**UNITED STATES DEPARTMENT OF AGRICULTURE**
Rural Utilities Service

**BULLETIN 1724D-105**

**SUBJECT:** **Rural Distribution System Voltage Conversion Considerations**

**TO:** Rural Utilities Service Electric Borrowers and Rural Utilities Service Electric Staff

**EFFECTIVE DATE:** Date of Approval.

**OFFICE OF PRIMARY INTEREST:** Electric Staff Division

**INSTRUCTIONS:** This is a new bulletin.

**AVAILABILITY:** This bulletin can be accessed via the Internet at
http://www.usda.gov/rus/electric/bulletins.htm

**PURPOSE:** This bulletin recommends that, during initial development and periodic updating of system Long-Range Plans (LRPs), system planners include an evaluation of whether it would be beneficial to convert some system circuits to a different voltage energization level. To assist planners, the bulletin provides engineering guidance on the economic and other factors that should be considered in voltage conversion evaluations. This bulletin was prepared with the intent that planners also refer to Rural Utilities Service Bulletin 1724D-101A, "Electric System Long-Range Planning Guide."

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*The System Planning Subcommittee and Rural Utilities Service wish to dedicate this publication to the memory of David Obenshain, past Subcommittee Chair and Engineering Manager at Piedmont Electric Membership Corporation, Hillsborough, NC. His hard work, leadership, and character will be missed.*

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**ABBREVIATIONS**

BIL – Basic impulse insulation level; a reference value of electrical insulating capability expressed in terms of the crest value of withstand voltage of a standard full-impulse voltage wave.

CFR – Code of Federal Regulations.

DV – Dual voltage; applicable to transformers that have multiple taps allowing the user to select optional voltage excitation levels.

FCR – Fixed charge rate; an estimate of the percentage carrying costs of an investment, usually taking into consideration the cost of capital, operations and maintenance, taxes, and depreciation.

GrdY – Grounded wye; most common three-phase distribution system phase and grounding conductor connection scheme where one end of each of three transformer windings (comprising the individual phases of a three-phase system) is solidly connected to one another and effectively grounded to earth via a grounding conductor.

IEEE – Institute of Electrical and Electronics Engineers.

kV – Kilovolts, or 1000 volts.

kVA – Kilovolt-amperes; measure of apparent power on electrical systems.

LRP – Long-Range Plan; *see RUS Bulletin 1724D-101A.*

Mil – Unit of length equal to 1/1000 of an inch (25.4 micrometers) used especially for dimensioning the diameter of wire and the thickness of conductor insulation on underground power cables.

OSHA – Occupational Safety and Health Administration.

RUS – Rural Utilities Service – An Agency of the USDA.

# 1 INTRODUCTION

a Electric distribution system planning engineers should routinely include, as part of their Long-Range Plan (LRP) and LRP update process, the study and evaluation of possible conversion of system circuits to a higher utilization voltage. Voltage conversion can provide an effective means to economically improve service and reliability when implemented at the correct time and when thoroughly and meticulously coordinated. Conversions, however, can negatively impact the budget when prematurely implemented or poorly planned and coordinated.

b Before implementing a voltage conversion, conversion plans and projections need to show that a conversion will provide significant benefits to the organization. Thus, planning engineers' recommendations to go forward with conversions have to be based on comprehensive justification studies that show that the projected benefits outweigh the projected costs of the conversion.

c Planning engineers will find it helpful to review papers that document the voltage conversion experiences of other utilities, as well as discuss experiences directly with utility personnel. For Cooperatives considering 34.5 kV as a distribution voltage, one paper of interest is "Case Study of Radial Overhead Feeder Performance at 12.5 kV and 34.5 kV" by Roger E. Clayton and John M. Undrill of Electrical Power Consultants, Inc., and Eugene L. Shlatz of Green Mountain Power Company (document available from IEEE).

d This non-codified bulletin presents some of the many considerations that need to be included in voltage conversion studies. This bulletin should not be considered a complete guide for preparing voltage conversion studies. No matter how many points the bulletin discusses, there will always be additional points that the planning engineer should consider for a particular system.

e It should also be stated that, when economically justified, there are many benefits to Cooperatives that convert portions of their systems to higher voltages. While recognizing and acknowledging these benefits, this document focuses more on the cautions and considerations prior to making a voltage upgrade. Cooperatives considering conversions to a new system voltage are also encouraged to talk with other Cooperatives in their area who have experience with the higher voltage.

# 2 PRINCIPLES

a A decision to commit to convert the voltage on a circuit or circuits or the entire distribution system is a consequential decision in the life of a distribution power system. The decision to leave circuits on a system at their present voltage is just as crucial. It is crucial to the long-term welfare of the system to examine whether voltage conversion is in the best interests of system operation and the ratepayers.

b Anyone involved in a voltage conversion study (and an LRP) should be concerned with the basic question of overall costs to the ratepayers, which, for electric cooperatives, are the system member-owners. Although conversion costs to a distribution system may appear to be low under some scenarios, be careful to view the entire picture.

c In some voltage conversion scenarios, costs and obligations could be transferred to and obligate the distribution system's power supplier and/or other distribution systems. A "one utility" cost comparison should be developed and the least cost option, with an acceptable expectation of reliability should be utilized.

d This bulletin does not recommend retaining the present system voltage any more than a conversion to a higher voltage. The bulletin simply recommends the voltage conversion question be studied thoroughly and objectively.

e Most RUS electric borrower distribution line conversions involve upgrading 12.47GrdY/7.2 kV lines to 24.9GrdY/14.4 kV lines, but the principles provided in this bulletin apply to any conversion under study.

f Theoretically, if a system voltage conversion results in the voltage being doubled, load currents of the converted lines should be one-half their previous level, and the losses should be cut to one-quarter their former amounts. The overall effects of losses on lines and connected equipment, such as transformer core (iron) and copper (winding) losses, should be considered in studies. For voltage conversion projects that involve long time periods to completion, the use of step transformers, dual-voltage distribution transformers, and other equipment with appreciable iron losses should also be factored into your analysis.

g Distribution line voltage conversion may become necessary for reasons other than sound engineering economics. For example, an electric system may be faced with the need for transmission construction that is not practical, requiring an alternative solution such as voltage conversion. Other similar situations, which may make voltage conversion a likely solution, include state or local government regulations on the placement of electrical facilities, and difficult geographic considerations.

h Some LRP strategies involve employing an estimated growth rate greater than that actually expected for the purpose of "stressing" the system's key components. This strategy is not recommended for voltage conversions, where the use of a realistic system growth rate should be employed. Overestimating the growth rate may result in premature initiation of a voltage conversion project that is not economically nor technically justified.

i A meaningful voltage conversion study looks at the long-term costs of two or more technically feasible alternatives. Proposed alternatives should be capable of handling projected system loads at all times throughout the entire period covered by the LRP, and each alternative should address and eliminate the voltage problems found within the LRP study period. Since voltage conversion is a process that takes quite a few years to accomplish on many systems, the LRP provides a recommended way to evaluate the merits and timing of voltage conversion possibilities. Via the LRP, system components can be “stressed” for both the existing system voltage and the proposed converted voltage and rational decisions can be made on whether and when to initiate any conversions. If stressing scenarios applied for the last few years of the LRP indicate that the system does not yet need to be fully converted to a higher voltage, there could be concern that it is not economical to convert the system at all during the LRP planning period.

j It is typical to study conversion of an entire system, but partial system conversion may be more practical and economical for some systems. If different portions of a system have load characteristics that vary considerably, it may be best to concentrate the study on conversion of a portion of the system. However, it needs to be noted that a decision to convert a portion of a system might reduce the ability to shift load to alleviate losses, or to restore or backfeed circuits in case of outages. Because of these reduced abilities, for effective analysis, voltage conversion studies that focus on converting a portion of a system need to include more scenarios or alternatives than studies that concentrate on full system conversion.

k All factors that can be studied using engineering economics need to be evaluated thoroughly using expected load for each year or each “load block” (i.e., 5 years, 10 years, and 20 years) of the plan. Many of these economic considerations are discussed in Section 3 of this bulletin. However, many voltage conversion considerations are difficult or impossible to study quantitatively. A number of these factors are presented in Section 4 of this bulletin.

l Voltage conversion to a higher voltage can typically result in fewer new substations and thus fewer new transmission taps or transmission line extensions than a 7.2/12.47 kV system. Alternative voltages may be carefully evaluated as a means to mitigate the ever increasing cost and difficulty in obtaining transmission right-of-way.

3 ECONOMIC ANALYSIS FACTORS

a A study of economic alternatives is readily performed and detailed by using a specifically designed spreadsheet or other computer software application, hereinafter in this bulletin to be referred to as a spreadsheet. Planning engineers should examine available spreadsheets before making a decision as to which tool they wish to use or before developing their own spreadsheet. Some consultants have developed spreadsheets that may be good for a certain area’s wholesale rates or for certain delivery point policies. The Agency has developed an economics analysis spreadsheet that may be useful. The Agency spreadsheet is described in RUS Bulletin 1724D-104, “Engineering Economics Computer Workbook

Procedure." An electronic copy of the spreadsheet is available on the Agency Web site at http://www.usda.gov/rus/electric/bulletins.htm. Statewide associations may also have appropriate spreadsheets available. Spreadsheets can be linked so transmission costs may be separated from distribution costs, and power suppliers' costs can be separated from and/or combined with distributors' costs.

b Spreadsheets should be designed to display and summarize the engineer's cost estimates for the various alternatives by time period. Spreadsheets should contain all quantifiable factors including the following:

(1) Evaluation of the costs associated with ordinary system improvements that will be needed under each scenario. It will generally be necessary to modify existing plans for ordinary system improvements if the voltage conversion process is undertaken.

(2) Evaluation of the cost associated with losses under each scenario.

(3) Evaluation of the costs associated with member service extensions should be evaluated. These costs, on a per unit length basis, usually will be higher at the higher converted voltage.

(4) Evaluation and planning for distribution transformer replacement. For instance, planning engineers need to decide whether to use dual-voltage (DV) transformers or two transformers on a pole in preparation for the actual conversion day. Planning should include consideration of the long-term use of DV transformers and what to do with them after a section is converted.

(5) Evaluation of the use of two-winding transformers or autotransformers when a step bank is required. Overvoltage as well as overcurrent protection schemes need to be developed and appropriately included in the spreadsheet for evaluation. Standardization of kVA sizes should be studied, and appropriate evaluation factors should be included in the spreadsheet.

(6) Evaluation and replacement of underground primary cable with higher voltage circuits or maintaining existing lower voltage cables and feeding them with step-down transformers.

(7) Evaluation and use of capacitors under each scenario.

(8) Evaluation and planning with regard to sectionalizing. There are many decisions to be made while the conversion process is under way. Some systems have reported that smaller fuse sizes at higher voltages tend to nuisance-fail from lightning surges. Effective preparation for voltage

conversion includes proper consideration and application of protective devices. Such higher voltage devices may be purchased and installed for application long before the conversion actually takes place. However, be careful to ensure that these devices will work properly at the lower operating voltage. For example, reclosers may be purchased for the higher operating voltage, but they will require the proper closing coil ratings for the lower operating voltage while used at the lower voltage energization levels. Later, reclosers will require appropriate different closing coil ratings for their higher operating voltage at the time of conversion. If the voltage conversion impacts areas with DG or other energy sources, the Cooperative will need to ensure that any associated protective systems are not negatively impacted by the voltage change.

(9) Evaluation and planning for new substations or changes to existing substations that might be necessary during the LRP. This should also include any changes to inventory of spare major substation equipment.

(10) Evaluation and planning related to new transmission. New transmission should be considered even for systems that have no current transmission facilities. The solution that is economical for the distribution system and the distribution system's power supplier usually is the soundest solution.

(11) Evaluation and planning for right-of-way maintenance. There may be differences in methods and cost associated with maintenance of higher voltage overhead lines with respect to tree limbs, etc.

(12) Evaluation and planning to avoid ferroresonance problems. Systems operating at higher voltage levels are more susceptible to the flow of objectionably high currents related to ferroresonance conditions. Attention to proper use and protection of three-phase reclosers and three-phase switching equipment becomes extremely important. The system’s three-phase distribution transformer bank connection schemes need to be studied, and all costs for protection and additional provisions need to be included in the spreadsheet.

(13) The effect of voltage conversion on large-load consumers. Special utility-owned electrical equipment and the spares to be maintained need to be included in the spreadsheet. Planning engineers need to also consider whether large-load consumers may be required to change their own equipment as a result of voltage conversion.

(14) Evaluation of and planning for lower voltage surplus equipment. Depending on how rapidly the conversion process proceeds, there may be a surplus of electrical equipment used on the old lower voltage system. This equipment may have a low salvage value but may be used on other parts of the system depending upon the conversion timeframe.

(15) The implementation, extent, and timing of the voltage conversion. Many line construction activities are undertaken to prepare for a voltage conversion. Included are replacing lower voltage insulators with higher voltage insulators, hanging dual-voltage transformers (or a second transformer), installing step transformers, removing pole ground wires above the system neutral (*see* RUS Bulletin 1728F-803, "Specifications and Drawings for 24.9/14.4kV Line Construction"), and changing out underground cable and associated riser installations on poles. There also may be a need to change out a number of poles. With so many activities and items to complete, there may be a desire to do more to "make the system as good as it can be" in the first years of operation at the higher voltage. If considerable resources were to be expended in pursuit of such a desire in excess of a need, a system might not follow the most economical path. There is a certain amount of benefit to be derived, however, from replacement of aged equipment incidental to voltage conversion. For appropriate, effective evaluation, studies need to involve methodical inclusion of the various activities and installations during the time period when they are actually needed.

(16) Evaluation and planning for the purchasing, warehousing, and handling of extra amounts of materials during the entire conversion process. The most notable material items will include underground cable and arresters and distribution transformers with three different primary voltage schemes (the existing voltage, dual voltage, and the final conversion voltage). When converting to a higher voltage for the first time, the planning engineer needs to study whether it is better, for example, at 25kV to be conservative and use 345-mil primary underground cable or to use 260-mil cable. Plans should be made as to whether all new construction will follow the specifications for the new voltage level, keeping in mind the length of time until conversion is planned. Materials for the lower voltage level could continue to be handled by the warehouse for years. Of course, a system with new equipment using existing performance specifications may experience a measurable benefit regarding losses, maintenance costs, and/or reliability.

(17) Evaluation and planning decisions need to be made about the order of conversion. Such decisions may be handled, if necessary, by modeling them year-by-year in the worksheet. Many questions need to be answered. A few examples are the following:

- Is it best to build a temporary substation adjacent to an existing one? If so, is the temporary substation built for the new voltage or the existing voltage?

- Does an existing substation need to be relieved of load?

- Is it better to use step transformers in a substation to step the voltage up, or step it down?

- Is it better to convert starting from the ends of the distribution system or from the substation?

(18) Evaluation and planning for deteriorated system components. How will deteriorated components be handled? When converting to a higher voltage, the replacement of existing equipment with new equipment rated for the higher voltage is classified as betterment, and is eligible for both financing and capitalizing. Replacing existing equipment with like equipment (when not converting the voltage) may not be financeable.

(19) Evaluation and planning for the means and cost of training employees in staking, construction, materials, mapping and services to design and apply specifications and safe work practices for higher voltage.

(a) System maps, especially those used in the field, should clearly indicate the different voltages and should be kept up-to-date throughout a conversion process. Mapping should detail where two dead-ends are installed between the line energized at one voltage and the line energized at another voltage with a dead span in between.

(b) Training and safety-related cost may also result from changes in purchasing and testing specifications for rubber goods and other safety-related products for proper performance at the higher, converted, voltages. In most cases, costs for training and safety considerations can be estimated for planning purposes.

c Engineering economics studies should be prepared that easily detail the plan's parameters and are of such presentation quality that plan alternatives are well contrasted for understanding by non-engineers. Usually, economic studies involve the use of spreadsheets for ease of development and "what if" scenarios for understandable presentation to decision makers. The Agency recommends that the template used for presentation of the study results show the investment by LRP steps and by major construction and material factors, such as new distribution lines, distribution line conversions, new substations, major substation changes, step transformers, distribution transformers, meters, service upgrades, sectionalizing equipment, security lights, ordinary replacements, conductor replacements, capacitors, and regulators. Transmission factors include new line, line changes, and new substations.

(1) The substation presentation spreadsheet could detail each substation's conditions at the various steps of the LRP. This would show high-side

voltage, distribution voltage, load, transformer size, and regulator size. Temporary substations would also be shown.

(2) A spreadsheet would be needed to show operating cost. The rows of the spreadsheet might be each year of the LRP, and the columns could be present investment cost, future (inflated) investment cost, fixed charges (determined by applying the fixed charge rate), the difference in losses, total annual operating cost, the present worth of the particular year's costs, and the cumulative present worth cost.

(3) Detailed spreadsheets will include a listing of improvements, their unit costs year by year, and a sum of all those items. There may be separate spreadsheets for a power supplier's costs.

(4) Spreadsheets should show actual costs in the year incurred as well as the present worth of costs for all years studied.

## 4 QUALITATIVE CONSIDERATIONS

Many factors need to be considered when undertaking voltage conversion that may be difficult to quantify and evaluate on an economic basis. RUS borrowers should make every attempt to evaluate, as far as practical, alternatives on an economic basis. Factors difficult to quantify may be included in the narrative portion of the conversion study. The following are some items that may not be easy to quantify:

a The margin of protection will not rise as much as the voltage increases. The industry standard basic impulse insulation level for equipment and apparatus used on a 12.47/7.2 kV system is 95 kV BIL. The same standard for a 29.9/14.4 kV system increases only to 110 kV BIL. As a result, the susceptibility of the higher voltage system to lightning flashovers needs to be studied. Will lightning cause more cable and/or transformer failures at the higher voltage?

b Distribution circuits maintained at higher voltages have a lower associated voltage drop. This can allow system planners to extend the length of distribution circuits and serve a greater number of customers. However, longer distribution circuits incur more exposure to outages, accompanied by greater numbers of customers affected by an outage. A sectionalizing study and additional equipment may be required to address the economic considerations of extended circuits.

c In sectionalizing 12.47/7.2 kV systems, there may be situations where it becomes difficult for the planning engineer to apply simple, inexpensive protection solutions. An example is a situation in which actual minimum fault currents may not readily be sensed by typical protective devices. Because of the higher magnitude minimum fault currents associated with operating at a higher voltage, these types of protection problems may be less troublesome.

d Backfeed opportunities (or the lack thereof) need to be examined and appropriately included in the design and implementation of a voltage conversion project, especially if a lengthy voltage conversion process is expected.

e System design and implementation courses of action have to be well thought out and carried out to ensure there will not be objectionable numbers of outages to consumers during preparations for voltage conversion and on conversion day.

f Special care is necessary to make certain that adequate, problem-free, sectionalizing measures are designed and applied where step transformers are used to feed underground construction serving larger distribution transformers.

g For systems converting to a higher voltage for the first time, higher voltage cable is not as pliable as lower voltage cable. Cooperative personnel should acquire conductor samples to help evaluate the new cable to gain installation and operational experience.

h The LRP should include two alternative evaluations of load growth on the system. One alternative would detail accommodating the growth with the existing, lower voltage system, while the other alternative assesses accommodation of the load growth by converting one or more substation areas to a higher voltage. The economic development climate or load growth characteristics within a system's service area should be considered as an influence on conversion plans.

i The use of the proposed voltage by other distribution cooperatives and statewide purchasing organizations should be considered in terms of access to properly equipped and trained storm restoration line workers and emergency supplies of materials.

j Since more customers may be served from each circuit, respectively, with higher as opposed to lower primary voltages, more customers are likely to see power quality problems if they arise on the circuit. It should be stated that a higher voltage system will be stiffer and should see fewer voltage dips, all things equal.

k Radio interference has been reported to be a greater problem on systems operating at higher voltage levels. This is one reason why Agency specifications for "pole protection" do not show use of a grounding conductor above the neutral at voltages higher than 12.47/7.2 kV, except for a crossarm mounted arrester. Some experts recommend keeping the clearance between hardware (such as pins or bolts) and grounds at greater than 10 inches (25.4 centimeters). However, maintaining this separation can be a design problem when there is a need to install a ground wire up to a crossarm-mounted arrester.

l Aesthetics, population, congestion of facilities, or contaminated areas could affect a decision.

m A decision may be required to consider the application of step-up or step-down transformer banks for a variety of reasons. Either autotransformers or two-winding transformers may be purchased for these applications. Many utilities report that two-winding transformers are more reliable, especially at or near substations. Experience has shown that autotransformers work better when applied on feeders away from substations, and they last longer when their impedance is more than 4 percent (on their own rating base). Reactance inserted in the delta tertiary winding may help autotransformers better withstand lightning and through faults. For any application of either type of transformer, good grounding and adequate lightning arrestors are a primary consideration.

## 5 ANALYSIS

Once all the estimates and facts have been gathered and the analyses of the base system with the alternatives have been evaluated, the total present worth dollars for each economic factor under each option studied have to be developed. The appropriate economic factors have to be summed to determine the grand total. If the economics show two alternatives are close in evaluated cost, then the system planner should perform sensitivity analyses to see if a change in one or more assumptions will clarify the system planning decision. Examples of sensitivity variables would be growth rates, interest rates, and/or real estate costs (for substations and transmission lines). Another sensitivity variable might be the longevity of a plan beyond the time range studied. A system planner might also evaluate two alternatives for their load-carrying capability in the intermediate conversion steps. In the absence of a clear economic recommendation to change the system voltage, many planners believe that the present system voltage should be retained because of what is known about the existing system in comparison to the unknown situations to be faced with the alternatives.