DOYLE WIND FARM
FLORENCE, KS
FOR M.A. MORTENSON CO.

345 KV TRANSMISSION LINE
DESIGN CRITERIA

PREPARED BY:
ULTEIG ENGINEERS, INC.
PROJECT NO. 13.01771

REV. A
12/18/14

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Overview:
Define the design and loading criteria used to design a new 18 mile 345 kV transmission line near Florence, KS, for the Doyle Wind Farm Project.

Methodology:
The overhead transmission line design follows the RUS Design Manual for High Voltage Transmission Lines (Bulletin 1724E-200), and the National Electrical Safety Code, C2-2012, (NESC 2012). The design manual and the NESC code document refer to the following standards:

1. Cable tension criteria
2. Cable and conductor sagging criteria
3. Structure loading criteria
4. Load and strength factors
5. Vertical clearance requirements
6. Horizontal clearance requirements
7. Galloping recommendations
8. Insulator design criteria.
9. Grounding design criteria
10. Lightning/Shielding Design criteria

Assumptions:
The following sections outline the specific recommendations and requirements for the ten (10) standards listed above:

Weather Conditions:
Weather conditions determine the loads applied to conductors and structures. Table 1 summarizes the weather cases used for transmission structure design.

Notes:

- Weather cases 1, 3, 4, 8, 11, and 20 are used for structure analysis.
- Weather cases 1, 3, 4, 8, 12, and 15 are used for determining conductor design tensions.
- Weather cases 3, 13, and 18 are used for checking vertical conductor clearances.
- Weather cases 3, 9, 11, 15, and 18, are used to check horizontal conductor clearances.
- Weather cases 3, 9, 13, 15, and 18 are used to check clearances between conductors carried on the same supporting structure.
- Weather cases 7, 10, 15, and 21 are used to check insulator swing limits.
- Weather cases 5 and 6 are used for galloping calculations.
- Weather case 2 is provided if the Line Designer wishes to check loads that do not include the NESC K-factor. Using weather case 1 will typically be conservative.

Table 1 - Weather Cases

WC #	Weather Case Description	Air Density Factor (Q) (psf/mph²)	Wind Velocity (mph)	Wind Pressure (psf)	Wire Ice Thickness (in)	Wire Ice Density (lbs/ft³)	Wire Temperature (deg F)	Weather Load Factor	NESC Constant (lbs/ft)	Wire Wind Height Adjust Model	Wire Gust Response Factor
1	0, NESC HEAVY, W/K	0.00256	40	4.1	0.5	57.00	0	1.0	0.3	None	1
2	0, NESC HEAVY, W/O K	0.00256	40	4.1	0.5	57.00	0	1.0		None	1
3	32, ICE (1.0), HEAVY ICE	0.00256			1.0	57.00	32	1.0		None	1
4	15, ICE (1.0), WIND (40), EXTREME ICE W/ CONCURRENT WIND	0.00256	40	4.1	1.0	57.00	15	1.0		None	1
5	32, ICE (.5), GALLOP SAG	0.00256			0.5	57.00	32	1.0		None	1
6	32, ICE(.5), WIND (2 PSF), GALLOP ANG	0.00256	28	2.0	0.5	57.00	32	1.0		None	1
7	60, WIND (6 PSF), SWING NESC	0.00256	48	6.0			60	1.0		None	1
8	60, WIND (90), HEIGHT ADJ.	0.00256	90	20.7			60	1.0		NESC 2012	NESC 2012
9	60, WIND (6 PSF), H-CLEAR	0.00256	48	6.0			60	1.0		None	1
10	-20, WIND (4 PSF), SWING	0.00256	40	4.1			-20	1.0		None	1
11	-20, BARE, UPLIFT WINTER AMB.	0.00256					-20	1.0		None	1
12	0, BARE, COND. TENSION LIMIT	0.00256					0	1.0		None	1
13	32, BARE, ICE OFF	0.00256					32	1.0		None	1
14	40, BARE, NORMAL CAMBER	0.00256					40	1.0		None	1
15	60, BARE	0.00256					60	1.0		None	1
16	90, BARE, SUMMER AMB.	0.00256					90	1.0		None	1

Table 1 (cont'd) – Weather Cases

WC #	Weather Case Description	Air Density Factor (Q) (psf/mph²)	Wind Velocity (mph)	Wind Pressure (psf)	Wire Ice Thickness (in)	Wire Ice Density (lbs/ft³)	Wire Temperature (deg F)	Weather Load Factor	NESC Constant (lbs/ft)	Wire Wind Height Adjust Model	Wire Gust Response Factor
17	120, BARE, NEUTRAL	0.00256					120	1.0		None	1
18	212, BARE, 100 deg. C.	0.00256					212	1.0		None	1
19	167, BARE, 75 deg. C.	0.00256					167	1.0		None	1
20	40, WIND (2#), DEFLECTION	0.00256	28	2			40	1.0		None	1
21	60, WIND (.84x90), HIGH WIND SWING	0.00256	75.6	14.7			60	1.0		None	1

Maximum Conductor Tension Criteria

The RUS Bulletin Table 9-3 on page 9-10 refers to the recommended tension limits for ACSR conductor. Those limits are summarized in Table 2 and are more stringent than those listed in the NESC.

Table 2 –Tension Limits for ACSR Conductor

Weather Case	Percent Allowable	Cable Condition
0° F, no wind	33.3%	Maximum Initial Unloaded
0° F, no wind	25%	Maximum Final Unloaded
NESC Heavy (0° F, 4 psf wind, ½" ice)	50%	Standard Loaded
Extreme Wind (60° F, 20.7 psf wind)	70%	Maximum Extreme Wind Final Loaded
Heavy Ice (32° F, no wind, 1" ice)	70%	Maximum Extreme Ice Final Loaded
Extreme Ice & Wind (15° F, 1.0" ice, 40 mph wind)	70%	Extreme Ice with Concurrent Wind Final Loaded

Cable and Conductor Design Tension Criteria

The conductor will be sagged initially based on the criteria listed below. Tensions will be reviewed and adjusted accordingly to provide the optimum balance between sag, tension, and design loads at guyed structures. Allowable tension in guy wires may require a slight reduction in design tension.

Table 3 – Conductor Design Tension Criteria

Weather Case	Percent Allowable	Cable Condition
NESC Heavy (0° F, 4 psf wind, ½" ice)	50%	Final Loaded
60° F, no wind	35%	Initial Unloaded
60° F, no wind	25%	Final Unloaded
0° F, no wind	20%	Initial Unloaded

The shield wire will be sagged at 75-80% of the conductor sag at 60° F under a final unloaded condition.

Structure Design Criteria
The structures will be designed with applied loads listed in the structure loading criteria above. Non-linear analysis will be used for all structure loading criteria to design the structures.

The line design will consist of single pole, direct-embedded steel tangent structures, single pole, direct-embedded steel guyed angle/dead end structures, and single pole, self-supporting angle and dead end structures.

Structure Loading Criteria
Structure strength requirements will be checked using the following load cases:

1. NESC HEAVY: 0.5 in. ice, 4 psf wind, 0° F, +k factor, NA+/- directions
2. EXTREME WIND: 0 in. ice, 20.7 psf wind, 60° F, NA+/- directions
3. EXTREME ICE W/ CONCURRENT WIND: 1.0 in. ice, 4.0 psf wind, 15° F, NA+/- directions
4. HEAVY ICE: 1.0 in. ice, 0 psf wind, 32° F
5. UPLIFT: 0 in. ice, 0 psf wind, -20° F
6. DEFLECTION: 0 in. ice, 2 psf wind, 40°F, NA+/- directions
7. BROKEN SHIELD WIRE: 0.5 in. ice, 4 psf wind, 0° F, NA+/- directions, where applicable
8. BROKEN CONDUCTOR: 0.5 in. ice, 4 psf wind, 0° F, NA+/- directions, where applicable
9. WIND ON POLE: 13 psf wind on projected pole area, 60° F, NA+/- directions
10. CONSTRUCTION LOADS: 2 psf wind, 60° F, 45° arm loading, on applicable steel structures

Load and Strength Factors
The NESC code requires the use of load factors and strength factors. The load factors applied in each load case are, at a minimum, in accordance with the NESC code. Strength factors are per the NESC. Load and Strength factors used are shown in Table 4.

Table 4 – Load and Strength Factors

Description	Weather case	Cable condition	Vertical Load Factor	Transverse (Wind) Load Factor	Tension Load Factor	Steel Str. Strength Factor	Insulator Strength Factor	Guy Wire Strength Factor
1. NESC HEAVY W/K	0, NESC HEAVY, W/K	Initial RS	1.5	2.5	1.65	1.0	1.0	0.9
2. EXTREME WIND	60, WIND(90), HEIGHT ADJ	Initial RS	1.1	1.1	1.1	1.0	0.7	0.9
3. EXTREME ICE W/ WIND	15, ICE(1.0), WIND(40), EXT. ICE W/ WIND	Initial RS	1.1	1.1	1.1	1.0	0.7	0.9
4. HEAVY ICE	32, ICE (1.0), HEAVY ICE	Initial RS	1.1	1.1	1.1	1.0	0.7	0.9

5. UPLIFT	-20, BARE, UPLIFT WINTER AMB	Initial RS	1.0	1.0	1.0	1.0	1.0	0.9
6. DEFLECTION	40, WIND (2#), DEFLECTION	Initial RS	1.0	1.0	1.0	1.0	1.0	0.9
7. BROKEN GW	0, NESC HEAVY, W/K	Initial RS	1.1	1.1	1.1	1.0	1.0	0.9
8. BROKEN CONDUCTOR	0, NESC HEAVY, W/K	Initial RS	1.1	1.1	1.1	1.0	1.0	0.9
9. WIND ON POLE	60, WIND (13#)	Initial RS	1.1	1.1	1.1	1.0	1.0	0.9
10. CONSTRUCTION LOADING	60, WIND (2#) 45 DEG ARM LOADING	Initial RS	1.1	1.1	1.1	1.0	1.0	0.9
11. NESC HEAVY (INSULATOR CHECK)	0, NESC HEAVY, W/K	Initial RS	1.0	1.0	1.0	1.0	0.4 (P) 0.5 (T)	1.0

Structure Deflection Criteria
Structure deflections will be limited to 1.5-2% of the above grade structure height for steel structures.

Deflection criteria is included so that structure deflections will not negatively affect conductor tension, sag or structure strength characteristics, while maintaining a minimum structure stiffness. The weather condition for this case has been chosen to ensure that a structure does not exceed a maximum deflection in a typical weather condition the line is likely to experience on a regular basis. This load case will also be used to determine any necessary pole raking at the time of structure installation.

Failure Containment Structures
Failure containment structures are structures designed to resist dead-end loads at intervals along a transmission line to limit the number of cascading structures in the event of structure failure. Failure containment structures will be installed approximately every 5 miles.

Vertical Clearance Requirements
Vertical clearance requirements for this transmission line will be based on the NESC 2012 values and are listed in Tables 5, 6 & 7. Vertical clearances are checked at the following weather cases:

1. 212°F, no wind, final sag (Maximum operating temperature for ACSR conductor)
2. 32°F, ICE (1.0"), No Wind (Heavy Ice)
3. 32°F, no wind, no ice (temperature of lower conductor for calculating clearances at wire crossing locations)

Vertical clearances above other obstacles such as railroads, signs, buildings, etc, will also be based on NESC 2012.

Table 5 – Design Vertical Clearances of Conductors above Ground, Roadways, Rails, or Water Surfaces (Values taken from NESC 2012, Section 232)

Nature of surface underneath wires, conductors, or cables	Clearance (ft.) NESC 2012 345 kV	Clearance (ft.) Design 345 kV*
1. Track Rails	32'-9"	**35'-3"**
2. Roads, streets, and other areas subject to truck traffic	24'-9"	**27'-3"**
3. Driveways, parking lots, and alleys	24'-9"	**27'-3"**
4. Other land traversed by vehicles, such as cultivated, grazing, forest, orchards, etc.	24'-9"	**27'-3"**
5. Spaces and ways subject to pedestrians or restricted traffic only	20'-9"	**23'-3"**
6. Water areas not suitable for sailboating or where sailboating is prohibited	23'-3"	**25'-9"**
7. Water areas suitable for sail boating including lakes ponds, reservoirs, tidal waters, rivers, streams, and canals with unobstructed surface area of…		
a. Less than 20 acres	26'-9"	**29'-3"**
b. Over 20 to 200 acres	34'-9"	**37'-3"**
c. Over 200 to 2000 acres	40'-9"	**43'-3"**
d. Over 2000 acres	46'-9"	**49'-3"**

***Design clearances in Table 5 have an additional 2'-6" safety buffer included.**

Table 6 – Design Vertical Clearances from Other Supporting Structures, Buildings and Other Installations.
(Values taken from NESC 2012, Section 234)

Nature of surface underneath wires, conductors, or cables	Clearance (ft.)	
	NESC 2012 345 kV	**Design 345 kV***
1. From a lighting support, traffic signal support, or supporting structure of a second line	10'-10"	**13'-4"**
2. Over or under roofs or projections not readily accessible to pedestrians	18'-9"	**21'-3"**
3. Over roofs accessible to pedestrians and vehicles but not subject to truck traffic	19'-9"	**22'-3"**
4. Over roofs accessible to truck traffic	24'-9"	**27'-3"**
5. Signs, chimneys, billboards, radio and television antennas, tanks, and other installations **not accessible to personnel**	14'-3"	**16'-9"**

***Design clearances in Table 6 have an additional 2'-6" safety buffer included.**

Table 7 – Vertical Clearances between Conductors where the Conductors of One Line Cross Over the Conductors of Another (Values taken from NESC 2012, section 233)

Lower Level Conductor	Upper Level Conductor Clearance (ft.) NESC 2012 345 kV	Upper Level Conductor Clearance (ft.) Design 345 kV*
1. Communication	11'-3"	**12'-6"**
2. OHGW	8'-3"	**9'-6"**
3. Distribution	8'-3"	**9'-6"**
4. Transmission Lines, by Voltage:		
46 kV & Below	8'-3"	**9'-6"**
69 kV	8'-11"	**10'-2"**
115 kV	9'-4"	**10'-7"**
138 kV	10'-4"	**11'-7"**
161 kV	10'-9"	**12'-0"**
230 kV	12'-2"	**13'-5"**
345 kV	14'-6"	**16'-0"**

***Design clearances in Table 7 have an additional 1'-3" safety buffer included.**

Horizontal Clearance Requirements
General horizontal clearances to existing objects will be based on NESC 2012.

The horizontal clearances specified apply under whichever conditions of the following produces the closest approach:

1. 212°F, no wind, final sag (Maximum operating temperature for ACSR conductor)
2. 32°F, no wind, final sag, 1.0" ice
3. -20°F, no wind, final sag (Minimum conductor temperature)
4. 60°F , 6.0 psf wind, final sag (Conductor blowout case)
5. 60°F , no wind, final sag (At Rest Case)

Table 8 – Horizontal Clearances from Other Supporting Structures, Buildings and Installations (Values taken from NESC 2012, section 234)

Nature of surface below wires, conductors, or cables / Horizontal Clearances	NESC 2012 345 kV	Design 345 kV*
1. From a lighting support, traffic signal support or supporting structure of another line		
At Rest	10'-4"	**11'-10"**
Displaced By Wind	10'-9"	**12'-3"**
2. Buildings		
a. To walls, projections, and guarded windows		
At Rest	13'-9"	**15'-3"**
Displaced By Wind	10'-9"	**12'-3"**
b. To unguarded windows		
At Rest	13'-9"	**15'-3"**
Displaced By Wind	10'-9"	**12'-3"**
c. To balconies and areas readily accessible to pedestrians		
At Rest	13'-9"	**15'-3"**
Displaced By Wind	10'-9"	**12'-3"**
3. Signs, chimneys, billboards, radio and television antennas, tanks, and other installations not classified as buildings		
a. To portions that are readily accessible to pedestrians		
At Rest	13'-9"	**15'-3"**
Displace By Wind	10'-9"	**12'-3"**
b. To portions that are not readily accessible to pedestrians		
At Rest	13'-9"	**15'-3"**
Displaced By Wind	10'-9"	**12'-3"**
4. Grain Bins		
a. w/ permanently attached conveyors		
At Rest	SEE NESC	
Displaced By Wind		
b. loaded w/ portable conveyors		
At Rest	SEE NESC	
Displaced By Wind		

***Design clearances in Table 8 have an additional 1'-6" safety buffer included.**

Note: The clearances shown are for displaced conductors and do not provide for the horizontal distance required to account for blowout of the conductor and the insulator string. This distance is to be added to the required clearance.

Galloping Recommendations
Galloping is a condition in which the conductors or shield wire vibrate with a very high amplitude. It typically occurs under moderate and steady wind with a thin layer of ice coating the surface of the conductor or shield wire. Galloping is a design consideration that can limit span length and dictate conductor and shield wire spacing on the structure. Several problems can arise when galloping occurs:

1. Electrical outages due to contact between phases or phases and shield wire
2. Conductor failure due to the stress of the contact
3. Structure damage
4. Excessive conductor sag due to overstressing of the conductors

Galloping is graphically displayed as a set of ellipses which occur either at mid-span or at the quarter span points. Mid-span ellipses typically occur in spans less than 750 feet in length and are referred to as “Single Loop.” Quarter span ellipses occur in spans greater than 750 feet in length and are referred to as “Double Loop.” This transmission line is designed considering both single and double loop ellipses depending on the span length under consideration. The following load cases are used to produce the elliptical analysis:

1. Swing – 2 psf wind, ½” radial ice, 32° F
2. Sag – no wind, ½” radial ice, 32° F

The transmission line will be designed with span lengths and wire spacing such that there will be no galloping overlap when analyzed with both the Davison (spans up to 750 feet) and Toye (spans longer than 750 feet) methods.

Aeolian Vibration
Aeolian vibration is a phenomenon that occurs when a smooth stream of air passes across a cylindrical shape (in the case of a transmission line, the conductor, shield wire, or OPGW), which generates vortices on the undisturbed, or leeward, side. These vortices alternate from the top and bottom surfaces, and create alternating pressures that tend to produce small movements normal to the direction of air flow. These repeated movements are vibrations.

Aeolian vibration of conductor, shield wire, and OPGW can cause damage that can adversely affect the reliability and/or serviceability of a transmission line. If left unattended for too long, lines damaged by such vibrations may have to be taken out of service for maintenance and repairs.

The transmission line will be designed with Aeolian vibration considered. Vibration dampers will be installed where needed (calculated by the damper manufacturer(s)) to ensure there will be minimal long-term maintenance issues related to Aeolian vibration.

Foundation Depths

The required transmission pole foundation requirements for steel pole on concrete caisson structures will be calculated using PLS Caisson. The program determines the required foundation depth based on the specified soil conditions, and specific structure loading. The design program determines the required foundation depth based on the structure's ability to withstand the following:

- Overturning moments
- Shear and moment along the length of the caisson foundation.

Additional foundation calculations will be performed to verify proper bearing capacity at guyed structure locations.

Insulation Requirements

The overhead transmission line insulator design follows the Design Manual for High Voltage Transmission Lines, RUS Bulletin 1724E-200 and the National Electrical Safety Code, C2-2012, (NESC 2012). The RUS design manual and the NESC code document refer to the following design criteria:

1. Insulator Materials and Types
2. Recommended Basic Insulation Levels
3. Mechanical Considerations
4. Elevation Considerations
5. Contaminated Environment Considerations
6. Isokeraunic (lightning) Considerations

Insulators will be designed as polymer insulators to withstand the mechanical loads with the given strength factors per Table 4 of this design criteria. Electrical insulation design requirements pertain to the Minimum 60Hz Dry flashover, the minimum positive and negative critical flash over (CIFO), and the leakage distance of the insulator.

Structure Grounding

Wood structures will utilize a full-length pole ground, tied to the shield wire and a minimum of two (2) 10' ½" copper bonded driven ground rods. Steel poles will utilize ground pads at the top and bottom of the pole tied into the shield wire at top and a minimum of two (2) 10' ½" copper bonded ground rods.

During construction ground resistance reading will be taken at each structure to ensure a maximum reading of 25 ohms is achieved. This may require the additional installation of ground rods.

Lightning Performance

A single OPGW shield wire will be used on the transmission line design to minimize the possibility of lightning contacting the phase wires and causing a flashover. Structure framing will be utilized to limit the shield angle of the conductor to a maximum of 30 degrees. (The shield angle is the angle measured from the vertical between the shield wire and the phase conductors). Where structure heights are in excess of 92 feet, RUS shield angle recommendations will be used, as shown in Table 9.

Table 9 – Reduced Shielding Angle Values

Above Ground Structure Height (ft)	Shielding Angle (degrees)
92	30
99	26
116	21

Right-of-Way/Easements

It is assumed that poles and conductor blowout will not be allowed to extend past the Kansas Department of Transportation (KDOT) easement, however, guy wires will be designed as extending past the KDOT easement, with the assumption that additional land rights will be acquired to allow guy wires to do so. Where this is not possible, a self-supporting structure will be designed for that location.

Additionally, it is assumed that road, highway, and railroad crossings are not required to be perpendicular.

There will be at least one creek crossing, and there may be environmental issues associated as such. Ulteig will review and adhere to suggestions from any environmental studies/assessments, should any be provided.

References:

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