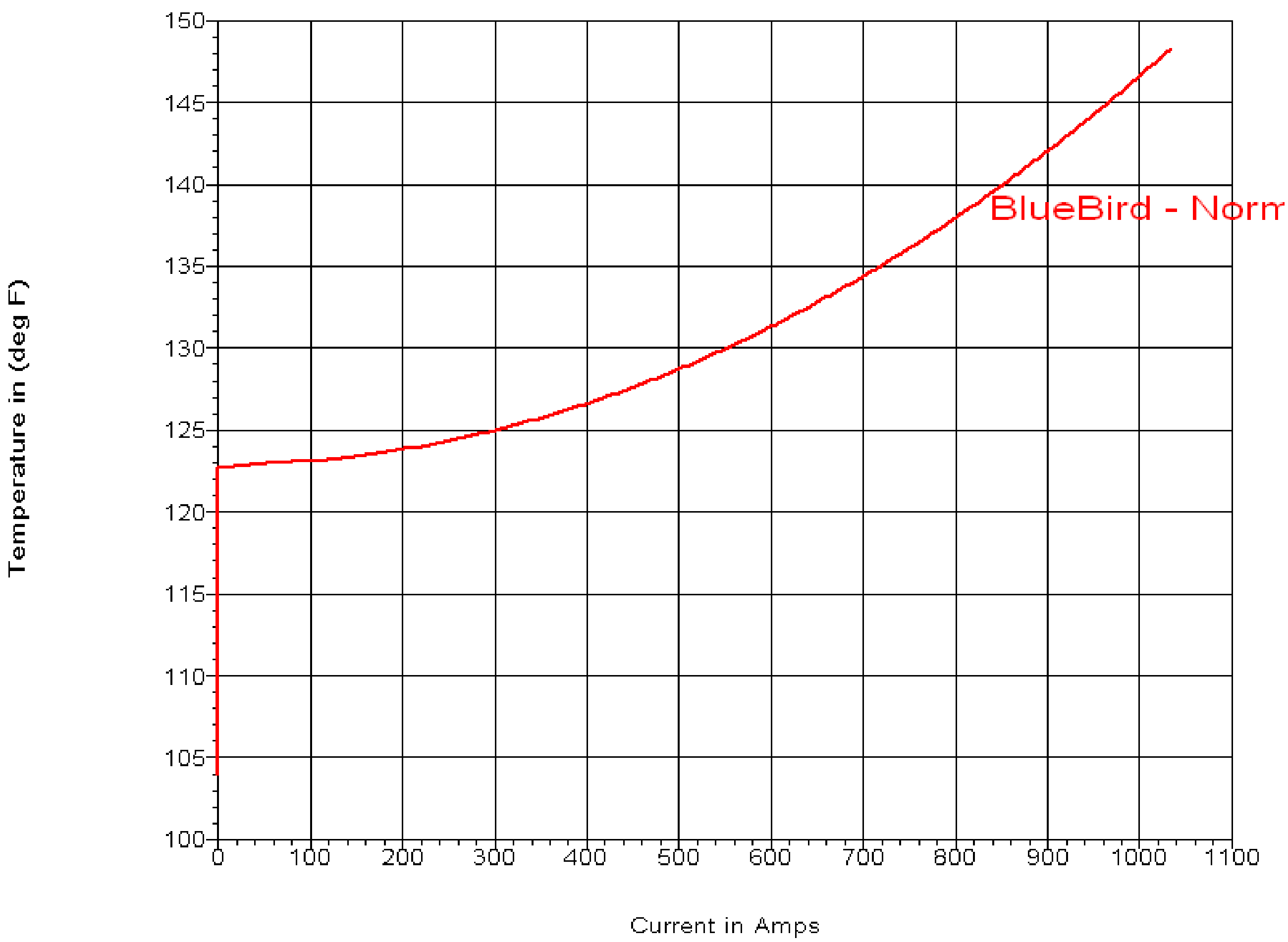
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 2.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar
heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with
most solar heating)

Conductor description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's
Publicly Available Data
Conductor diameter is 1.762 (in)
Conductor resistance is     0.0423 (Ohm/mile) at  68.0 (deg F)
                    and     0.0499 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is      7.105 (Watt/ft) (corresponds to Global Solar Radiation
of   96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is     4.127 (Watt/ft)
Convective cooling is   12.782 (Watt/ft)

Given a constant ac current of 1033.3 amperes,
The conductor temperature is 148.3 (deg F)=64 (deg C)
```



150
145
140
135
130
125
120
115
110
105
100
Temperature in (deg F)
0
100
200
300
400
500
600
700
800
900
1000
1100
Current in Amps
BlueBird - Norm

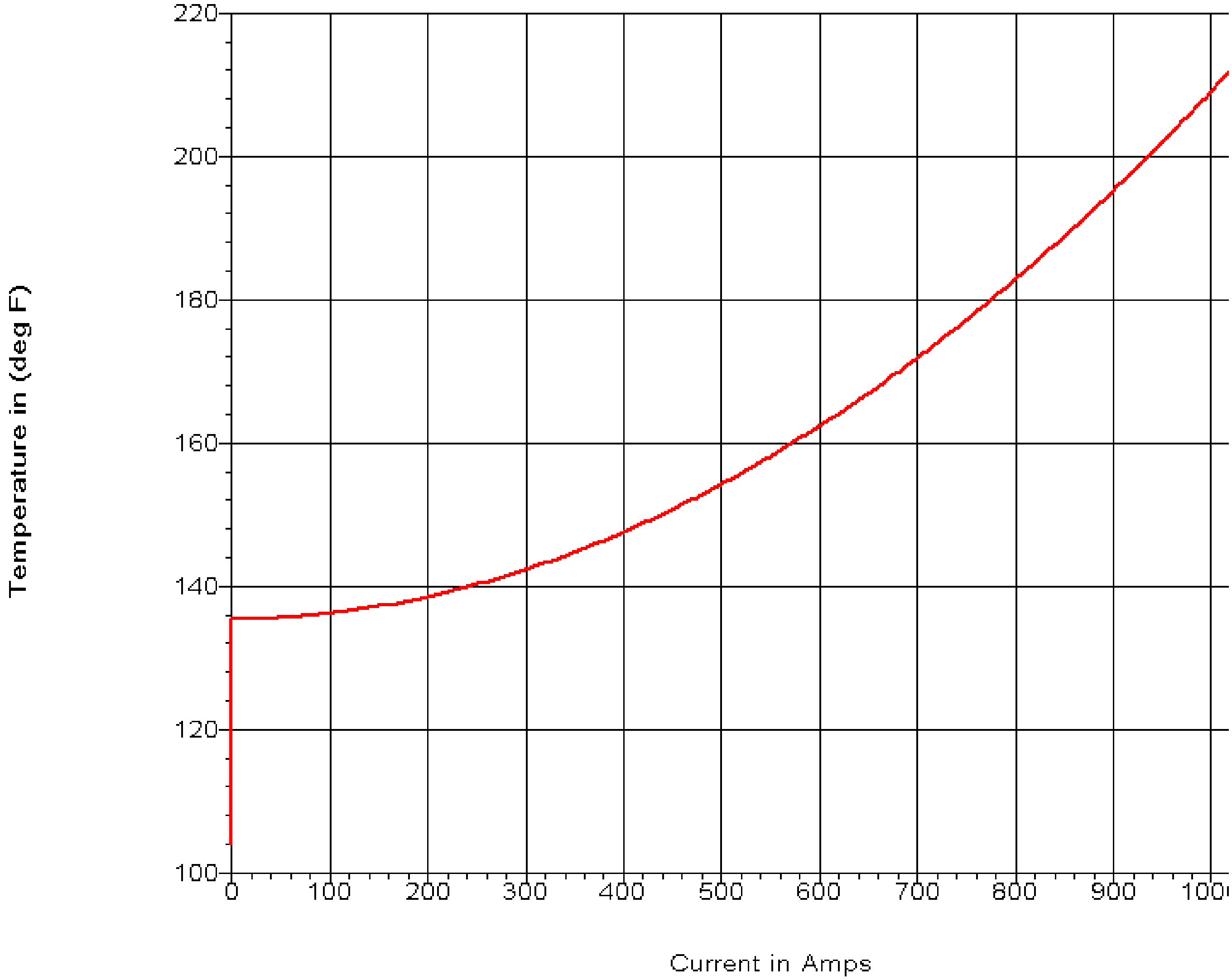
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 0.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: 1272 kcmil 45/7 Strands BITTERN ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.345 (in)
Conductor dc resistance is   0.0714 (Ohm/mile) at 68.0 (deg F)
                       and   0.0863 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is   5.424 (Watt/ft) (corresponds to Global Solar Radiation of 96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is   9.280 (Watt/ft)
Convective cooling is   15.029 (Watt/ft)

Given a constant ac current of 1033.3 amperes,
The conductor temperature is 214.1 (deg F)=101 (deg C)



220
200
180
160
140
120
100
Temperature in (deg F)
0
100
200
300
400
500
600
700
800
900
100
Current in Amps

PLS-CADD Version 10.60x64   2:36:38 PM Tuesday, August 10, 2010
Power Engineers

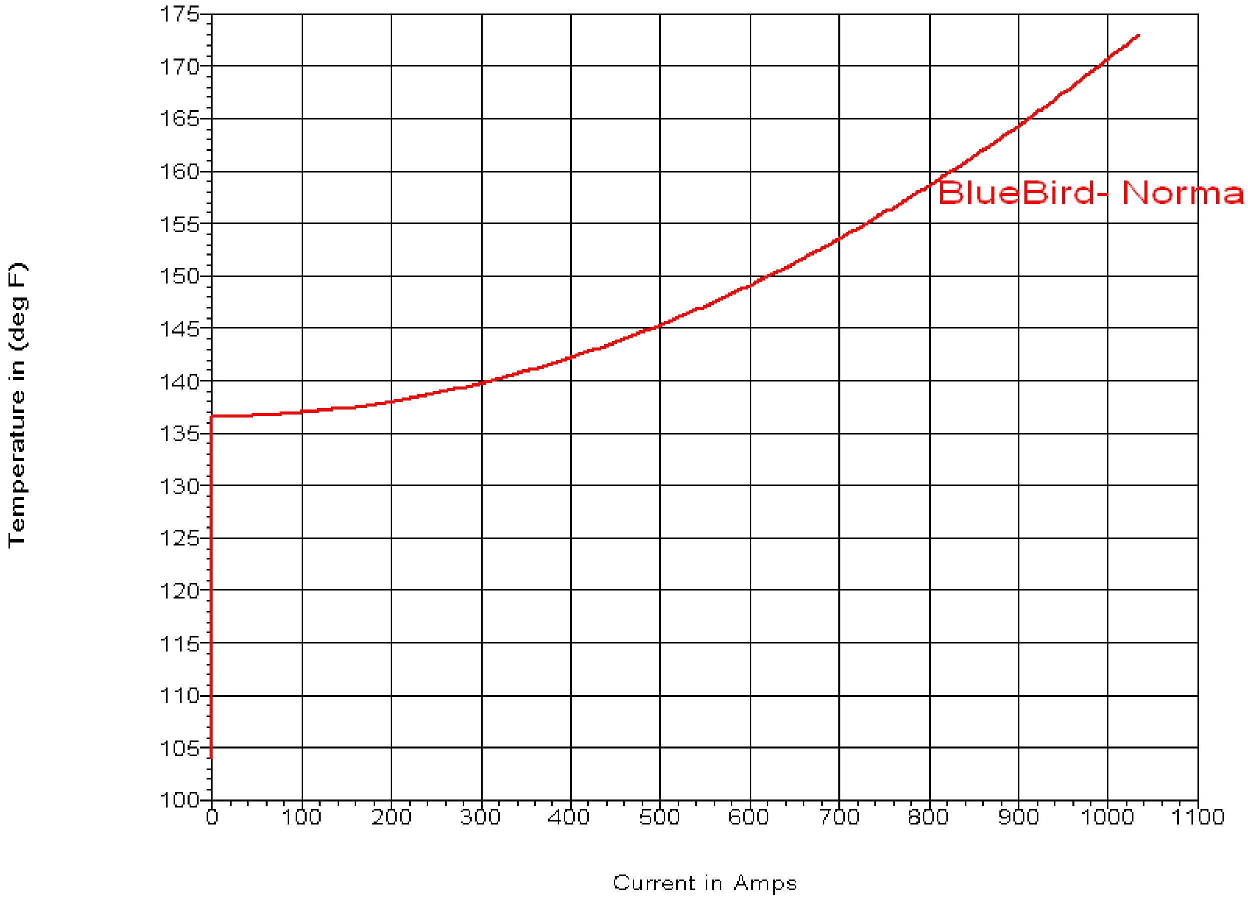
IEEE Std. 738-2006 method of calculation

Air temperature is 104.00 (deg F)=40 (deg C)
Wind speed is 0.00 (ft/s)
Angle between wind and conductor is 90 (deg)
Conductor elevation above sea level is 1000 (ft)
Conductor bearing is -7 (deg) (perpendicular to solar azimuth for maximum solar heating)
Sun time is 14 hours (solar altitude is 63 deg. and solar azimuth is -97 deg.)
Conductor latitude is 30.0 (deg)
Atmosphere is CLEAR
Day of year is 172 (corresponds to June 21 in year 2010) (day of the year with most solar heating)

Conductor description: 2156 kcmil 84/19 Strands BLUEBIRD ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.762 (in)
Conductor resistance is   0.0423 (Ohm/mile) at 68.0 (deg F)
                    and   0.0499 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.5 and solar absorptivity is 0.5

Solar heat input is   7.105 (Watt/ft) (corresponds to Global Solar Radiation of   96.778 (Watt/ft^2) - which was calculated)
Radiation cooling is   6.853 (Watt/ft)
Convective cooling is   10.437 (Watt/ft)

Given a constant ac current of 1033.3 amperes,
The conductor temperature is 173.0 (deg F)=78 (deg C)


Temperature in (deg F)
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
0
100
200
300
400
500
600
700
800
900
1000
1100
BlueBird- Norma
Current in Amps

Southwire SAG10™

8/11/2010

Power engineers

ACSR BlueBird @ MOT=284 F=140 C (Max Allowed for ACSR
Ruling Span=1500 ft
Max Sag @ MOT=284 F=140 C, Final=68.57 ft

Conductor: 2156.0 Kcmil 84/19 Stranding ACSR "BLUEBIRD"

Area = 1.8309 Sq. in Diameter = 1.762 in Weight = 2.511 lb/ft RTS = 60300 lb
Data from Chart No. 1-1020
English Units
Limits and Outputs in Average Tensions.

Span = 1500.0 Feet Customary Heavy Load Zone
Creep IS a Factor Rolled Rod

Design Points					Final				Initial	
Temp °F	Ice in	Wind psf	K lb/ft	Weight lb/ft	Sag Ft	Tension lb	RTS %	Sag Ft	Tension lb	RTS %
0.0	0.50	4.00	0.30	4.324	51.53	23714	39.3	47.16	25891	42.9
15.0	1.25	4.10	0.00	7.339	58.38	35571	59.0	57.72	35975	59.7
32.0	0.50	0.00	0.00	3.917	53.07	20866	34.6	47.84	23126	38.4
60.0	0.00	24.30	0.00	4.363	56.07	22008	36.5	51.19	24084	39.9
-20.0	0.00	0.00	0.00	2.511	45.27	15655	26.0	38.24	18515	30.7
0.0	0.00	0.00	0.00	2.511	47.03	15075	25.0*	39.89	17756	29.4
30.0	0.00	0.00	0.00	2.511	49.60	14301	23.7	42.36	16727	27.7
60.0	0.00	0.00	0.00	2.511	52.09	13623	22.6	44.82	15814	26.2
90.0	0.00	0.00	0.00	2.511	54.51	13025	21.6	47.25	15006	24.9
120.0	0.00	0.00	0.00	2.511	56.85	12494	20.7	49.65	14287	23.7
284.0	0.00	0.00	0.00	2.511	68.57	10386	17.2	61.93	11480	19.0

* Design Condition

POWER ENGINEERS

CLEAN LINE ENERGY: GRAIN BELT EXPRESS +/- 600kV HVDC
FOUNDATION DESIGN CRITERIA

Geotechnical Information:

The foundations will be designed using the soil profiles based on a desktop geotechnical study.

Applied Loading:

The governing intact load cases have an OLF of 1.0 (NESC Extreme Ice w/ Concurrent Wind & NESC Extreme Wind). The broken conductor/conductor stringing load case does govern in some cases and has an OLF of 1.1. This is the predicted load for a broken conductor load and or conductor stringing load therefore the OLF will not be taken out.

Laterally Loaded Drilled Piers:

Foundations will be designed using the design and analysis software MFAD. All foundations will meet the following criteria:

1. Ultimate Load
    a. Factor of safety of 2 with unfactored loads.
2. Allowable Deflection
    a. Maximum tolerable total deflection of 2.0" with unfactored loads.
    b. Maximum tolerable non-recoverable deflection of 0.5" with unfactored loads.
3. Pier Rotation
    a. Maximum tolerable pier rotation of 1.72°.
4. Pier projection of 2.0 ft.
5. Concrete Design
    a. Concrete design strength of 3,000 psi
    b. Concrete strength for construction 4,000 psi.
    c. Longitudinal Reinforcement: #11 bars (60 ksi)
    d. Shear Reinforcement: #4 or #5 ties
    e. 3" clear cover

Note: The allowable deflections for the foundations in some project regions may be adjusted from those shown above to accommodate large variations in subsurface priorities

Uplift and Compression Drilled Piers:

Foundations will be designed with using the design and analysis software SHAFT. All foundations will meet the following criteria:

1. Ultimate load
    a. Shaft determines ultimate load at vertical displacement of foundation diameter divided by 20 (Dia/20).
2. Vertical Displacement (Uplift)
    a. Maximum displacement of 1" with unfactored loads.

3. Vertical Displacement (Compression)
    a. Maximum displacement (settlement) of 1” with unfactored loads.
4. Lateral Performance
    a. The lateral performance of drilled piers shall follow the criteria for laterally loaded drilled piers.
5. Concrete Design
    a. The concrete design shall follow the criteria for lateral loaded drilled piers.