RUS Bulletin 1724E-104
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UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Utilities Service

Bulletin 1724E-104
RD-GD-1999-33

SUBJECT: **Reduced Size Neutral Conductors for Overhead Rural Distribution Lines**

TO: *RUS Electric Borrowers and RUS Electric Staff*

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PURPOS E: *This bulletin covers the principal considerations applicable to reduced size neutral conductors and outlines a procedure for their selection and installation. Tables of the more commonly used conductor combinations for existing Rural Utilities Service (RUS) standard construction are also included.*

Assistant Administrator
Electric Program

9/23/99
Date

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ABBREVIATIONS

AAAC	All Aluminum Alloy Conductor
AAC	All Aluminum Conductor
ACAR	All Conductor Alloy Reinforced
ACSR	Aluminum Conductor Steel Reinforced
AWG	American Wire Gauge
kcmil	Thousand Circular Mills
NESC	National Electrical Safety Code
RUS	Rural Utilities Service

1. INTRODUCTION:

1.1 <u>Use of Reduced Size Neutrals:</u> The use of reduced size neutral conductors can result in significant savings in distribution line construction or conversion cost with very little impairment to the electrical performance of the system. However, whenever a line is constructed with phase and neutral conductors of different sizes, materials, or stranding, it becomes necessary to observe certain precautions to avoid excessive tensions or reduced clearances which may not meet the minimum requirements of the National Electrical Safety Code (NESC). Furthermore, with increasing numbers of heavy and harmonically rich loads, consideration has to be given in some instances to the possibility of phase and neutral conductors operating at temperatures near their thermal limits. This differential temperature operation can cause unexpected reductions in both ground and phase-to-neutral clearances.

1.2 <u>Scope of Bulletin:</u> This bulletin covers the principal considerations applicable to reduced size neutral conductors and outlines a procedure for their selection and installation. Tables of the more commonly used conductor combinations for existing Rural Utilities Service (RUS) standard construction are also included.

2. NEUTRAL LOAD CURRENT CONSIDERATIONS:

2.1 <u>Stray Voltage:</u> In areas where stray voltage is a concern, a neutral conductor of the same size and type as the phase conductor should be used.

2.2 <u>Single-phase Lines:</u> On single-phase multigrounded neutral lines, the entire load current returns to the source through the neutral conductor and the earth. The earth carries most of the total current. For single-phase lines, the minimum conductivity (or current capacity) of the neutral conductor has to be somewhat more than 50 percent of the conductivity of the phase conductor.

2.3 <u>Two-phase Lines:</u> On two-phase multigrounded neutral distribution lines, the total vector sum of the two phase load currents, which is always less than their algebraic sum, returns to the source through the neutral conductor and the earth. The neutral carries less than 50 percent of this vector sum current. The neutrals on two-phase distribution lines generally need a minimum conductivity of at least 70 percent of the conductivity of each phase conductor in order to carry the above load currents and provide an adequate margin of capacity for fault and worst case conditions.

2.4 <u>RUS Recommendation:</u> RUS strongly recommends that a reduced size neutral not be used on single-phase or two-phase lines for the following reasons:

- Simplify engineering, materials and construction of the line;
- Improve overall appearance of the line;
- Minimize possible stray voltage problems;
- Comply with the rule of a minimum of 70 percent (of each phase conductor) neutral conductivity for two-phase lines; and
- Facilitate future conversion to three-phase where the initially installed full size neutral may possibly be used as a full or reduced size three-phase neutral.

2.5 <u>Three-phase Lines:</u> For three-phase lines with multigrounded neutrals, the neutral and earth together normally carry only the unbalanced system load current. During normal conditions this load unbalance seldom exceeds 20 percent of the phase currents.

2.5.1 The neutral and earth combination may, however, be forced to carry a greater percentage of the phase current during system outages when one or two phases are open and the unbalance is significantly increased. Even for these conditions, it is unlikely that the neutral and earth combination would carry more than 50 percent of the peak phase current since three-phase loads presumably drop off the line and reduce system loading.

2.5.2 There may also be locations on a three-phase feeder where an unbalance condition is more significant because of heavily loaded single-phase taps fed from the three-phase line. For properly designed systems, worst case unbalance conditions should not result in a need for more than a 50 percent neutral conductivity requirement.

2.6 <u>Secondary Underbuild:</u> Where primary lines are underbuilt with secondary, the primary neutral may also be used as the secondary neutral provided that its conductivity is suitable to carry both the secondary neutral loads plus the expected primary neutral loads as explained above.

3. FAULT CURRENT CONSIDERATIONS:

3.1 <u>High Fault Currents:</u> Consideration has to be given to the magnitude of available fault currents in the selection of neutral conductors. Usually this will be significant only where the maximum line-to-ground fault current exceeds 3000 amperes or where the neutral conductor is #2 ACSR (or its copper equivalent) or smaller. For such conditions, the annealing or threshold melting point of the neutral conductor has to be less than the clearing time of the time-current characteristics of all of the protective devices between the power source and the conductor in question. Where conductor damage is possible, a larger neutral conductor has to be used in the area of high fault current or else the fault current clearing time of all the relevant source side protection devices has to be reduced.

3.2 <u>Low Fault Currents:</u> In areas with low fault current, the clearing time of protective devices may be extended even where reduced size neutrals are used. Conversely, larger size neutrals provide increased phase-to-neutral fault current capability thus reducing the total time to clear a fault involving the neutral.

4. HARMONIC CONSIDERATIONS:

4.1 <u>Increased Neutral Loading:</u> With the increasing use of electronic devices for both home and industrial applications, the harmonic content on power lines is increasing. The use of electronic ballasts for lighting, switch mode power supplies in computers and other consumer electronic loads, and variable speed drives for commercial and industrial loads has greatly increased the level of harmonic current in neutrals. Harmonic current has to be considered when sizing the neutral conductors, especially reduced size neutrals, because overall harmonic current amplitudes may be greater than the normally expected load currents, and together they may exceed the conductor's capacity. If harmonic problems are suspected on a line, a study should be undertaken to determine the expected magnitude of harmonic currents and the neutral conductors should be sized accordingly.

4.2 <u>Increased Neutral Sag:</u> Increased neutral currents, due to harmonics, may cause the neutral to become thermally loaded and sag more than expected at any given temperature. This phenomenon has to be considered when staking and tensioning neutral conductors otherwise inadequate ground clearance may result.

5. MINIMUM CONDUCTIVITY REQUIREMENTS: Evaluation of the neutral load currents, fault currents and harmonics leads to the conclusion that the neutral conductivity requirements, particularly for three-phase lines, are lower than the phase conductor requirements. If conductivity were the only consideration, then relatively small neutral conductors could be used with phase conductors. However, RUS advocates that a neutral conductor have at least 20 percent of the current carrying capacity of the phase conductor with which it is used. Table I shows ACSR neutral and phase conductor combinations based upon this consideration.

6. ECONOMIC CONSIDERATIONS: While relatively small neutral conductors could be used to satisfy conductivity requirements, their possible increased sag characteristics may reduce ground clearances which in turn may require shorter spans or taller poles. Using larger or full-size neutrals may avert this problem. A cost analysis comparing the savings of a reduced size neutral conductor cost versus any additional cost for taller poles or shorter spans is needed to determine the least costly alternative. The electronic spreadsheet associated with RUS Bulletin 1724D-104 can aid in this analysis. However, seldom is a reduced size neutral cost savings offset by the additional cost of taller poles or shorter spans when required. For this reason, a neutral conductor larger than that required only for conductivity is frequently the best overall selection.

7. MECHANICAL CONSIDERATIONS:

7.1 <u>Sag Differences:</u> It is desirable that the neutral conductor selected has a final unloaded sag equal to the phase conductor sag under the same conditions. The normal maximum design sag is usually calculated at 120^{o}F (49^{o}C) maximum design temperature, or 32^{o}F (0^{o}C) with ice, whichever is greater. If the phase conductors are electrically loaded such that their temperatures are much higher than the neutral, then the separation between the phase and neutral conductors has to be considered. Table 235-5 of the 1997 NESC exhibits mid-span minimum clearance requirements for various primary voltages. Using the values in this table and the spacing on standard RUS three-phase pole-top assemblies in most cases results in an allowable sag difference between the neutral and phase conductors of generally less than approximately 18 inches (460 millimeters).

7.2 <u>Ground Clearances:</u> The 1997 NESC basic ground clearances (Table 232-1, line 9,) for wires that run along roads are 15.5 feet (4.7 meters) for the neutral and 18.5 feet (5.6 meters) for phase conductors. The vertical separation between the points of attachment of the neutral and phase conductor for a standard RUS three-phase pole-top assembly with crossarms is approximately 3 feet (0.9 meters). For such standard RUS construction, either the phase or the neutral conductor sag, at the maximum design sag conditions, may determine ground clearance. Thus, the line design has to consider sag and clearances for primary conductors, neutral conductors including reduced sized neutrals, under all of the conditions prescribed by the NESC. Likewise, the above calculations may be required to determine clearance to underbuilt joint-use facilities. Consequently, taller poles, shorter spans or increased separation may be required in the design and staking of the line.

8. LARGE PHASE CONDUCTORS:

8.1 <u>Conductor Sag:</u> Various sizes of single layered ACSR conductors (6/1 or 7/1) tend to have similar sag characteristics. It is relatively simple to find two different size conductors through 4/0 ACSR whose sag will match well over a wide range of temperature and loading conditions. The same is not true for larger phase conductors. Conductors larger than 4/0 in size are multilayered and are available in various ACSR strandings such as 18/1, 26/7, 54/7 etc. All aluminum conductors (AAC, AAAC, ACAR, etc.,) are frequently selected for large conductor distribution construction (where the mechanical strength of ACSR is not needed) because their electrical losses are lower than ACSR. The differences in strandings and materials of large conductors cause significant variations in sag characteristics. This phenomenon makes it difficult to match the sag of a large phase conductor to a single-layered ACSR neutral conductor.

8.2 <u>Thermal Loading:</u> Large phase conductors are likely to be thermally loaded and subjected to temperatures well above their corresponding neutral conductor temperature at certain times. Conductor creep will occur at a more rapid rate at elevated temperatures than at lower temperatures thus further reducing the separation between the phase and neutral conductors.

9. SUGGESTED PROCEDURE FOR THE SELECTION OF NEUTRAL CONDUCTOR SIZE FOR THREE-PHASE LINES – NOT THERMALLY LOADED:

9.1 General Comments: The number of variables involved with multilayered and different conductor materials makes it impractical to provide tables showing combinations of neutral/phase conductors which will be satisfactory for use with conductors above 4/0 ACSR. The engineer has to take all of these factors into consideration and decide upon a suitable neutral to use with large phase conductors. The procedure that follows is intended as a guide to assist in that determination.

9.2 Assumptions: The following procedure assumes that RUS standard pole-top assemblies are used and that the staking of the lines is to minimum NESC clearance requirements.

9.3 Suggested Procedure:

(1) Determine the probable maximum neutral load current over the life of the line under worst case conditions. Worst case is usually during the time when one or two phases are open following a fault. If this is estimated to be 20 percent or less than the maximum current carrying capability of the size and type of phase conductor to be used, then the conductor combinations provided in Table I may be used. Where the maximum neutral load current is estimated to be more than 20 percent of the current carrying capability of one of the phase conductors, a suitable minimum conductor size should be determined on the basis of the estimated maximum current.

(2) Based on the criteria for current carrying capacity, tabulate all possible neutral conductor sizes from the minimum as determined in Step (1) up to and including the phase conductor size.

(3) Prepare a chart using the ruling span of the line showing the initial and final sags of the phase conductor and all possible neutral conductors for various temperatures and loadings.

(4) From these data select those possible neutral conductors whose use would result in a decrease of vertical clearance between phase and neutral at the midspan of not more than 17 inches (430

millimeters) from the vertical clearance at the pole for all comparable conditions. Note: Usually a reduced neutral conductor will have a greater final sag than the phase conductor when the conductor stranding and material is similar. However, when dissimilar strandings or conductor materials are used, the separation between phase and neutral conductors may decrease more than permissible by NESC Rule 235. In such cases, the pole-top assembly may have to be modified to increase the clearance between phase and neutral conductors or other conductor strandings or conductor materials may be necessary for acceptable sagging.

(5) From the list of possible neutral conductors, discard any conductor with a sag of 3 feet (0.9 meters) greater than the sag of the phase conductor under final loaded conditions, the 120° F (49°C) final unloaded condition, or final unloaded maximum design temperature condition.

Where icing is a serious problem, a comparison with the phase loaded and the neutral unloaded should be made to ensure necessary separation is maintained if the neutral should lose its ice coating and the phase conductor does not.

Use the smallest neutral conductor that meets the above conditions.

10. SUGGESTED PROCEDURE FOR THE SELECTION OF NEUTRAL CONDUCTOR SIZE FOR THREE-PHASE LINES – WITH THERMALLY LOADED PHASE CONDUCTORS: Where it is possible that the phase conductors may be loaded at or near their thermal limit during the life of the line, provisions have to be made in the design of the line to maintain a minimum separation between the phase and neutral conductors for the anticipated conditions. The general procedure outlined in Section 9 above should be followed in selecting a neutral and phase conductor. However, the tabulation of sags should include the sag of the phase conductor at its maximum assumed operating temperature and the sag of the neutral at 60°F (15.5°C). In addition, the final sags of the various possible phase conductors at their maximum possible operating temperature should be compared with the final unloaded sags at 60°F (15.5°C) of the possible neutral conductors. Any reduction in midspan separation greater than 17 inches (430 millimeters) between the selected neutral and phase conductors use should be compensated for either by increasing the vertical separation at the point of attachment or by increasing the

60°F (15.5°C) sag of the neutral conductor. It is recommended that various types, sizes and strandings of conductor be evaluated for best sag characteristics for lines operating at or near the thermal limit of the phase conductors.

11. LINE STAKING AND CONDUCTOR SAGGING: In general, the line should be staked to that conductor, either phase or neutral, whose final sag controls the relationship between pole height, span and minimum NESC ground clearances. The vertical separation between phase and neutral conductors on standard RUS three-phase assemblies is such that either phase or neutral conductors can control the staking of the line. In any case all NESC ground clearances and conductor separations have to be met for all conductor sags both initial and final. If special sag and tension conditions are used in the selection of a neutral conductor, then those special sag and tension tables have to be used when staking the line and tensioning the conductors.

TABLE 1

Minimum acceptable neutral conductor size based on the 20 percent conductivity rule and 3000 amp fault current maximum

Phase Conductor Size (ACSR)	Minimum Acceptable Neutral Conductor Size (ACSR)
#4 AWG	# 4 AWG
# 2 AWG	# 4 AWG
1/0 AWG	# 4 AWG
2/0 AWG	# 4 AWG
3/0AWG	# 4 AWG
4/0 AWG	# 2 AWG
336.4 kcmil	1/0 AWG
557.5 kcmil	2/0 AWG
795.0 kcmil	3/0 AWG

TABLE 2

Commonly used phase conductor/reduced neutral combinations for ACSR type, single layer conductors – Three-Phase Lines
(Same for Each NESC Loading District)

Phase Wire Size	Reduced Neutral Size
1/0 (6/1)	# 2 (7/1)
2/0 (6/1)	# 2 (7/1)
3/0 (6/1)	# 1/0 (6/1)
4/0 (6/1)	# 1/0 (6/1)