

UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Utilities Service (RUS)

BULLETIN 1724D-113

SUBJECT: Voltage Levels on Rural Electric Distribution Systems

TO: All RUS Electric Borrowers

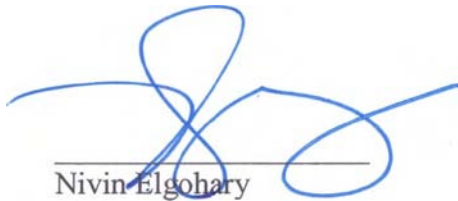
EFFECTIVE DATE: Date of Approval

OFFICE OF PRIMARY INTEREST: Distribution Branch, Electrical Staff Division.

INSTRUCTIONS: This bulletin replaces REA (Rural Electrification Administration) Bulletin 169-4 dated November 1970.

AVAILABILITY: This bulletin is available on the RUS Electric Program website at <http://www.usda.gov/rus/electric/bulletins.htm>.

PURPOSE: This bulletin provides recommended voltage levels and limits to serve as guidelines in the design and operation of electric distribution systems. Because utilities are responsible only for power supply up to the point of connection with the consumer's facilities, this bulletin limits its scope to the supply portion of the electric system. The bulletin refers, however, to the expected performance of consumer-owned wiring and its effect on utilization voltage.



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ABBREVIATIONS

ANSI – American National Standards Institute
 NEMA – National Electrical Manufacturers Association
 RUS – Rural Utilities Service
 USDA – United States Department of Agriculture

DEFINITIONS

Base Voltage – Base voltage is a reference value which is a common denominator to the nominal voltage ratings of transmission and distribution lines, transmission and distribution equipment, and utilization equipment. For example, the base voltage of a transmission line having a nominal voltage rating of 34,500 volts is 115 volts; and the base voltage of a distribution line having a nominal voltage rating of 7200 volts is 120 volts. In general, distribution lines and associated equipment having a nominal rating of from 2400 volts through 19,920 volts will have a 120-volt base, and the nominal voltage rating of utilization equipment served by these voltages will also have a 120-volt base.

Equipment - The term "equipment" is a general term that includes material, fittings, devices, appliances, fixtures, apparatus, and the like, used as part of, or in connection with, an electrical installation (Reference 1).

Maximum Voltage – Maximum voltage is the greatest sustained root-mean-square (RMS) voltage averaged over 10 minutes.

Minimum Voltage - Minimum voltage is the least sustained RMS voltage averaged over 10 minutes.

Nominal Voltage - The nominal voltage of a circuit or system is a nominal value assigned to the circuit or system for the purpose of conveniently designating its voltage class (See References).

For example, the nominal residential voltage is 120 volts, although the voltage may actually range from 114 volts to 126 volts.

Phase Unbalance (Reference 1)

Percent phase unbalance = $100 \times \frac{\text{maximum deviation from average phase-to-phase voltage}}{\text{average phase-to-phase voltage}}$

Service Voltage – Service voltage is the voltage at the point where the electric systems of the supplier and the user are connected (Reference 1). In distribution systems this is usually considered the voltage at the meter socket or entrance switch.

Voltage Regulator - A voltage regulator is a device consisting of a regulating transformer and means for adjusting the voltage of the circuit without interrupting the load.

Utilization Voltage – Utilization voltage is the voltage at the line terminals of utilization equipment (Reference 1). This is generally considered to be the voltage at the terminals of the device or appliance or the voltage at the convenience outlet to which these terminals are connected.

Voltage Drop – Voltage drop (in a supply system) is the difference between the voltages at the transmitting and receiving ends of a feeder, main, or service.

Voltage Level - Voltage level is a generalized term that is synonymous with the RMS voltage averaged over 10 minutes (Reference 1).

REFERENCES

ANSI C84.1 – 2011, American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hertz) published by National Electrical Manufacturers Association (NEMA).

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SUBJECT: Voltage Levels on Rural Electric Distribution Systems

- 1 Purpose: The purpose of this bulletin is to recommend voltage levels and voltage limits to serve as guidelines in the general design and operation of electric distribution systems. Because utilities are responsible only for power supply up to the point of connection with the consumer's facilities, this bulletin limits its scope to the supply portion of the electric system. The bulletin refers, however, to the expected performance of consumer-owned wiring and its effect on utilization voltage.
- 2 Voltage Standards: The American National Standards Institute (ANSI) Publication ANSI C84.1-2011, "American National Standard For Electric Power Systems and Equipment—Voltage Ratings (60 Hertz)", * establishes standards on voltage limits for the electric distribution supply system. It includes voltage limits within which utilization equipment should operate satisfactorily. It thus serves as a guideline for the electrical manufacturer in equipment design and for the user in designing an electrical wiring system. The recommendations in this bulletin are based on this ANSI voltage standard.
- 3 American National Standards Institute Voltage Ranges
Application of voltage ranges (quoted directly from the standard, ANSI C84.1-2011)
 - a Range A
 - (1) Service Voltage
Electric supply systems shall be so designed and operated that most service voltages are within the limits specified for Range A. The occurrence of service voltages outside of these limits is to be infrequent.
 - (2) Utilization Voltage
User systems shall be so designed and operated that with service voltages within Range A limits, most utilization voltages are within the limits specified for this range.

Utilization equipment shall be designed and rated to give fully satisfactory performance throughout this range.
 - b Range B
 - (1) Service and Utilization Voltages
Range B includes voltages above and below Range A limits that necessarily result from practical design and operating conditions on supply or user

*References are listed on page 3.

systems, or both. Although such conditions are a part of practical operations, they shall be limited in extent, frequency, and duration. When they occur, corrective measures shall be undertaken within a reasonable time to improve voltages to meet Range A requirements.

Insofar as practicable, utilization equipment shall be designed to give acceptable performance in the extremes of this range of utilization voltage, although not necessarily as good performance as in Range A.

4 RUS Recommended Voltage Limit Values

The voltage limits of Range A and Range B in ANSI-C84.1-2011 refer to utilization and service voltages. The effects of these limits on primary distribution voltages are discussed later in this bulletin.

Table 1. Voltage Ranges (120-volt base)

Range	Service Voltage	
	Minimum	Maximum
A	114	126
B	110	127

a Basic Design Criteria

- (1) Electric distribution systems should be designed and operated to meet the voltage level requirements of Range A in Table 1. Users' electrical equipment of all types will generally be designed to give satisfactory performance in this range.
- (2) Maintaining voltage levels within Range A on all parts of the system at all times cannot be assured. As a result of the economics of operation, there may be some system voltages that fall in the extremes of Range B and even beyond. This may occasionally occur as the feeder reaches its design loading limit at extreme loads.
- (3) When voltages extend into Range B during normal conditions or for an extended period of time they should be corrected immediately to conform to Range A requirements by using interim measures, and plans for a permanent solution should be developed.

- (4) If voltages on any part of the system fall outside the limits of Range B, corrective action shall be taken upon discovery of this condition to bring voltages within Range B. Interim measures should be taken if a permanent solution cannot be completed immediately.
- (5) As lines become loaded, the voltage can vary independently within the three phases that all distribution systems provide. This is termed “phase unbalance,” because the voltage levels depend on the method and settings of regulation at the substation and downstream along the circuit as well as the loading conditions. The utility should endeavor to maintain the voltages among the three phases to within a maximum of 3 percent phase unbalance under no-load conditions (Reference 1; also see Definitions).
- (6) The consumer is responsible for the design of the electric system and its subsequent voltage drop beyond the point of connection to the supplier. The consumer facility design is governed by applicable local codes as well as the National Electrical Code (Reference 2).

Some types of utilization equipment will not perform satisfactorily or efficiently at the extremes of Range B voltages. Outside Range B voltage limits, many types of utilization equipment may fail to operate and may be seriously damaged or suffer shortened operating life. Voltages above the limits of Range B may be especially damaging to the users' utilization equipment.

b System Voltage Design Recommendations

Table 1 indicates the allowable range of voltages delivered to consumers at the point of delivery. Table 2 provides recommendations on ranges of voltage drops allowable at various points in the distribution system. Table 3 provides recommendations on ranges of voltage levels allowable at various points in the distribution system. Regardless of the voltage drops recommended in Table 2, the voltage levels in Tables 1 and 3 must be maintained at all load levels.

(1) Distribution Substation

The output voltage of the distribution substation should be regulated to stay within the limits shown in Table 3. This can be accomplished by applying regulation equipment, by coordination with the power supplier, or both.

(2) Primary Distribution Lines

This zone extends from the load switches of the substation feeder breaker to the high-voltage terminal of the distribution transformer. Voltage drop occurs along the distribution feeders, and regulation can be placed as needed, but the resulting voltage drop should be within the limits shown in Table 2.

(3) Distribution Transformer and Services

(a) This zone extends from the high-voltage terminal of the distribution transformer to the point of delivery. The total voltage drop in this zone should be limited to the range shown in Table 2.

(b) While the voltage levels on ANSI C84.1-2011 are generally accepted as sustained voltages, the designer should not ignore the impact of flicker and motor starting on the level or quality of service voltage. These issues are beyond the scope of this document.

Table 2. Voltage Drops for Electric Distribution System Design (120-volt base)

	Maximum Volts Drop	Percent Volts Drop
Substation regulated bus (output) to last distribution transformer (primary)	8	6.67
Distribution transformer (primary) to service delivery connection to consumers' wiring (meter or entrance switch)	4	3.33

Table 3. Design Voltage Level Limits for Electric Distribution Systems. (120-volt base)

	Voltage Level (volts)	
	Minimum	Maximum
Substation regulated bus with regulator line drop compensator in use	122	126
Distribution transformer primary terminals	118	126
Service connection to consumer wiring	114	126