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SUBJECT: Distribution Conductor Clearances and Span Limitations

TO: RUS Electric Borrowers and RUS Electric Staff

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PURPOSE: The conductor clearance requirements of Rule 235 of the National Electrical Safety Code (NESC) may limit overhead distribution span lengths. This bulletin presents information and the equations needed to determine the maximum span lengths that will meet NESC mid-span and supporting structure clearance requirements between conductors.



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CONDUCTORS, DISTRIBUTION:

- Conductor clearances
- Span limitations

ABBREVIATIONS

- ACSR Aluminum conductor, steel reinforced
- ANSI American National Standards Institute
- AWG American Wire Gage
- IEEE Institute of Electrical and Electronics Engineers
- NESC National Electrical Safety Code
- RUS Rural Utilities Service

UNITS OF MEASURE

- inch 1 inch = 2.54 centimeters = 0.0254 meters
- foot 1 foot = 0.3048 meters
- kV kilovolts [1 kilovolt = 1,000 volts]
- °F Degrees Fahrenheit [$^{\circ}\text{F} = 9/5 \times ^{\circ}\text{C} + 32$]
- °C Degrees Centigrade [$^{\circ}\text{C} = 5/9 \times (^{\circ}\text{F} - 32)$]

Distribution Conductor Clearances and Span Limitations

1. INTRODUCTION

1.1 Purpose and Scope of Bulletin: The conductor clearance requirements of Rule 235 of the National Electrical Safety Code (NESC) may limit overhead distribution span lengths. This bulletin presents information and the equations needed to determine the maximum span lengths that will meet NESC mid-span and supporting structure clearance requirements between conductors. Only bare electric supply conductors supported by the Rural Utilities Service (RUS) standard distribution primary, pole-top assemblies are analyzed in this bulletin. However, the equations presented in this bulletin can be applied to other types of conductors and support assemblies. Diagrams and example solved problems are included in this bulletin to clarify the presentation.

1.2 National Electrical Safety Code: Throughout this bulletin are references to rules and selected data contained specifically in the 2002 Edition of the National Electrical Safety Code (NESC). The NESC is published by the Institute of Electrical and Electronics Engineers, Inc. (IEEE).^{1/} At the time this bulletin was written, the 2002 Edition was the latest edition of the NESC. Periodically the NESC is updated and revised. Users of this bulletin should use the rules and data, as may be revised and renumbered, from the most recent edition of the NESC.

1.3 RUS Standard Distribution Assemblies: Within this bulletin are references to RUS standard distribution pole-top assemblies. RUS standard distribution assemblies can be found in RUS Bulletin 1728F-803, "Specifications and Drawings for 24.9/14.4 kV Line Construction" (1998), or in RUS Bulletin 50-3 (D-804), "Specifications and Drawings for 12.5/7.2 kV Line Construction" (1983).^{2/}

2. CONDUCTOR CLEARANCES ON SAME SUPPORT STRUCTURES

2.1 NESC Conductor Clearance Requirements: NESC Rule 235 specifies horizontal and vertical clearances for conductors attached to the same supporting structure. Conductors need to be attached far enough apart on their supporting structures (and span lengths need to be short enough) such that for all loading conditions all of the NESC horizontal and vertical clearance requirements between conductors are maintained.

2.2 Definitions: For the purposes of this bulletin, *Separation* is defined as the distance between the centers of conductors and *Clearance* is defined as the clear surface-to-surface distance

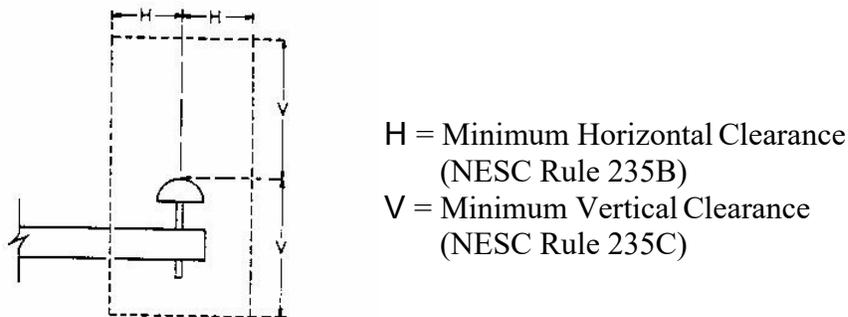
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between conductors. Generally, and specifically in this bulletin, where spacings or distances between conductors are mentioned they are intended to be interpreted as separations unless otherwise specifically defined as clearances. In this bulletin, RUS assumes that conductors have a ½-inch radius and thus conductor clearances are one inch less than given conductor separations.

2.3 Depiction of NESC Rule 235D Clearances: NESC Rule 235D pertains to the diagonal clearance between conductors located at different levels on the same supporting structure. The rule requires that the surface of any conductor be a minimum horizontal distance (H) and a minimum vertical distance (V) away from the surface of any another conductor, (shown in the center of the rectangle in Figure 2-1 of this bulletin). The relationship between these simultaneous minimum horizontal and vertical clearance requirements, determined in other parts of Rule 235, is shown in Figure 2-1.

Figure 2-1: Minimum Clearances Between Conductors



3. HORIZONTAL CLEARANCES BETWEEN CONDUCTORS ON THE SAME SUPPORTING STRUCTURE

3.1 Minimum Horizontal Clearances: As per NESC Rule 235B1a and NESC Table 235-1, the minimum horizontal clearance between any two electric supply conductors attached to a pole-top assembly is: 12 inches plus 0.4 inches per kilovolt (kV) for voltages over 8.7 kV and up to 50 kV. The following minimum horizontal clearances (rounded up to the nearest whole numbers) between electric supply conductors for standard RUS distribution voltages are based on NESC Rule 235B1a:

- 12.47Y/7.2 kV - Phase-to-Neutral: 12 inches
- 12.47Y/7.2 kV - Phase-to-Phase: 14 inches
- 24.94Y/14.4 kV - Phase-to-Neutral: 15 inches
- 24.94Y/14.4 kV - Phase-to-Phase: 19 inches

3.2 Horizontal Clearances Based on Sags: NESC Rule 235B1b specifies minimum horizontal clearances between conductors on the same supporting structure based on conductor size and sag. The horizontal separations between conductor attachments on RUS standard distribution pole-top assemblies usually allow relatively long span lengths. Table 3.1 of this bulletin shows

the maximum conductor sags allowed by NESC Rule 235B1b for the standard horizontal conductor clearances on RUS standard primary pole-top assemblies.

Table 3.1: Conductor Sags Allowed on Standard RUS Assemblies

Standard RUS Assembly	Conductor Horizontal Clearances (inches)	Maximum Allowed Sags (inches) ⁽²⁾			
		Conductor Smaller Than No. 2 AWG		No 2 AWG Conductor or Larger	
		24.94 kV	12.47 kV	24.94 kV	12.47 kV
8-foot Crossarm	43	101	118	236	288
10-foot Crossarm	36	73	87	152	195
Narrow Profile ⁽¹⁾	29	52	63	86	119

⁽¹⁾ Proposed standard design.

⁽²⁾ RUS recommends these sags be reduced by at least 5 percent to compensate for errors in design or construction.

The conductor sags for NESC Rule 235B1b (and Table 3.1 of this bulletin) are to be calculated at 60 °F (15 °C) at final unloaded sag with no wind. The maximum allowed sag values in Table 3.1 of this bulletin were calculated using the following equations that were derived from the equations of NESC Rules 235B1b(1) and 235B1b(2):

$$Sag = 0.1875 \times [C - 0.3 (in / kV) \times V]^2 \text{ inches} \quad \text{EQ 3.1}$$

$$Sag = 24 + \frac{[C - 0.3 (in / kV) \times V]^2}{16.3216} \text{ inches} \quad \text{EQ 3.2}$$

Where;

C = the clearance between the primary conductors (inches)

V = Supply voltage (kV)

EQ 3.1 is applicable for No. 2 American Wire Gage (AWG) or larger conductors, and,

EQ 3.2 is applicable for conductors smaller than No. 2 AWG

For the sag calculations for Table 3.1 of this bulletin (using equations EQ 3.1 and EQ 3.2), 1 inch was subtracted from the RUS standard assembly center-to-center *separation* of the conductors to convert to the surface-to-surface *clearance* of the conductors shown in the table.

When using RUS standard pole-top assemblies, *spans may need to be shortened* such that maximum conductor sags do not exceed the values shown in Table 3.1 of this bulletin.

3.3 Maximum Allowable Spans Based on Horizontal Clearances: The maximum allowable span based on horizontal conductor clearances can be determined using the following equation:

$$S_m = S_r \times \sqrt{\frac{D_m}{D_r}} \quad \text{EQ 3.3}$$

Where:

S_m = Maximum allowable span base on horizontal clearances

S_r = Design ruling span

D_m = Defined sag limit (Table 3.1 for RUS standard pole-top assemblies)

D_r = Design ruling span sag (final unloaded sag at 60 °F with no wind)

3.4 Example Problem 1: Maximum Span Based on Horizontal Clearances: Determine the maximum span allowed for #4/0 aluminum conductor, steel reinforced (ACSR) primary conductors supported at each end by RUS standard 24.9/14.4 kV, VC1.11 (8-foot crossarm), pole-top assemblies. (See Figure 5-1 in paragraph 5.1 of this bulletin.) The phase-to-phase horizontal conductor separation for these RUS standard assemblies is 44 inches; the conductor clearances are 43 inches. The allowed sag for this design is 224 inches (236 inches less 5 percent, from Table 3.1 of this bulletin). Assume for this problem that the design ruling span is 350 feet and the ruling span sag, unloaded with no wind at 60 °F, is 51 inches.

The maximum allowable span for the conditions given in this problem is calculated using equation EQ 3.3 as follows:

$$S_m = S_r \times \sqrt{\frac{D_m}{D_r}} = 350 \times \sqrt{\frac{224}{51}} = 733 \text{ feet}$$

4. VERTICAL CLEARANCES BETWEEN CONDUCTORS ON THE SAME SUPPORTING STRUCTURE

4.1 Vertical Clearance Requirements: NESC Rule 235C requires a basic vertical clearance between conductors attached to the same supporting structure and also requires additional “voltage-related” and “sag-related” clearances. However, additional “voltage-related” clearances need not be considered for voltages less than 50 kV.

4.2 Basic Vertical Conductor Clearances: The basic vertical clearances for open supply conductors belonging to the same utility can be calculated using the values in NESC Table 235-5 which are: 16 inches plus 0.4 inches per kV over 8.7 kV. Table 4.2 of this bulletin compares the calculated NESC basic vertical clearance requirements to the standard vertical clearances of RUS standard primary pole-top assemblies.

Table 4.2: Vertical Clearances Between Supply Conductors on the Same Structure

Voltage	NESC Basic Vertical Clearances (inches)	Standard Clearances Between Supply Conductors on RUS Standard Pole-Top Assemblies (inches) ⁽¹⁾		
		Crossarms <i>e.g., VC1.11</i>	Vertical <i>e.g., VC3.1</i>	Narrow Profile <i>(Proposed Standard)</i>
12.47Y/7.2 kV <i>Phase-to-Neutral</i>	16	47	47	47
12.47Y/7.2 kV <i>Phase-to-Phase</i>	18	--	47	47
24.94Y/14.4 kV <i>Phase-to-Neutral</i>	19	47	47	47
24.94Y/14.4 kV <i>Phase-to-Phase</i>	23	--	47	47

⁽¹⁾ 1 inch, assumed to be the sum of the radii of the adjacent conductors, has been subtracted from the standard separation between the conductors to convert to clearances between the conductors.

4.3 Sag-Related Vertical Conductor Clearances: NESC Rule 235C2b(1)(a) requires that the conductor attachments at the supporting structure be adjusted such that **the vertical clearance between conductors at any point in the span be at least 75% of the required vertical clearances at the supports.** Note that this rule is (only) applicable when the horizontal clearances of NESC Rule 235B are not satisfied (see Figure 2-1 in paragraph 2.3 of this bulletin). Thus, for RUS standard distribution voltages, the following minimum vertical clearances (rounded up to the nearest whole number) between supply conductors throughout any span needs to be maintained:

12.47Y/7.2 kV - Phase-to-Neutral: 12 inches
 12.47Y/7.2 kV - Phase-to-Phase: 14 inches
 24.94Y/14.4 kV - Phase-to-Neutral: 15 inches
 24.94Y/14.4 kV - Phase-to-Phase: 18 inches

4.4 Conductor Sag Calculation Requirements: NESC Rule 235C2b(1)(a) further specifies that mid-span vertical conductor clearances are to be considered under the worst conductor loading conditions. To that end, NESC Rule 235C2b(1)(c) requires that the conductor sags be calculated twice, and that each calculation uses the following sets of conductor loading conditions:

- i. “The upper conductor is at the maximum operating temperature for which the line is designed to operate and the lower conductor is at final sag at the same ambient conditions as the upper conductor without electrical loading, and without ice loading, or,
- ii. The upper conductor is at final sag at 32 °F with the radial thickness of ice, if any, specified in Rule 250B for the loading district concerned and the lower conductor is at final sag at the same ambient conditions as the upper conductor without electrical loading, and without ice loading.”

4.5 Exception to NESC Rule 235C2b(1)(c): The above conductor sag calculation requirements do not apply if the conductors are: owned by the same utility, the same size and type, and, installed at the same sag and tension. However NESC Rule 235C2b(1)(c) remains in effect where experience shows different icing conditions between the upper and lower conductors.

4.6 Maximum Span Based on Vertical Clearance of Conductors with Different Sags: The equation to calculate the maximum span based on the vertical clearance of conductors is:

$$S_m = S_r \times \left[\frac{\sqrt{V_1 - C_v} + \sqrt{V_2 - C_v}}{2 \times \sqrt{D_{um} + C_t - D_b}} \right] \quad \text{EQ 4.1}$$

Where:

- S_m = Maximum span based on vertical clearances
- S_r = Design ruling span
- V_1 = Vertical clearance between conductors at support 1
- V_2 = Vertical clearance between conductors at support 2
- C_v = Required mid-span vertical clearance between conductors
- D_{um} = Final ruling span sag of the upper conductor at its:
 - (1) maximum design operating temperature; or,
 - (2) final sag at 32 °F with radial thickness of ice
- D_b = Corresponding final ruling span sag of the lower conductor at:
 - (1) same ambient temperature as $D_{um}(1)$ without electrical or ice loading; or,
 - (2) same ambient temperature as $D_{um}(2)$ without electrical or ice loading
- C_t = Clearance tolerance for engineering and construction errors (***RUS recommends adding a minimum of 5 percent to D_{um} to compensate for engineering and construction errors.***)

If V_1 equals V_2 , which is usually the case when using RUS standard primary pole-top assemblies ($V_1 = V_2 = V = 47$ inches), then equation EQ 4.1 reduces to:

$$S_m = S_r \times \left[\frac{\sqrt{V - C_v}}{\sqrt{D_{um} + C_t - D_b}} \right] \quad \text{EQ 4.2}$$

4.7 Example Problem 2: Maximum Span Based on Vertical Clearances: Determine the maximum span allowed (S_m) for a single-phase distribution span supported at each end by standard RUS 24.9/14.4 kV, VA1.1, primary pole-top assemblies. The primary conductor for this span is #1/0 ACSR and the neutral is #2 ACSR. The standard phase-to-neutral vertical conductor clearance (V) for these assemblies is 47 inches (48-inch separation). The allowed mid-span sag clearance (C_v) between the conductors is 15 inches (See paragraph 4.3 of this bulletin).

The distribution line section, assumed to be situated in the NESC Heavy Loading District, has been designed with a design ruling span (S_r) of 325 feet. The following final sags have been determined for the primary and neutral conductors for a 325-foot span:

Condition 1: (Primary conductor is at 120 °F; Neutral conductor is at an ambient temperature of 60 °F and has no electrical or ice loading);

$$D_{um} = 57 \text{ inches (plus 3 inches recommended by RUS); } D_b = 47 \text{ inches}$$

The decrease in clearance equals $(57 + 3) - 47 = \underline{13 \text{ inches}}$

Condition 2: (Primary conductor is at 32 °F with one-half inch of ice loading; Neutral conductor is at an ambient temperature of 32 °F with no electrical or ice loading);

$$D_{um} = 73 \text{ inches (plus 4 inches recommended by RUS); } D_b = 37 \text{ inches}$$

The decrease in clearance equals $(73 + 4) - 37 = \underline{40 \text{ inches}}$

Condition 2 is the worst loading condition because the clearance between the conductors decreases the most. The maximum span based on the vertical clearances and loading Condition 2 is calculated using equation EQ 4.2 as follows:

$$S_m = 325 \times \left[\frac{\sqrt{47 - 15}}{\sqrt{73 + 4 - 37}} \right] = 325 \times 0.894 = 290 \text{ feet}$$

4.8 Example Problem 3: Vertical Clearance on Assemblies Based on Span Length: For the data and information given in Example Problem 2 in paragraph 4.7 of this bulletin, what vertical clearance (V) between the primary and neutral conductors on the poles is required to achieve a 350 foot span (S_m) that meets the mid-span conductor clearance (C_v) of 15 inches?

To solve this problem, Equation 4.2 can be rewritten to solve for the required vertical clearance (V) in terms of the other independent variables of the equation as follows:

$$V = \left(\frac{S}{S_r} \right)^2 \times (D_{um} + C_t - D_b) + C_v \quad \text{EQ 4.3}$$

By substituting the known data into equation EQ 4.3, V can be determined as:

$$V = \left(\frac{350}{325} \right)^2 \times (73 + 4 - 37) + 15 = 61.4 \text{ inches}$$

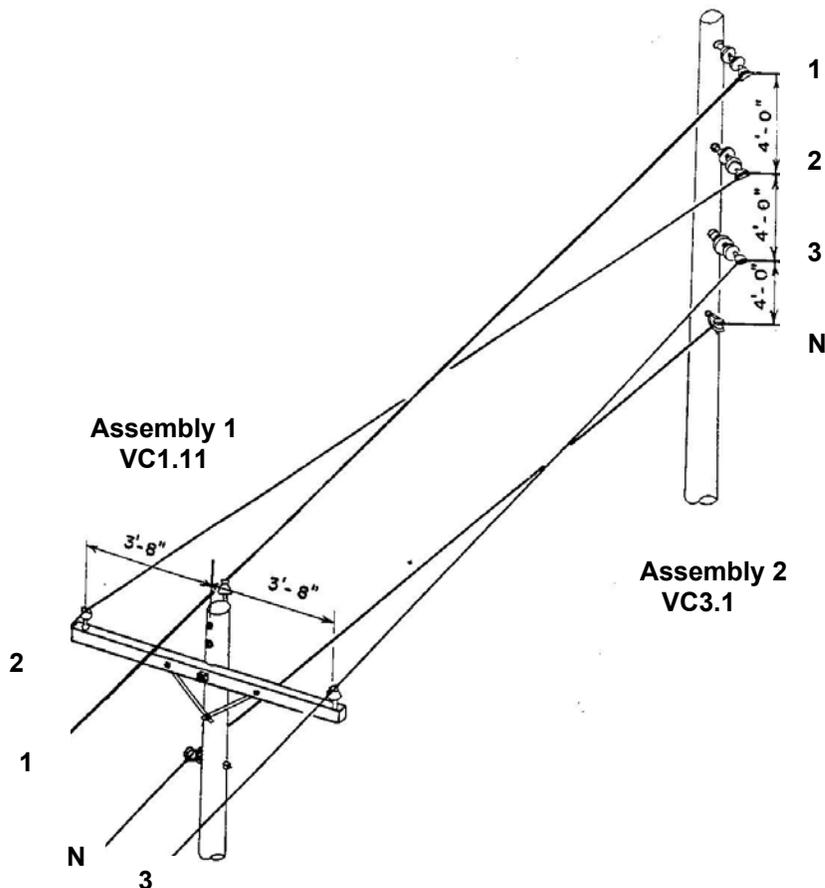
Thus, a 350 foot span than complies with the NESC mid-span vertical clearance requirements can be achieved by lowering the neutral 15 inches (62 inches – 47 inches) at each adjacent pole.

4.9 Alternative Solution for Example Problem 3: For Example Problem 3 in paragraph 4.8 of this bulletin, a 350 foot span that meets the NESC clearance requirements can alternatively be achieved by re-installing the neutral (at the same pole height) on offset neutral brackets. However, the horizontal clearance between the primary conductor and the relocated neutral conductor has to be at least 15 inches. If the NESC Rule 235B requirements for both the (15 inch) basic and (236 inch) sag-related horizontal clearance between conductors attached at the same supporting structure are met, then the vertical clearance requirements of NESC Rule 235C need not be applied.

5. MAXIMUM SPANS OF NON-PARALLEL CONDUCTORS BASED ON CLEARANCES

5.1 Parallel and Non-parallel Conductors: Only supply conductors that are generally horizontally and vertically parallel (except for conductor sag), and supported by identical pole-top assemblies, are analyzed in Sections 3 and 4 of this bulletin. Frequently in distribution construction, adjacent pole-top assemblies are not identical and thus the conductors between the assemblies are not parallel. Figure 5-1 of this bulletin shows a common distribution line section (vertical roll to turn a large angle) in which the adjacent pole-top assemblies are not identical and thus the supply conductors are not parallel.

Figure 5-1: Crossarm to Vertical Construction



5.2 Application of Clearance Equations: The equations in Sections 3 and 4 of this bulletin are used to determine maximum allowable spans independently based on either the horizontal or the vertical NESC conductor clearances. When the conductors in a span are not parallel, both the horizontal and vertical conductor clearances have to be calculated simultaneously for all points in the span for each pair of conductors to determine compliance with NESC conductor clearances. Thus, as shown in Figure 5-1 of this bulletin, both the horizontal and the vertical conductor clearances between the closest phase-to-phase conductors (phases 1 and 2) and the closest phase-to-neutral (phase 3 and N) need to be determined.

Note that for the conductor configuration shown in Figure 5-1 of this bulletin, the horizontal clearance requirements are applicable to the conductors extending from the VC1.11 assembly and the vertical clearance requirements are applicable to the conductors extending from the VC3.1 assembly. It is unknown where in the span the applicable conductor clearance requirements shift from horizontal to vertical.

5.3 Maximum Spans Limited by Non-parallel Phase Conductors: The maximum allowable span for non-parallel phase conductors (phases 1 and 2 in Figure 5-1 of this bulletin) can be calculated with the following equation:

$$S_m = \left[\frac{K \times S_r}{\sqrt{D_r}} \right] \times \left[\frac{(H_1 \times (V_2 - C_v) - H_2 \times (V_1 - C_v))}{(V_2 - V_1)} \right] \text{ feet} \quad \text{EQ 5.1}$$

Where,

- S_m = Maximum allowable span (feet)
- K = Calculation constant = 1.5
- S_r = Design ruling span (feet)
- D_r = Phase conductor final ruling span sag at 60 °F (feet)
- H_1 = Horizontal clearance at support 1 (feet)
- H_2 = Horizontal clearance at support 2 (feet)
- V_1 = Vertical clearance at support 1 (feet)
- V_2 = Vertical clearance at support 2 (feet)
- C_v = Required vertical clearance (feet) (See paragraph 4.3 of this bulletin)

Inherent to the application of equation EQ 5.1 are the following reasonable assumptions:

- The size, types and lengths of the 2 phase conductors are the same, and
- The sags and tensions of the conductors are the same. (See paragraph 4.5 of this bulletin.)

5.4 Example Problem 4: Maximum Allowable Span of Non-parallel Phase Conductors: For the RUS standard 24.9/14.4 kV distribution pole-top assemblies and conductor configuration shown in Figure 5-1 of this bulletin and the following given data, determine the maximum span

(S_m) based on the clearance of the uppermost primary phase conductors. The final ruling span sag (D_r) is based on #4/0 ACSR conductor in the NESC Heavy Loading District.

K	= 1.5	(Calculation constant)
S_r	= 375 feet	(Design ruling span)
D_r	= 4.26 feet	(Phase conductor final ruling span sag at 60 °F)
H_1	= 3.583 feet	(Horizontal clearance at support 1) (43 inches)
H_2	= 0 feet	(Horizontal clearance at support 2)
V_1	= 1.25 feet	(Vertical clearance at support 1) (15 inches)
V_2	= 3.917 feet	(Vertical clearance at support 2) (47 inches)
C_v	= 1.5 feet	(Required vertical clearance) (18 inches)

The maximum span (S_m) based on the clearance of the uppermost primary phase conductors can be determined by substituting the above given values into equation EQ 5.1 as follows:

$$S_m = \left[\frac{1.5 \times 375}{\sqrt{4.26}} \right] \times \left[\frac{(3.583 \times (3.917 - 1.5) - 0 \times (1.25 - 1.5))}{(3.917 - 1.25)} \right] = 885 \text{ feet}$$

5.5 Maximum Spans Limited by Clearances of Non-Parallel Phase-to-Neutral Conductors:

The following paragraphs of this bulletin examines non-parallel, phase-to-neutral conductors whose separation is controlled by horizontal clearance requirements at one end of the span and vertical clearance requirements at the other end of the span. The determination of the maximum allowable span based on clearances between these conductors needs to consider:

- The simultaneously horizontal and vertical clearances between the conductors throughout the span, and
- The different sags of the conductors as required by NESC Rule 235C2b(1)(a). (See paragraph 4.4 of this bulletin.)

The allowable span determination is further complicated because the conductor sags are a function of the length of the span. The maximum allowable span based on NESC clearances can be determined by performing the following steps:

Step 1: Select the maximum span length desired or required for the distribution line section being designed.

Step 2: Determine the maximum allowable span based on phase-to-phase horizontal and vertical conductor clearances as presented in paragraphs 5.3 and 5.4 of this bulletin. If the span under consideration (Step 1) is longer than maximum allowable span length based on phase-to-phase clearances, then stop! The maximum allowable span based on conductor clearances has already been determined by the phase-to-phase clearances.

Step 3: Determine the final unloaded sag (D_m) at 60 °F, for both the phase and the neutral conductors, for the span length selected in Step 1 above. The following equation EQ 5.2 can be used to calculate the sags:

$$D_m = D_r \times \left| \frac{(S_m)^2}{(S_r)^2} \right| \text{ inches} \quad \text{EQ 5.2}$$

Where:

D_m = The final unloaded sag (D_m) at 60 °F

D_r = Design ruling span sag (final unloaded sag at 60 °F with no wind) (inches)

S_m = Selected span length (from Step 1) (feet)

S_r = Design ruling span (feet)

Select the greater of the 2 sags calculated.

Step 4: Calculate the NESC minimum horizontal clearance (C_{hm}) between the conductors based on the greater of the 2 sags calculated in Step 3 above. The following equation EQ 5.3 can be used to calculate (C_{hm}):

$$C_{hm} = 0.3(\text{inches}/kV) \times V(kV) + 8 \times \sqrt{\frac{S(\text{inches})}{12}} \text{ inches} \quad \text{EQ 5.3}$$

Where,

C_{hm} = NESC minimum horizontal clearance (inches)

V = Voltage (kV)

S = Sag (inches) (calculated in Step 3 above)

Step 5: Calculate the distance (D_x) from Assembly 1 as shown in Figure 5-1 in paragraph 5.1 of this bulletin to the point in the span where the actual horizontal clearance between the conductors equals the required horizontal clearance (C_{hm}) for the given pair of conductors. This distance can be calculated using the following equation EQ 5.4:

$$D_x = S_m \times \left| \frac{(H_1 - C_{hm})}{(H_1 - H_2)} \right| \text{ inches} \quad \text{EQ 5.4}$$

Where,

D_x = Distance from Assembly 1 (feet)

S_m = Selected span (feet) (from Step 1)

H_1 = Horizontal clearance at Assembly 1 (inches)

H_2 = Horizontal clearance at Assembly 2 (inches)

C_{hm} = NESC minimum horizontal clearance (inches) (from Step 4)

Step 6: Calculate the actual vertical clearance between the conductors at the distance (D_x) calculated in Step 5 above. The sags used for the conductors have to be the worst case sag condition as per NESC Rule 235C2b(1)(c). The methodology used to select the worst condition sags is presented in paragraphs 4.6 and 4.7 of this bulletin. The vertical clearance between the conductors (V_x) at distance D_x can be calculated using the following equation EQ 5.5:

$$V_x = V_1 + \left(\frac{D_x}{S_m} \right) (V_2 - V_1) - \left(\frac{S_r^2}{S_m^2} \right) (D_{um} + C_t - D_b) \times 4 \times \left[\left(\frac{D_x}{S_m} \right) - \left(\frac{D_x}{S_m} \right)^2 \right] \text{ inches} \quad \text{EQ 5.5}$$

Where,

- V_x = Vertical clearance between conductors at distance D_x from Assembly 1
- V_1 = Vertical clearance between conductors at Assembly 1 (inches)
- V_2 = Vertical clearance between conductors at Assembly 2 (inches)
- D_x = Distance from Assembly 1 where horizontal clearance equals required horizontal clearance (feet) (from Step 5)
- S_m = Selected span (feet) (from Step 1)
- S_r = Design ruling span (feet)
- D_{um} = Final ruling span sag (feet) of the upper conductor at its:
 - (1) maximum design operating temperature; or,
 - (2) final sag at 32 °F with radial thickness of ice
- D_b = Corresponding final ruling span sag (feet) of the lower conductor at:
 - (1) same ambient temperature as $D_{um}(1)$ without electrical or ice loading; or,
 - (2) same ambient conditions as $D_{um}(2)$ without electrical or ice loading
- C_t = Clearance tolerance for engineering and construction errors (***RUS recommends adding a minimum of 5 percent to D_{um} to compensate for engineering and construction errors.***)

Step 7: If the vertical clearance (V_x) between the conductors, calculated in Step 6 above, is greater than 12 inches (for 12.47/7.2 kV) or 15 inches (for 24.9/14.4 kV) (see paragraph 4.3 of this bulletin), then the NESC clearance requirements are met for the span selected in Step 1. Otherwise, select a shorter span and repeat Steps 3 through 6 above.

5.6 Example Problem 5: Maximum Allowable Span of Non-parallel Phase-to-Neutral Conductors:

Determine if a 275 foot span (S_m) meets the NESC conductor clearance requirements for the 24.9/14.4 kV distribution line section shown in Figure 5-1 in paragraph 5.1 of this bulletin. The following ruling span sag (D_r) data is known for the #4/0 ACSR primary and #1/0 ACSR neutral conductors. The line has a 375 foot design ruling span (R_s) and is located in the NESC Heavy Loading District.

Temperature (°F)	Ice Loading (inches)	#1/0 ACSR Neutral Final Sag (feet)	#4/0 ACSR Primary Final Sag (feet)
32	0	4.72	3.24
32	1/2	8.31	6.21
60		5.83	4.26
120		6.90	6.21

Step 1:

A 275 foot span has been selected.

Step 2:

In Example Problem 4 in paragraph 5.4 of this bulletin, the maximum allowed span for the #4/0 ACSR primary conductors based on NESC clearances has been determined to be 885 feet which is longer than the span selected in this problem.

Step 3:

The final unloaded sag (D_m) at 60 °F, for both the phase and the neutral conductors for a 375-foot span is calculated using equation EQ 5.2 as follows:

$$D_m = D_r \times \left| \frac{S}{S_r} \right|^2 = 70 \times \left| \frac{275}{375} \right|^2 = 38 \text{ inches (}\#1/0 \text{ ACSR neutral conductor)}$$

$$D_m = D_r \times \left| \frac{S}{S_r} \right|^2 = 51 \times \left| \frac{275}{375} \right|^2 = 28 \text{ inches (}\#4/0 \text{ ACSR primary conductor)}$$

The #1/0 ACSR neutral conductor has the greater sag and thus is selected.

Step 4:

The NESC minimum horizontal clearance (C_{hm}) between the conductors based on the #1/0 ACSR neutral conductor sags calculated in Step 3 above is calculated using equation EQ 5.3 as follows:

$$C_{hm} = 0.3(\text{inches}/kV) \times V(kV) + 8 \times \sqrt{\frac{S(\text{inches})}{12}} \text{ inches}$$

$$C_{hm} = 0.3(\text{inches}/kV) \times 7.2(kV) + 8 \times \sqrt{\frac{38(\text{inches})}{12}} = 16.4 \text{ inches}$$

Step 5:

The distance (D_x) from Assembly 1 of Figure 5-1 of this bulletin to the point in the span where the actual horizontal clearance between the conductors equals the required horizontal clearance (C_{hm}) for this problem is calculated using equation EQ 5.4 as follows:

$$D_x = S_m \times \left| \frac{(H_1 - C_{hm})}{(H_1 - H_2)} \right| = 275 \times \left| \frac{(51 - 16.4)}{51 - 7} \right| = 216 \text{ feet}$$

As depicted in Figure 5-1 in paragraph 5.1 of this bulletin, the horizontal separation (H_1) between the neutral (N) and the bottom phase conductor (3) on Assembly 1 is approximately 52 inches (~ 51 inches clearance). If the neutral were installed on the other side of the pole the separation would be approximately 36 inches. Also as shown in Figure 5-1 of this bulletin, the horizontal separation (H_2) between the neutral and the bottom phase conductor on Assembly 2 is approximately 8 inches (~ 7 inch clearance). Depending on the use of eyebolts, angle brackets or fiberglass primary extension links, H_2 can vary from 0 inches to approximately 42 inches.

Step 6:

The worst case sag condition for the primary and neutral conductor pair as per NESC Rule 235C2b(1)(c) for a 375-foot design ruling span (see paragraph 4.7 of this bulletin) is:

Condition 1: (Primary conductor at 120 °F; Neutral conductor at an ambient temperature of 60 °F with no electrical or ice loading)

$$D_{um} = 75 \text{ inches (plus 4 inches recommended by RUS)} \quad D_b = 70 \text{ inches}$$

The decrease in clearance equals $(75 + 4) - 70 = \underline{9 \text{ inches}}$

Condition 2: (Primary conductor at 32 °F with one-half inch of ice loading; Neutral conductor at an ambient temperature of 32 °F with no electrical or ice loading)

$$D_{um} = 75 \text{ inches (plus 4 inches recommended by RUS);} \quad D_b = 57 \text{ inches}$$

The decrease in clearance equals $(75 + 4) - 56 = \underline{23 \text{ inches}}$

Condition 2 is the worst loading condition.

The actual vertical clearance (V_x) between the conductors at the distance (D_x) calculated in Step 5 above is calculated using equation EQ 5.5 as follows:

$$V_x = V_1 + \left| \frac{D_x}{S_m} \right| \times (V_2 - V_1) - \left| \frac{D_x^2}{S_r^2} \right| \times \left(D_{um} + C - D_b \right) \times 4 \times \left[\left| \frac{D_x}{S_m} \right| - \left| \frac{D_x}{S_m} \right|^2 \right] \text{ inches}$$

$$V_x = 31 + \left| \frac{216}{275} \right| \times (47 - 31) - \left| \frac{275^2}{375^2} \right| \times (75 + 4 - 56) \times 4 \times \left[\left| \frac{216}{275} \right| - \left| \frac{216}{275} \right|^2 \right] \text{ inches}$$

$$V_x = 35 \text{ inches}$$

Step 7:

The vertical clearance (V_x) between the conductors, calculated in Step 6 above, is greater than the required vertical clearance of 15 inches for 24.9/14.4 kV, at the point D_x on the span where the horizontal clearances become critical. Thus, **the NESC clearance requirements are met for a 275-foot span** for the conditions given in Example Problem 5 of this bulletin.

EXHIBIT A: CONTRIBUTORS

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