

**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) + <b>Working Space</b> (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 <sup>2</sup> (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 <sup>2</sup> (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 <sup>2</sup> (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 <sup>2</sup> (2000 acres) Mississippi River Crossing	51.96' (bare) 52' (rounded) 55' (w/3' buffer)	54.6' (bare) 55' (rounded) 58' (w/3' buffer)			55'

<b>Case</b>	<b>NESC- DC</b> V nom=600 KV peak, pole-ground  V max=632 KV (5% over V nom)	<b>NESC- AC Equivalent</b> 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)	<b>EPRI</b> T/L Reference Book HVDC Lines	<b>MAD* for Tools</b> (IEEE 516-2009) + <b>Working Space</b> (NESC Rule 236& 237)	<b>Conclusion:</b> 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	<b>17.33'</b>
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	<b>17.33'</b>
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	<b>5'</b>

\*MAD=Minimum Approach Distance.

**NESC-Clearance Conductor to Ground calculation:**

<p><b><u>NESC- DC;</u></b>  V nom=600 KV  peak, pole-ground</p> <p>V max=632 KV  (5% over V nom)</p>	<p><b><u>NESC- AC Equiv</u></b>  V nom=735 KV  rms, phase-to-phase  <math>735=600*\sqrt{3}/\sqrt{2}</math>  Rule 230 H  V max=772 KV  (5% over V nom)</p>
<p>Rule 232D, table 232-3:</p> <p>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'</p> <p>For Ref Altitude &lt; 1500 ft:  V max=1.05*V nom=632 kV  <math>C\ ref=3.28*(632*1.8*1.15/(500*1.15)^1.667*1.03*1.2=15.96'</math>  For assumed maximum altitude for this line (worst case scenario): 3000 ft:  Altitude Adder: <math>(3000'-1500')/1000'*3%=4.5\%</math>  <math>C\ alt=C\ ref*1.045=15.96'*1.045=16.68'</math></p> <p>a. Track rails of railroads:  C total=H ref + C alt=22' + 16.68'=<b><u>38.68' (bare)</u></b>  <b><u>39' (rounded)</u></b>  <b><u>42' (w/3' buffer)</u></b>  <b>CHOSEN</b></p> <p>b. Streets, Alleys, roads, driveways, and parking lots:  C total=H ref + C alt=14' + 16.68'=<b><u>30.68' (bare)</u></b>  <b><u>31' (rounded)</u></b>  <b><u>34' (w/3' buffer)</u></b>  <b>CHOSEN</b></p> <p>c. Spaces and ways subject to pedestrians or restricted traffic:  C total=H ref + C alt=10' + 16.68'=<b><u>26.68' (bare)</u></b>  <b><u>27' (rounded)</u></b>  <b><u>30' (w/3' buffer)</u></b>  <b>CHOSEN</b></p> <p>d. Vehicular Areas:  C total=H ref + C alt=14' + 16.68'=<b><u>30.68' (bare)</u></b>  <b><u>31' (rounded)</u></b>  <b><u>34' (w/3' buffer)</u></b>  <b>CHOSEN</b></p>	<p>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:</p> <p>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'</p> <p>Voltage Adder: C adder=<math>(446-22)*0.4'/12=14.1'</math></p> <p>Altitude adder : zero</p> <p>a. Track rails of railroads:  C total=H basic + C adder= 26.5' + 14.1'=<b><u>40.6' (bare)</u></b>  <b><u>41' (rounded)</u></b>  <b><u>44' (w/3' buffer)</u></b></p> <p>b. Streets, Alleys, roads, driveways, and parking lots:  C total=H basic + C adder= 18.5' + 14.1'=<b><u>32.6' (bare)</u></b>  <b><u>33' (rounded)</u></b>  <b><u>36' (w/3' buffer)</u></b></p> <p>c. Spaces and ways subject to pedestrians or restricted traffic :  C total=H basic + C adder= 14.5' + 14.1'=<b><u>28.6' (bare)</u></b>  <b><u>29' (rounded)</u></b>  <b><u>32' (w/3' buffer)</u></b></p> <p>d. Vehicular Areas:  C total=H basic + C adder= 18.5' + 14.1'=<b><u>32.6' (bare)</u></b>  <b><u>33' (rounded)</u></b>  <b><u>36' (w/3' buffer)</u></b></p>

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

<p><b><u>NESC- DC:</u></b> V nom=600 KV peak, pole-ground</p> <p>V max=632 KV (5% over V nom)</p>	<p><b><u>NESC- AC Equiv</u></b> V nom=735 KV rms, phase-to-phase <math>735=600*\sqrt{3}/\sqrt{2}</math> Rule 230H V max=772 KV (5% over V nom)</p>
<p>Rule 235E3b For Ref Altitude &lt; 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: <math>(3000'-1500')/1000'*3\%=4.5\%</math> C alt=C ref*1.045=12.4'*1.045=12.96' C alt=<b><u>12.96' (bare)</u></b> <b><u>13' (rounded)</u></b> <b><u>16' (w/3' buffer)</u></b> <b><u>CHOSEN</u></b></p>	<p>Equivalent max ac system voltage=735*1.05=772 KV Equivalent max ac system voltage, phase-to-ground=<math>772/\sqrt{3}=446</math> kV NESC Rule 235 E, 4b, open supply conductor up to 50 kv: H basic=11''=0.917' Voltage Adder: C adder=<math>(772-50)*0.25''/12=12.033'</math> Altitude adder : zero C total=H basic + C adder= 0.917' + 12.033'= <b><u>12.95' (bare)</u></b> <b><u>13' (rounded)</u></b> <b><u>16' (w/3' buffer)</u></b></p>

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

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

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

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

**NESC- Clearance Conductor-to-Water calculation**

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