GRAIN BELT EXPRESS
CLEAN LINE

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CLEAN LINE ENERGY

GRIAN BELT EXPRESS HVDC LINE

DESIGN CRITERIA
Revision A

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133798

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REVISION HISTORY		
DATE	REVISED BY	REVISION
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ABBREVIATIONS

ACSR:	Aluminum Conductor, Steel Reinforced
ACSS:	Aluminum Conductor, Steel Supported
ACCR:	Aluminum Conductor Composite Reinforced
AGS:	Armor Grip Support
ASCE:	American Society of Civil Engineers
CTZFS:	Cable Tension For Zero Fiber Strain
CSZFS:	Cable Strain For Zero Fiber Strain
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
MRC:	Metallic Return Conductor
PC:	Pole Conductor
MAD:	Minimum Approach Distance
WS:	Working Space

GENERAL

Project Information

Owner's Name:	Clean Line Energy Partners ("Clean Line")
Project Name:	Grain Belt Express HVDC Transmission Line
Length:	Approximately 725 miles
Voltage:	+/- 600 kV DC (Bi-Pole)
Planned Energization Date:	2022

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Project Description

This project includes developing Preliminary Design Criteria and other supporting information for the purpose of supporting regulatory, permitting, estimating, and other preliminary design activities by Clean Line Energy Partner's ("Clean Line") and its project partners for the proposed Grain Belt Express HVDC transmission line. The project is currently in a regulatory phase in Missouri having received approvals in Kansas and Illinois, and is moving from the conceptual and preliminary design and estimating stage to the final design criteria definition to be used in final detailed design after the all regulatory approvals are received. The purpose of this design update is to advance the project definition from the prior conceptual and preliminary design level to a design level which will serve as the basis for detailed pre-construction design of the transmission line. This design and associated specifications will be used by Clean Line and the Grain Belt Express project partners to complete the next level design and contracting requirements for the project execution.

The design reflected in this Design Criteria document generally reflects updates to the conceptual and preliminary designs performed by POWER for several potential Clean Line HVDC projects. As such, the revisions and updates to this Design Criteria document reflect a combination of revised or updated studies reflecting the information known at this stage of the project. The format and approach taken by POWER is to update the conceptual design information, revising where appropriate. In some cases, primarily in appendices, prior content has not been updated since the conclusions are known to be unchanged. In such cases, a clarifying note has been added to the appendix.

The design parameters for this initial publication of a Grain Belt Express Design Criteria reflect current design criteria for Plains & Eastern Clean Line from March 2016, revised to reflect known changes due to project location, primarily NESC loading district requirements. Other changes will be incorporated as further project definition is known.

HVDC SYSTEM DESIGN PARAMETERS

Based on information available after selection of an HVDC vendor and establishment of performance specifications for the converter stations, the following overall inputs are applicable for line design purposes:

Nominal operating voltage for the project is +/- 600 kV.

The convertor overrating factor (used for prior line emergency condition design) is now 1.0, so there are no longer normal and emergency design regimes commonly referred to in prior publications of the design documents associated with Grain Belt Express.

Windward HVDC Station (Kansas):

- Maximum Power at Rectifier: P rect= 4356 MW
- Maximum Power per Pole: P pole=P rect /2= 2178 MW
- Maximum Current per Pole: I pole= (P pole /V) *1000=(2178 MW / 600 kV) *1000=3630 Amps
- Maximum Current per Conductor: I cond= I pole/3=1210 Amps (3 conductors/pole)
- Maximum Current per Metal Return Conductor (MRC): I mrc= I pole/2=1815 Amps
  (Operating condition when one pole is lost and all current from that pole must be split between the 2 MRC)

Missouri HVDC Station:

- 500 MW maximum delivery to a HVDC converter in Ralls County Missouri.

Illinois HVDC Station:

- 3500 MW delivery to a HVDC converter in Clark county, Illinois.

CODE(S) AND LOADING CONDITIONS

Controlling Code(s)

NESC:	NESC Rule 250 B Heavy District NESC Rule 250C Extreme Wind, adjusted for 50-year return period NESC Rule 250D Extreme Ice with Concurrent Wind, adjusted for 50-year return period
Location or State Specific:	Kansas, Missouri, Illinois
Client Specific:	Clean Line Energy

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 250B, 253-1 / 261-1A	Initial	1.5	2.5	1.65	1
2	EXTREME WIND ALL WIRES INTACT (STEEL & CONCRETE)	60°F 90 MPH (50 YR RP) ASSUMED 230' MAX STR HEIGHT, WITH 820' SPAN; Kz,c=1.57, Kz,s=1.35; Gf,c=0.66; Gf, s=0.80 Results: 20.74 PSF ON WIRE 23.00 PSF ON STR	NESC 250C, 253-1 / 261-1A Table 250-2 Table 250-3	Initial	1.0	1.0	1.0	1
3	NESC EXTREME ICE WITH CONCURRENT WIND ALL WIRES INTACT (STEEL & CONCRETE)	15°F 1.00" ICE (50 YR RP) 4.1 PSF WIND	NESC 250D, 253-1 / 261-1A	Initial	1.0	1.0	1.0	1
4	F2 TORNADIC WIND <u>ON STRUCTURE WITH 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	IEEE524 Annex D	Initial	1.5	1.5	1.5	1
7	STRINGING/BROKEN SHIELD WIRE LOAD	0°F, 4 PSF	ASCE #74 3.3.2 Failure Containment	Initial	1.5	1.5	1.5	1
8	STRINGING/BROKEN METAL RETURN CONDUCTOR LOAD	0°F, 4 PSF	ASCE #74 3.3.2 Failure Containment	Initial	1.5	1.5	1.5	1
9	STRINGING/BROKEN POLE CONDUCTOR LOAD	0°F, 4 PSF	ASCE #74 3.3.2 Failure Containment	Initial	1.5	1.5	1.5	1

Notes:

1. Load cases 1 through 5 shall be analyzed assuming a foundation rotation of 1.72° (3%) when used with pole structures.

2. Load case 3 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 6 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 (ruling spans, wind spans, weight spans, etc. for each type of structure), see attached Appendix AA-Design Assumptions.

5. Load Case 3 shall be analyzed with the wind in a transverse direction, at a 45° yawed angle, and in a longitudinal direction.

6. Load Case 7, snub-off, is applied with wires snubbed off at three horizontal to one vertical. All wires (shieldwires, MRCs, pole conductors) should be assumed that will snub-off simultaneously (worst case). See attached Appendix AB, for Snub-Off Case Loadings example of calculations (based on IEEE 524, Annex D).

7. Load Case 8, stringing/broken shield wire, accounts for a stringing block getting hung up at one of the shieldwires or for breaking one of the shieldwires. The longitudinal load applied to the structure at that broken shield wire position: back span: 0% of tension, 100% of weight span, ahead span: 100% of tension, 100% of weight span (assumed the shield wire breaks in the middle of back span, which is the worst case, that means its vertical load remains intact, assumed leveled spans). All other wire loads should be assumed intact. See ASCE Manual 74-2010, Section 3.3.2. Longitudinal Loads and Failure Containment for detailed calculations and attached Appendix AE-Stringing /Broken Case Example of Calculation.

8. Load Case 9, stringing/broken MRC (metal return conductor), accounts for a stringing block getting hung up at one of the MRCs or for breaking one of the MRCs. The longitudinal load applied to the structure at that broken MRC position: back span: 0% of tension, 100% of weight span; ahead span: 70% of tension (the broken MRC insulator string is assumed to swing longitudinally at a 45 deg angle towards ahead span), 100% of weight span (assumed the MRC breaks in the middle of back span, that means its vertical load remains intact, which is the worst case, assumed levels spans). All other wire loads should be assumed intact. See ASCE Manual 74-2010, Section 3.3.2. Longitudinal Loads and Failure Containment for detailed calculations and attached Appendix AE-Stringing /Broken Case Example of Calculation.

9. Load Case 9, stringing/broken pole conductor, accounts for a stringing block getting hung up at one sub-conductor out of three in the bundle, of only one pole (positive or negative) or for breaking of one sub-conductor out of three in the bundle, of only one pole (positive or negative). The longitudinal load applied to the structure at that broken sub-conductor: back span: 0% of tension, 100% of weight span; ahead span: 70% of tension (the broken pole conductor insulator string is assumed to swing longitudinally at a 45 deg angle towards the ahead span), 100% of weight span (assumed that sub-conductor breaks in the middle of back span, which is the worst case, that means its vertical load remains intact, assumed levels spans). The other two sub-conductors, from the pole where we broke one sub-conductor, and all the other pole three sub-conductors, both shield wires, and both MRCs locations should be assumed intact. See ASCE Manual 74-2010, Section 3.3.2. Longitudinal Loads and Failure Containment for detailed calculations and attached Appendix AE-Stringing /Broken Case Example of Calculation.

10. The structure should be designed for an additional load case, for loads anticipated due to rigging for wire clip in during construction. Loads shall be applied as follows: at one pole conductor location, apply load: W_{CL} directly above the work point (WP). Each location should be analyzed separately. The values should be:
    - Tangent Suspension 0-2 deg:
        - Basic: W_{CL}=26,650 lbs; Medium: W_{CL}=31750 lbs; Heavy: W_{CL}=43600 lbs.
    - Small Angle Suspension 2-10 deg:
        - W_{CL}=31750 lbs
    - Medium Angle Suspension 10-30 deg:
        - W_{CL}=31750 lbs

    Apply load case 6 to all other attachment points.

11. All load cases shall include the weight of the clamp and hardware (shieldwires) and the weight of insulators and hardware (for MRC and pole conductors) provided in attached Appendix AC-Clamps and Insulator Parameters and attached Appendix AD1 & AD2- Insulator Assembly Types (“Medium” & “Light” Pollution). The wind load on clamps (shieldwire) and insulators (MRC, pole conductor) will use the Area Exposed to Wind [ft^2] provided in attached Appendix AC-Clamps and Insulator Parameters.

12. Load case 6 will also include 800 lb. additional vertical load at the tip of each arm to account for two maintenance men and equipment.

13. Load Case 5 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.

14. 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. All the other cases: Overload Factor = 1.0, Strength Reduction Factor = 0.5 for non-ceramic, 0.65 for ceramic and glass.

15. 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 6.

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 250 B, 253-1 / 261-1A	Initial	1.5	2.5	1.65	1
2	EXTREME WIND ALL WIRES INTACT (STEEL & CONCRETE)	60°F 90 MPH (50 YR RP) ASSUMED 230' MAX STR HEIGHT, WITH 820' SPAN; Kz,c=1.57, Kz,s=1.35; Gf,c=0.66; Gf, s=0.80 Results: 20.74 PSF ON WIRE 23.00 PSF ON STR	NESC 250C, 253-1 / 261-1A Table 250-2 Table 250-3	Initial	1.0	1.0	1.0	1
3	NESC EXTREME ICE WITH CONCURRENT WIND ALL WIRES INTACT (STEEL & CONCRETE)	15°F 1.00" ICE (50 YR RP) 4.1 PSF WIND	NESC 250D, 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 250B, 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 90 MPH (50 YR RP) ASSUMED 230' MAX STR HEIGHT, WITH 820' SPAN; Kz,c=1.57, Kz,s=1.35; Gf,c=0.66; Gf, s=0.80 Results: 20.74 PSF ON WIRE 23.00 PSF ON STR	NESC 250C, 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	15°F 1.0" ICE (50 YR) 4.1 PSF WIND	NESC 250D, 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 (ruling spans, wind spans, weight spans, etc. for each type of structure), see attached Appendix AA-Design Assumptions.

5. Load Cases 6, 7, and 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 clamp and hardware (shieldwires) and the weight of insulators and hardware (for MRC and pole conductors) provided in attached Appendix AC-Clamps and Insulator Parameters and attached Appendix AD & AD2- Insulator Assembly Types ("Medium" & "Light" Pollution). The wind load on clamps (shieldwire) and insulators (MRC, pole conductor) will use the Area Exposed to Wind [ft^2] provided in attached Appendix AC-Clamps and Insulator Parameters.

8. Load case 5 will also include 800 lb. additional vertical load at the tip of each arm to account for two maintenance men and equipment.

9. 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.

10. 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 and 6: Overload Factor = 1.0, Strength Reduction Factor = 0.4
    b. All the other cases: Overload Factor = 1.0, Strength Reduction Factor = 0.5 for non-ceramic, 0.65 for ceramic and glass.

11. 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.

WIRES FOR THE MAIN LINE

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):	I_{PC} =I pole/3=3630/3=1210 A: 72 Deg C (162 Deg F)

Appendix J provides comparison between the possible conductors which could be selected for this contract and ends with a recommendation of the selection. Sag and Tension calculations for the Pole Conductor (PC): ACSR Bluebird, Metal Return Conductor (MRC): ACSR Chukar, and OPGW are shown in Appendices E & E1, while Appendices F & F1 reports Ampacity calculation.

OPGW

There will be two shield wires, one to protect each pole conductor:

- Shield Wire Alternative 1: Two OPGW (Limited Use)
- Shield Wire Alternative 2: One OPGW and One ACSR Leghorn (Primary Design)

It is anticipated that Alternative 1 with two OPGW will only be used in isolated situations, such as river crossings or other areas that may warrant redundancy in OPGW for ease of communication service restoration in case of an OPGW failure.

Detailed Specification for the OPGW is presented in Appendix B. POWER requested quotations from several vendors and all of them came back with a “stranding stainless steel tube” type of OPGW design, trying to match the Power’s specification. POWER chose the vendor with the design providing the highest CTZFS (Cable Tension for Zero Fiber Strain), and highest CSFZFS (Cable Strain for Zero Fiber Strain), also called “Strain Margin”, and which had also the lowest cost for OPGW and its hardware. Details of the chosen OPGW are listed below.

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

Appendix C lists the Lightning Algorithm used to check the OPGW while Appendix D shows the outer layer's wire required diameter calculation based on expected lighting charge at line location.

OPGW Selection based on fault current rating is presented in 2 appendices:
*Appendix AJ-1: OPGW Selection based on Fault Current-Variant 1: Two OPGW.
*Appendix AJ-2: OPGW Selection based on Fault Current-Variant 2: One OPGW and One ACSR Leghorn.
*Appendix AJ-3: OPGW Specification-Clean Line Projects.

OPGW will be paired with ACSR Leghorn, which has a similar DC Resistance at 40 C: **0.6833 [Ohm/mile**] as the OPGW: **0.8517 {Ohm/mile**] (where 40 C is the initial temperature in fault current calculations). Therefore, the maximum fault current expected at the Converter Stations, (1LG): 62.7 kA) will be split nearly in half between the 2 shieldwires: 45% in the OPGW and 55% in the ACSR Leghorn. The similar DC resistance makes the ACSR Leghorn a better shield wire to pair with the OPGW than a smaller shield wire, such as 7#8 Alumoweld, which would have a higher DC resistance, and would therefore take only 25-30% of the fault current, leaving 70-75% of the fault current to go to the OPGW. This would result in the fault current exceeding the capacity of the OPGW.[1] Pairing the Brugg 49AY85ACS-2C OPGW with ACSR Leghorn, the OPGW will take 45% and the ACSR Leghorn 55% of the maximum fault current.[2]

Appendices AJ-1 & AJ-2 contain all the Electrical Calculations, in all scenarios:

- Fault current At AC/DC Converter Substation and within 1 mile from AC/C Converter Station: worst case: 1LG: I=62.6 kA; t=0.1 sec

- Over 1 mile away from AC/D Converter Substation: 1LG:
  - I=20.8 kA; t=0.25 sec (best scenario)
  - I=20.8 kA; t=0.75 sec (worst scenario: maximum duration: 0.75 sec, coming from: 0.1 sec (primary)+0.25 sec (back-up)+4x0.1 sec (4 reclosures at 0.1 sec primary each)).

Appendix AJ-3 is the OPGW Specification for procurement of OPGW.

[1] 70% of the fault current would be: 62.6 kA*0.7=43.8 KA, which would mean (assuming the fault current at substation will be cut in t=0.1 sec) a fault current rating of: I^2*t=43.8^2*0.1 sec=192 kA^2*sec, which exceed the maximum allowed for the OPGW: 100 kA^2*sec.
[2] 62.6 kA*0.45=28.17 kA, thus the fault current rating will be: I^2*t=28.17^2*0.1=80 kA^2*sec, under the maximum allowed for the OPGW design: 98 kA^2*sec.

Shieldwire

In Shield Wire Alternative 2, OPGW will be paired with ACSR Leghorn, the specifications of which are shown below:

Size (kcmil/AWG):	134.6 kCMIL 12/7 Strands
Composition (AW, ACSR etc.):	ACSR
Code Word:	Leghorn
Diameter:	0.530 inches
Weight:	0.304 lbs/ft
Rated Breaking Strength:	13,000 lbs
Cross-Sectional Area:	0.1674 sq. inch

Optical Amplifier Repeaters for OPGW

Optical Amplifier Repeaters are used to extend the reach of optical communications links by overcoming loss due to the attenuation of the optical fiber (signal degradation in dB/km with distance) and distortion of the optical signal.

The maximum allowed distance between Optical Amplifier Repeater depends on many factors, not just the type of fiber used. These factors are discussed in detail in Appendix AL.

In general, optical repeaters (fiber optic regeneration sites) are required every 50 to 63 miles.

Because the OPGW for this project will **use G.655** type of single mode fiber instead of **G.652D** type of single mode fiber, with its advantages presented in detail in Appendix AL, we anticipate repeaters to be necessary every 63 miles. For 700 miles, this will result in at least 11 repeaters (regeneration sites).

A typical fiber regeneration site will be approximately 100'x100', with a fenced area of approximately 75'x75'. Regeneration sites are typically adjacent to the ROW, and may or not may abut the ROW. Regeneration Equipment will be enclosed within a small control building made of either metal or concrete, approximately 12x32' x 9' tall. Access road and power supply to the site will be required, which will be typically be provided from an existing electric distribution line near the fiber optic regeneration site. The voltage of the power supply is typically 34.5 kV or lower.

The location of the regeneration sites and obtaining power for the new sites will be addressed during the detailed design process.

An emergency generator with fuel storage is typically installed at the site, inside the fenced area.
Two cables routes (aerial and/or buried) between the transmission ROW and the equipment shelter will be required. A permanent access road to each fiber regeneration site will be required. These access roads will also be used for permanent access to the transmission lines and should be included in the access road numbers for the HVDC and HVAC transmission lines.

Metal Return Conductor (MRC)

Size (kcmil/AWG):	1780 kcmil
Composition (ACSR, AAC, etc.):	ACSR
Code Word:	Chukar
Diameter:	1.602 inches
Weight:	2.075 lbs/ft
Rated Breaking Strength:	51,000 lbs
Design Voltage:	104 kV HVDC
Typical Operating Voltage:	104 kV HVDC
Maximum Operating Voltage:	109 KV HVDC
Maximum Conductor Temperature (Temperatures calculated using IEEE 738 methodology for predicted line loadings under normal and emergency conditions):	I_{MRC} =I pole/2=3630/2=1815 A: 117 Deg C (242 Deg F)

Appendix P lists the required Metal Return Conductor clearances while appendix Q presents the Metal Return Conductor selection analysis.

WIRES FOR MISSISSIPPI RIVER CROSSING SPANS

Transmission Conductor- FOR MISSISSIPPI RIVER CROSSING SPANS

Size (kcmil/AWG):	1622 kcmil
Composition (ACSR, AAC, etc.):	ACCR-TW_1622-T13
Code Word:	Pecos (this trap wire is diameter equivalent to round wire Martin)
Diameter:	1.417 inches
Weight:	1.774 lbs/ft
Rated Breaking Strength:	55500 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: Emergency Regime: I_{PC} =I pole/3=3630/3=1210 A: 82 Deg C (180 Deg F)

The ampacity calculations and corresponding MOTs are presented in attached Appendices F& F1 - Ampacity calculations 2014; Appendix F2- Ampacity Calculations 2015-for River Crossing.
The comparison leading to the selection of the ACCR/TW Pecos wire is shown in Appendix G, titled Mississippi River Crossing-Conductor Comparison and Selection.

OPGW - FOR MISSISSIPPI RIVER CROSSING SPANS

Like the main line, there will be two OPGW, one to protect each pole. But the OPGE design for the Mississippi River Crossing, is different than the OPGW for the rest of the line, due to the fact the OPGW for the river crossing has to go over a very long span, so a special OPGW design is required, with high CTZFS (over 80%) and CSFZFS (over 0.55%), even for a span of 4000' or more.

Size (kcmil/AWG):	161 ACS-2C
Composition (EHS, AW, etc.):	17 Aluminum Clad Steel Wires ACS20.3% IACS 2 Stainless Steel Tubes 304 containing 6-24 fibers each and gel
Diameter:	0.646 inches
Weight:	0.678 lbs/ft
Rated Breaking Strength:	38,079 lbs
Number of Fibers:	12-48, depending on final project requirements

Metal Return Conductor (MRC) - FOR MISSISSIPPI RIVER CROSSING SPANS

Size (kcmil/AWG):	1622 kcmil
Composition (ACSR, AAC, etc.):	ACCR/TW_1622-T13
Code Word:	Pecos
Diameter:	1.417 inches
Weight:	1.774 lbs/ft
Rated Breaking Strength:	55,500 lbs
Design Voltage:	114 kV HVDC
Typical Operating Voltage:	114 kV HVDC
Maximum Operating Voltage:	120 KV HVDC
Maximum Conductor Temperature (Temperatures calculated using IEEE 738 methodology for predicted line loadings under normal and emergency conditions):	I_{MRC} =I pole/2=3630 A/2=1815 A: 128 Deg C (262 Deg F)

Information pertaining to the type of MRC selected for Mississippi river crossing is in appendix G1-Mississippi river crossing-metal return conductor comparison and selection and appendix P1-Mississippi river crossing-metal return conductor clearances tables.

Notes:

1) The ACCR/TW Pecos conductor has a different maximum conductor temperature when it is used as pole conductor vs. when it is used as metal return conductor, due to the different ampacity for each case.

- Pole Conductor:
  - I conductor=I pole/3=3630/3=1210 A, with MOT=82 C (180 F)

- Metal Return Conductor:
  - I conductor=I pole/2=3630/2=1815 A, with MOT=128 C (262 F)

2) The Metal Return Conductor ACSR Chukar used on the entire line (except Mississippi River Crossing) will be energized at +/- 104 KV, and its required clearances are provided in Appendix P, while the Metal Return Conductor ACCR/TW Pecos used on the Mississippi River Crossing will be energized at +/-114 kV, and its required clearances are provided in Appendix P1.

CONDUCTOR RATING CRITERIA

The following table summarizes conductor ampacity calculated using IEEE 738 methodology under the maximum 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 (expect for conductors “with special coating”, for which Emissivity factor = 0.9; and Solar absorptivity factor = 0.2).

See Appendix F (Ampacity Calculations 2014), F1 (Ampacity Calculations 2015) & F2 (River Crossing Ampacity Calculations 2015), for other parameters used in these calculations, and the resulting maximum operating temperatures for the conductors analyzed.

Please note that an analysis was included to compare any potential to alter the project design by using an optional coating system available from General Cable. While the data required for that analysis is included in some of the appendices, the alternative was not deemed cost effective due to the relatively cool operating temperatures on the line.

<table>
<tr><th rowspan="3">Circuit</th><th rowspan="3">Conductor</th><th rowspan="3">Voltage (kV)</th><th colspan="4">Maximum Line Ratings</th></tr>
<tr><th colspan="2">Winter</th><th colspan="2">Summer</th></tr>
<tr><th>MW</th><th>Amps</th><th>MW</th><th>Amps</th></tr>
<tr><td>Plains & Eastern</td><td>ACSR Bluebird 3 sub-conductors per pole</td><td>Nominal: 600 Maximum: 632</td><td>4356 At rectifier</td><td>3630 Per pole
1210 Per sub-conductor</td><td>4356 At rectifier</td><td>3630 Per pole
1210 Per sub-conductor</td></tr>
<tr><td>Plains & Eastern Mississippi River Crossing Span</td><td>ACCR-TW Pecos 3 sub-conductors per pole</td><td>Nominal: 600 Maximum: 632</td><td>4356 At rectifier</td><td>3630 Per pole
1210 Per sub-conductor</td><td>4356 At rectifier</td><td>3630 Per pole
1210 Per sub-conductor</td></tr>
</table>

WIRE SAG/TENSION LIMITS

Conductor and Metalic Return Conductor Sag-Tension Limits for main line.
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 Appendices E & E1-Sag & Tension Files.

Weather Case				Sag or Tension Limit		
Wind (psf)	**Ice (inches)**	**Temp (°F)**	**Cond.**	**NESC Limit**	**South wire Sag10 Program Limit**	**Project Specific Limit**
4	0.5	0	I	60% RBS	50% RBS	50% RBS
4	0.25	15	I	60% RBS	50% RBS	50% RBS
20.74	0	60	I	--	--	75% RBS
4.1	1	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	0.5	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.
4	0.25	15	I	--	---	
20.74	0	60	I	--	--	
4.1	1	15	I	--	--	

Conductor and Metallic Return Conductor Sag-Tension Limits - for river crossing spans.
The following table summarizes all sag-tension limits considered. The Mississippi River Crossing Span is about 5000 ft. The most stringent limit will be utilized to control the sag-tension in each span, or an agreed upon control tension that will also meet the requirements below. See Appendices E & E2-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	0.5	0	I	60% RBS	50% RBS	50% RBS
4	0.25	15	I	60% RBS	50% RBS	50% RBS
20.74	0	60	I	--	--	75% RBS
4.1	1	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

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 Appendices E, E1,-Sag & Tension Files.

Weather Case				Sag or Tension Limit		
Wind (psf)	**Ice (inches)**	**Temp (°F)**	**Cond.**	**NESC Limit**	**South wire Sag10 Program Limit**	**Project Specific Limit**
4	0.5	0	I	60% RBS	50% RBS	50% RBS
4	0.25	15	I	60% RBS	50% RBS	50% RBS
20.74	0	60	I	--	--	60% RBS
4.1	1	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	25% RBS
0	0	-20	I	--	--	Uplift Condition
4	0.5	0	I	--	--	Slack Tension Into Substation D.E. Frame. 3000 lbs maximum per OPGW
4	0.25	15	I			
20.74	0	60	I	--	--	
4.1	1	15	I	--	--	

<u>OPGW to Conductor Sag Ratios Requirements</u> (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

The second ratio at 32 F with Ice vs. 32 F without ice (95%) controls the sag and tension of OPGW.
See Appendices E, E1 -Sag and Tension Files.

OPGW Sag-Tension Limits – FOR RIVER CROSSING SPANS
The following table summarizes all sag-tension limits considered. The Mississippi River Crossing Span is about 5000 ft. The most stringent limit will be utilized to control the sag-tension in each span, or an agreed upon control tension that will also meet the requirements below. See Appendices E, E2-Sag & Tension Files.

Weather Case				**Sag or Tension Limit**		
Wind (psf)	**Ice (inches)**	**Temp (°F)**	**Cond.**	**NESC Limit**	**Alcoa Sag10 Program Limit**	**Project Specific Limit**
4	0.5	0	I	60% RBS	50% RBS	50% RBS
4	0.25	15	I	60% RBS	50% RBS	50% RBS
20.74	0	60	I	--	--	75% RBS
4.1	1	15	I			75% 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	25% RBS
0	0	-20	I	--	--	Uplift Condition

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

The second ratio at 32 F with ice vs 32 F without ice (95%) controls the sag and tension of OPGW.
See Appendices E, E2, E3-Sag and Tension Files.

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; k=0.3 (for Oklahoma State only)
	NESC Medium Rule 250 B: 15 Deg F, 4 PSF Wind, 0.25" Ice; k=0.2 (for Arkansas and Tennessee States only)
Condition for Final Sag after Creep:	60 Deg F, No Wind, No ice

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.

For ACSR and ACCR conductors, that is over 100 C (212 F).

The ACSR Bluebird (used as a pole conductor, for entire line, except for Mississippi River Crossing), does not follow “aluminum can go into compression” model, because its MOT (Maximum Operating Temperature), under both normal and emergency regime, does not go over 100 C (212 F).

The ACSR Chukar (used as metal return conductor for entire line, except Mississippi River Crossings), does follow “aluminum can go into compression” model, because its MOT (Maximum Operating Temperature), under both normal and emergency regime, does go over 100 C (212 F).

Note: The MRC will reach such high temperatures, over 100 C (212 F), only if one entire pole (positive or negative) is lost, in normal regime or emergency regime, with all its 3 sub-conductors, in which case, the current that was supposed to go through the 3 sub-conductors of that pole, will be split between the 2 MRCs. The probability of this to happen is very low, and even if it will ever happen, it will be just for a short period of time, up until the lost pole (positive or negative) will be repaired.

Under Emergency Case, the MRC ACSR Chukar MOT=242 F > 212 F, therefore the conductor model must be: ” Aluminum can go into compression” (does not bird-cage).
Plus, being an ACSR conductor with % steel area: (At- Ao)/A t= (1.5126-1.3986)/1.5126*100=7.5%, and MOT over 212 F, it will have also “High Temperature Creep”.

No issues there, for both “aluminum can go into compression” and “high temperature creep”, several major US Utilities allow ACSR Conductors, during Emergency Regime, to reach maximum MOT=284 F (140 C), higher than it will be in this DC line application: 242 F (I17 C). Of course, taking into consideration the model with “aluminum can go into compression” and “high temperature creep”, the sag will be larger at MOT=242 F.

The ACCR/TW Pecos, when used as pole conductor in Mississippi River Crossing Spans, does not follow “aluminum can go into compression” model, under emergency regime: I cond=I pole/3=3630 A/3=1210 A because its MOT (Maximum Operating Temperature)=82 C (180 F), does not go over 100 C (212 C),

The ACCR/TW Pecos, when used as metal return conductor in Mississippi River Crossing Spans, does follow “aluminum can go into compression” model, under emergency regime: I mrc =I pole/2= 3630 A/2= =1815 A because its MOT (Maximum Operating Temperature)=128 C (262F), does go over 100 C (212 C),

The ACCR/TW Pecos when used as both pole conductor and metal return conductor in Mississippi River Crossing Spans, does not follow aluminum can go into compression” model under the normal regime, because in normal regime it does not go over 100 C (212 C).

Note: The ACCCR/TW Pecos, will still have its MOT, under both normal and emergency regime, under its limits imposed by the manufacturer (3 M) : 210 C (410 F), under normal regime, and 240 C (464 F), under emergency regime.

The maximum virtual compressive stress for ACSR Chukar, to be used in aluminum can go into compression” model is: 1.5 kpsi*($A_{AL\ outer}$/ A_{total})=1.5*1.3986/1.5126=1.387 kpsi

The maximum virtual compressive stress for ACSSR/TW Pecos, to be used in aluminum can go into compression" model is:

- Theoretical: 1.5 kpsi*($A_{AL\ outer}$/ A_{total})=1.5*1.274/1.437=1.329 kpsi

- Practical: based on manufacturer (3M) extensive testing of high temperature sag, the value that 3M found that it will give temperature sag results that are consistent with these extensive tests, is:
  - EF o actual=1.45 ksi
  - EF virtual=(ARo/AT)*EF o actual
  - EF virtual=0.862*1.45=1.25 ksi

Therefore, in PLS-CAD wire file model for ACCR/TW Pecos, when used as MRC, in emergency regime, the virtual stress value used is: 1.25 ksi.

STRUCTURES

Circuits	
No. Circuits (Single or Double):	2-Pole Horizontal HVDC with 2 Dedicated Metallic Return Conductors (MRC)
Bundled:	3 conductors per bundle (positive pole and negative 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 was performed during the conceptual design phase 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. A secondary data mining effort may be used to further refine the geotechnical assumptions used for estimating foundation designs during the preliminary design phase.
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	Drilled piers and direct embed poles subject to uplift/compression loads will be designed per POWER standard as shown in Appendix K.

Loads ______________________________

Calculated Lightning Outages

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

Appendix C lists the Lightning Algorithm used to check the OPGW while Appendix D shows the outer layer's wire required diameter calculation based on expected lighting charge at line location.

Distance between Deadends

A deadend structure will be placed approximately every 10 miles.

But a dead end structure will be used anyway for any line angle over 30 degrees.

The suspension structures will be used only for line angles under or equal with 30 degrees.

Other

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

Raptor Protection: YES ☐ NO ☐ Distance: APLIC (51" ht x 71" span)

Maximum or Minimum Pole Height Limitations (specify): TBD

Anodes 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		X	
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	TBD	TBD	N/A	TBD	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 (AFL), Vortex software (PLP), or Select 4R-Fargo software (Hubbell). For final design, vibration analysis would be performed by the damper supplier.

- At 89 mm=3.5 in from end of suspension clamp, the Maximum Allowed Endurance Limits, per EPRI Orange Book, are:
  - Maximum Allowed Bending Strain=125 microns/m (0-to-Peak) (ACSR conductors)
  - Maximum Allowed Bending Amplitude=240 microns=10 mills (Peak-to-Peak)
  - Maximum Allowed Bending Stress: Sigma a =22 MPa=3190 psi
- Endurance Limit: f*Y max=118 mm/sec=4.65 in/sec (per EPRI Orange Book, for all ACSR Conductors, except 7/1 strands)
- Per EPRI Orange Book “Transmission Line-Wind Induced Conductor Motion”, For ACSR Bluebird (Entire Line) Maximum Allowed Bending Amplitudes are:
  - At 15%RBS: Y_B=0.28 mm=11 mills
  - At 25%RBS: Y_B=0.24 mm=10 mills
  - At 35%RBS: Y_B=0.22 mm= 9 mills

Note: the same maximum allowed amplitudes will be applicable also for the ACCR/TW Pecos (used for Mississippi River Crossing).

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, preferably, asymmetrically, with 10-15% detuning, with maximum sub-span of 200 ft, minimum sub-span 100 ft, ratio of adjacent sub-spans=0.8 to 0.9, first and last sub-spans=0.5*(maximum sub-span), 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:	Considered, but Not Chosen.
V-String:	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:	Considered, but Not Chosen
Glass:	Considered; Currently Preferred Material
Polymer:	Considered, but Not Chosen.
Other (fog, etc.):	To Be Considered
Corona Rings:	To Be Considered
End Fittings:	To Be Considered

Insulation Ratings-Transmission

	Electrical Characteristics *			
	DC Withstand Voltage*		Dry Lightning Impulse Withstand Voltage (kV)	DC SF6 Puncture Withstand Voltage (kV)
M&E Strength (lbs)	Dry one minute (kV)	Wet one minute (kV)		
25K	125	60	140	225
40K	150	65	140	225
50K	140	60	135	225
66K	140	60	135	225
90K	160	70	140	225
120K	160	70	140	255

Data based on the following toughened glass, ball & socket coupling, Sediver's DC fog type bells, all used, in different assemblies and configurations, in the different structure types (towers and poles) of this +/- 600 kV DC Transmission Line:

- 25 kips (N120PR/C 146 DR)
- 40 kips (N180P/C 160 DR)
- 50 kips (N220PJ/C 180 DR)
- 66 kips (F300PJ/C 195 DR)
- 90 kips (F400PQ/C 205 DR)
- 120 kips (F550/C 240 DR)

*Electrical characteristics in accordance with IEC 61325.

Bells Type Testing and Insulator Assemblies (Bells + Hardware) Type Testing will be performed per "PECL DC Insulator Assembly Testing Specification-Rev. G":

- Bells Type Testing: ,per IEC 61325 and ANSI C29.1
- Hardware Type Testing: per IEC 61284
- Insulator Assembly (Bells + Hardware):
  - Corona test and RIV (Radio Interference Voltage) Test: per IEC 60437
  - Pollution Test (DC Fog Withstand Test): per IEC 61245 (separate "Medium" & "Light" Pollution)
  - Rain (Wet) Withstand Voltage Test: per IEC 60060-1 & IEEE-4
  - Dry Lightning Impulse Voltage Test: per IEC 61325 & IEC 60060-1
  - Wet Switching Impulse Voltage Test: per IEC 60060-1

Additional required parameters regarding the insulators are presented in attached Appendices:
Appendix AA- Design Assumptions, Appendix AC-Clamp and Insulator Parameters
Appendix AD1and AD2- Insulator Assembly Types ("Medium" and "Light" Pollution)
Appendix AF-Tower and Pole Insulator Loading Check
Appendix AG-Required Clearances and Corresponding Insulator Swing Angles
Appendix AO1- Insulator, Jumper String, Jumper Loop Swing Angle Calculations-Towers
Appendix AO2- Insulator, Jumper String, Jumper Loop Swing Angle Calculations-Poles
Appendix P2- MRC Voltage Drop Calculation
Appendix P3-MRC Voltage Drop Calculation-River Crossing
Appendix P4-MRC Required Number of Bells Calculation
Appendix P5-MRC Required Number of Bells Calculation-River Crossing

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 20.74 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 required 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, Missouri, and Illinois 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 voltage (RIV) limits to be maintained at the edge of right-of-way. If no values are provided, the typical industry guidance of 40 dB (100 μV) will be used for RIV and the EPA recommendation of no greater than 55 dBA (563 μV) 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 700 miles as the specific line length is yet to be determined.

CLEARANCES

All clearances, for Pole Conductor (PC), will be determined using 600 kV DC, nominal, pole-to-ground, and 632 kV DC, maximum, pole-to-ground.

For Pole Conductor (PC), for comparison purposes, clearances were calculated using an "AC equivalent" voltage of 735 KV, resulted from:

600 kV DC, peak, nominal, pole-to-ground is equivalent to:

600*sqrt(3)/sqrt(2)= 735 kV AC, rms, nominal, phase-to-phase.

All clearances, for Metal Return Conductor (MRC), will be determined using 104 kV DC, nominal, pole-to-ground, and 109 kV DC, maximum, pole-to-ground.

For Metal Return Conductor (MRC), for comparison purposes, clearances were calculated using an "AC equivalent" voltage of 127 KV, resulted from:

104 kV DC, peak, nominal, pole-to-ground is equivalent to:

104*sqrt(3)/sqrt(2)= 127 kV AC, rms, nominal, phase-to-phase.

All clearances, for Metal Return Conductor (MRC), ACCR/TW Pecos, used in Mississippi River Crossing Spans, it will be determined using 114 kV DC, nominal, pole-to-ground, and 120 kV DC, maximum, pole-to-ground.

For Metal Return Conductor (MRC), for comparison purposes, clearances were calculated using an "AC equivalent" voltage of 140 KV, resulted from:

114 kV DC, peak, nominal, pole-to-ground is equivalent to:

114*sqrt(3)/sqrt(2)= 140 kV AC, rms, nominal, phase-to-phase

See Appendix A-Pole Conductor Clearances Calculation Table and Appendix P-Metal Return Conductor Clearances Calculation Table (ACSR Chukar –Voltage=104 KV) and Appendix P1- Metal Return Conductor Clearances Calculations Table (ACCR/TW Pecos-Voltage=114 kV).

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 Pole Conductor (PC) ±600 kV nominal & ±632 kV maximum to Own Structure	Clearance for Metal Return Conductor (MRC) ± 104 kV nominal & ±109 kV maximum to Own Structure
Load Case 1	13.5 ft	2 ft
Load Case 2	13.5 ft	2 ft
Load Case 3	5 ft	0.90 ft

Load Case 1, Load Case 2, Load Case 3 required clearance is based on necessary air gap equivalent (dry arc distance) under to following combination of mechanical and electrical parameters:

- Case 1: best mechanical: no wind, with worst electrical: lighting impulse withstand voltage.
- Case 2: medium mechanical: medium wind, with medium electrical: switching impulse withstand voltage.
- Case 3: worst mechanical: extreme wind, with best electrical: steady state, normal regime.

Load Case 1 and Load Case 2 clearance based on NESC Rule 235 E.

Important Note:

Load Case 1 and 2 minimum clearances were NOT increased to 17.33' to meet IEEE 516-2009 MAD (Minimum Approach Distance) for tools (12.33') and the Working Space (4.5').

Live Line Maintenance was considered at the conceptual design stage, and the clearance requirements are noted in this document. However, Live Line Maintenance clearance requirements are no longer included in the structure geometry and design calculations. If maintenance work is necessary on a pole, that pole must be de-energized.

The line will still function in mono-pole regime (the other pole will still be energized).

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 also for detailed clearance calculations attached 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 miliAmp 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:	Horizontal: 21.2 ft (at rest): 21.7’ (displaced under 6 psf wind) (w/3 ft buffer) Vertical: 21,7 ft (w/3 ft buffer) (Reference NESC Rule 234B, 24C, 234D, 234E, 234G1)
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 and Pole Conductor to MRC, 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 Conductor-to-OPGW: 19 ft (w/ 3’ buffer) (at support); 18.5 ft (w/ 3’ buffer) (in span);
Pole Conductor-to-MRC: 21.5 ft (w/3’ buffer) (at support); 21.0 ft (w/ 3’ buffer) (in span)
MRC-to-OPGW: 5 ft (w/ 1’ buffer) (at support); 4.0 ft (w/ 1’ buffer) (in span)

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: 13.5’ per NESC Rule 235 E, under both no wind and 6 psf wind (see for details Appendix A-Clearances Calculation Tables)

The “Live Line Maintenance values are no longer a design requirement, but are provided below for reference:
17.33’ (MAD for Tools”12.33 per IEEE 516-2009+Working Space: 4.5’ per NESC Rule 236&237)

To anchor guys: 16.9’ per NESC235E, 4 b., where 600 kV, dc equivalent to 735 kV ac.

REA:	N/A
Other:	N/A

Clearances of the Metal Return Conductors

For Clearances of the Metal Return Conductor , see Appendix P (for entire line, except Mississippi River Crossings; used ACSR Chukar energized at +/- 104 kV) and Appendix P1 (for Mississippi River Crossings; used ACCR/TW Pecos energized at +/-114 kV).

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.

SUBSTATION/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):