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Thermal current-carrying capacities of bare and covered overhead distribution size conductors.

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THERMAL CURRENT-CARRYING CAPACITIES OF
BARE AND COVERED OVERHEAD DISTRIBUTION SIZE CONDUCTORS

by

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ABSTRACT

This thesis presents a method to calculate the thermal current-carrying capacity (ampacity) of bare and covered overhead distribution conductors. These conductors range in size from #8 AWG to 556.5 KCMIL and would be used by an electric utility on their distribution system. The method is based on determining the amount of conductor sag increase allowable in a phase conductor relative to its neutral conductor at certain ambient temperatures; noting the final phase conductor temperature when that point is reached and comparing it with other temperature limitations; and then calculating the conductor ampacity under those design conditions. This method incorporates conductor sag and loss-of-tensile strength restrictions, while system stability, voltage drop, and line loss considerations and their limitation effects on ampacity are not considered.

In January 1973 the Pennsylvania-New Jersey-Maryland (PJM) Interconnection Conductor Rating Task Force published a report which included a computer program to rate bare overhead transmission conductors. The method that will be demonstrated in this paper utilizes the PJM conductor ampacity rating computer program and basic background information in

that report and adapts it to meet distribution engineering criteria for determining ampacity ratings of distribution size conductors.

The test utility required substantiated evidence that could be presented before the Pennsylvania Public Utility Commission in condemnation and future rate cases. This evidence or data would be used as a basis for line section loading determinations. Also, recent revisions to the National Electrical Safety Code required the utility to define its maximum conductor operating temperatures.

Calculations are presented for different type and size distribution conductors, demonstrating the application of this ampacity rating method. A list of distribution conductor sizes and related ampacities produced by this rating method is then provided.

Assumptions used when developing and applying this rating method are discussed and examined to see if they are justifiable and produce end results which are realistic for everyday operating conditions. A sensitivity analysis of certain input parameters in the method demonstrates the reasonableness of the various assumptions.

Conclusions and recommendations reached in this thesis provide a beginning for further research into this area of distribution conductor ampacity. Based on the work described in this thesis, it was concluded that:

- past methods used to determine distribution conductor ampacity ratings are unacceptable since they were based on a limited group of input parameters,
- a procedure now exists to redetermine the ampacity ratings of distribution conductors, and rating tables in use by the planning and operating departments should be revised,
- existing distribution facilities, except Case B framing, should not and need not be replaced in rerating these distribution conductors, and
- recent revisions to the National Electrical Safety Code require that ampacity rating methods consider conductor sag, phase and neutral combinations, and pole framing clearances, which past rating methods usually treated less rigorously.

By using a method such as outlined in this thesis, the actions described in these conclusions can be implemented.

INTRODUCTION

A method to calculate the thermal current-carrying capacity, or ampacity, of selected bare and covered overhead distribution conductors will be presented. These conductors range in size from #8 AWG through 556.5 KCMIL, and would be used by an electric utility on their primary distribution system. The method determines conductor ampacity as opposed to circuit ampacity.

Conductor thermal ampacity is the current-carrying capability of a conductor --- the maximum load current which can be passed through the conductor without causing significant mechanical damage to the conductor, specifically, its tensile properties. Since the method's main purpose was to calculate thermal ampacity of overhead distribution conductors, voltage drop and line loss effects were not considered in the calculations.

Circuit ampacity is the current-carrying capability of a specific section of electric power line, which could be single, two, or three phase construction. The circuit ampacity is limited by the lowest rated current-carrying device in the line section. This device could be the conductors which comprise the line, or more likely would be the electrical apparatus, such as air and oil switches, oil circuit reclosers, fused devices, or hot line connectors. If these devices have a lower current-carrying capacity than the line conductors, then these devices limit the amount of current which can be passed through the circuit.

Thermal ampacity of overhead transmission conductors has received considerable attention, as evidenced by numerous papers on the subject.[1-4] On the contrary, insufficient information has been available in the related subject area of calculating overhead distribution ampacities, other than manufacturers' product data sheets.

With the absence of technical papers on this latter subject, a thermal ampacity study of bare and covered overhead distribution conductors was undertaken by the test utility*, so that substantiated evidence could be presented before the Pennsylvania Public Utility Commission (PPUC) in

*Pennsylvania Power & Light Co. (PP&L)
Allentown, PA 18101

condemnation and future rate cases[5]. This evidence or data would be used as a basis for line section loading determinations. Also, the 1977 National Electrical Safety Code required the utility to define its maximum conductor operating temperatures to determine code clearances. Maximum conductor ampacity must be defined before conductor operating temperature can be calculated.

Prior to this study, two methods were being used by the test utility to calculate conductor ampacity[1,6]. Since both methods were based on different design criteria (i.e. - wind speed, ambient temperature, conductor temperature, heat balance equation), identical conductors used in distribution, substation, and transmission engineering designs had different assigned ampacities and maximum conductor operating temperatures.

One method was a carryover from a July 1960 ampacity study prepared by the utility's former Electrical Research and Development Section[6]. This and two follow-up reports addressed conductor thermal capability of copper, aluminum, and ACSR bare conductors on the utility's system. The original study (T-44) covered thermal capability of only the 220 kV transmission lines and substation terminal equipment. Later it was expanded to include 66 kV transmission lines and more conductors, with an expanded conductor temperature range. A set of curves, referred to as "K" curves, were produced as part of this study. These curves described winter and summer ampacity versus conductor temperature in graphical form for the numerous conductor sizes.

A second method to calculate conductor thermal ampacity was developed and has been used since 1976 by certain departments in the test utility. This method is based on a 1973 Pennsylvania-New Jersey-Maryland (PJM) Interconnection Task Force project[1]. This project included a detailed report, ampacity tables, and a method to calculate these ampacity values for transmission line conductors. This study incorporated the latest "state of the art" ideas available.

Either method, if applied to determine distribution conductor ampacity, had shortcomings. These problems will be discussed in detail in Chapter 1. The method presented in this thesis provides a uniform approach in calculating distribution conductor ampacity, overcoming the other methods' limitations. The results are definitive, supportable conductor ampacity ratings and are listed in Chapter 4, pages 126 through 128.

In the development of this method, it was necessary to take into consideration the impact of any possible drastic changes that might result from the method versus the current planning and operating standard practices. All assumptions had to be reviewed very carefully to ensure that they did not give results that would theoretically contradict known practical experience. The existence of a vast distribution facility, not uncommon among electric utilities, which could not economically be replaced on a wholesale basis became, in effect, a boundary condition on the basic assumptions.

If this limiting assumption was not considered, a possible reduction in conductor ampacity ratings could force an advancement, of a year or more, in the timing of system reinforcements. This could significantly increase the construction costs forecast in the utility's annual and 5 year budgets. Distribution lines now loaded near full capacity could immediately become "overloaded," and load transfers would be more difficult due to reduced line reserve capacity. When this ampacity rating method was developed, careful consideration was given to these possible consequences, expecially when finalizing the assumptions.

Conductor ampacity is directly related to the maximum permitted conductor operating temperature. The factors which have an influence when selecting the maximum conductor operating temperature (MCOT) are:

o pole framing (conductor spacing),

o maximum allowable sag increase in the phase conductor,

o National Electrical Safety Code (NESC) clearance requirements for conductors on the same support,

o loss-of-tensile strength (L-O-S) in the phase conductor, and

o maximum conductor insulation temperature.

These factors were included in the final conductor ampacity values and will be discussed in later chapters.

This distribution ampacity rating method considered the design of the utility's existing extensive overhead distribution system, recognizing that little could be done to alter the physical configuration (pole type framing). Existing construction is the limiting condition for conductor ampacity, since it would not be practical to reconstruct the existing plant to allow greater ampacity ratings. Additionally, it would be difficult to accurately identify existing versus new construction on local system operating boards and primary operating maps. Circuit ampacity would be limited by older construction.

Because of the system physical configuration, one of the main concerns was conductor sag and its relation to conductor thermal ampacity. The effect of conductor temperature on sag at the assigned ampacity was re-examined for all phase and neutral conductor combinations used on the system, to assure that clearances between conductors as required by national safety codes were not violated. Since the utility had to contine operation of its existing distribution sytem, conductor sag increase became an important criterion in the ampacity study.

The method that will be demonstrated in this thesis utilizes the test utility's version of the PJM conductor ampacity computer program and basic background information in the PJM report[1] (PP&L-PJM method), and adapts it to meet distribution engineering criteria for determining ampacity ratings of distribution size conductors.

The PP&L-PJM method was not used in its entirety because it is a transmission conductor ampacity rating method with different design criteria, and there were other limitations with the method. These will be discussed in the next chapter.

A brief review of conductor ampacity rating at the test utility will be presented, which will explain in more detail why this particular method was developed. Then the assumptions used in the distribution ampacity rating method will be discussed. Even though the method was used to calculate distribution conductor ampacity for a specific utility*, the method should be applicable to all electric utilities, expecially those companies which minimize phase and neutral conductor vertical spacing and yet use the conductor's thermal ampacity limit.

*PP&L Co.

CHAPTER 1

HISTORICAL BACKGROUND

Various methods to determine conductor thermal ampacity have been proposed by individuals in the electric power industry[1-4,6-8]. In January 1973, the Pennsylvania - New Jersey - Maryland (PJM) Interconnection Conductor Rating Task Force published a report that defined the ampacity of bare overhead transmission conductors which were used on the PJM Interconnection[1]. The report included a computer program which enabled the user to calculate ampacity ratings of other transmission conductors. Various utilities in the Interconnection have copied this PJM computer program for in-house use, including the test utility. This chapter will deal with an analysis of and modifications made to the test utility's version of the PJM rating method (PP&L-PJM method). An examination of maximum conductor operating temperature (MCOT) with respect to distribution engineering criteria, as opposed to transmission or substation design criteria, will also be covered.

Prior to the issuance of the 1973 PJM Interconnection report[1], most engineering departments within the test utility used the T-44 method[6] to determine conductor ampacity. This latter method was based on an overall heat balance equation slightly different than the PJM equation[9]. The T-44 equation had been derived by combining certain terms in the Schurig and Frick formulas[6,7]. The equation could not be adjusted for changes in: (1) air film temperature, (2) viscosity of air, (3) thermal conductivity of air, or (4) air density at sea level --- all of which are a function of conductor and ambient temperature. The conductor emissivity, which was used in the radiated heat loss sub-equation, was lumped in the heat balance equation and not defined for the various material types.

The T-44 method established the "K" curves using certain initial wind speed, ambient temperature, and conductor temperature values, making it difficult to calculate a conductor ampacity at various wind speeds and ambient temperatures without monumental calculations.

Furthermore, there was some uncertainty and disagreement on the summer and winter ambient temperatures used in the T-44 method[9,10,11]. If the "K" curves of 40 for summer and 55 for winter are used to determine a conductor ampacity from the T-44 graphs, to obtain identical results by use of the heat balance equation, the following parameters must be used for ACSR conductor at 100°C (125°C emergency):

- o wind velocity = 0.6 meters per second (2 feet per second)
- o summer ambient temperature = 9.48°C (49.06°F)
- o winter ambient temperature = -23.25°C (-9.85°F).

The method calculated the number of hours per year that the conductor would operate in excess of annealing temperatures. It was determined that satisfactory results would be obtained if ACSR conductors were not operated continuously above 93°C (200°F), or at 125°C (257°F) for more than 10,000 hours. Copper conductor operating temperatures were not discussed, other than to state that the annealing curve indicated that a copper conductor operating continuously at 60°C (140°F) experiences no annealing. If it were operated at 85°C (185°F), a 3 and 20 percent loss-of-tensile strength would occur in 1000 and 10,000 hours, respectively.

The PP&L-PJM method used a heat balance equation which was separated into two sub-equations for radiated heat (Q_r). The classical formula for radiated heat loss was used for nighttime ampacity determinations, while a modified version was used for daytime ampacity calculations[1] (Table 1, page 16). Q_r was separated because the bottom half of the aerial conductor was exposed to the earth heat sink, while its top half radiated to a deep space heat sink, which would be at a much lower temperature.

The PP&L-PJM method combined historical weather data from the Washington, DC and Pittsburgh, PA areas for a 16 and 10 year period, respectively, which resulted in a composite 26 year hourly record. The T-44 method contained Allentown-Bethlehem-Easton Airport* weather data for a 3 year summer and winter period, plus a 1 year summer period from the Harrisburg Airport*. The weather data were used only once in the T-44 method --- to initially determine the "K" constants (i.e. - K = 40,55,60). The PP&L-PJM weather data were an integral part of the ampacity rating method calculations.

Each time a conductor ampacity was determined in the PP&L-PJM method, the maximum conductor temperature was selected. Since this value could be adjusted, the maximum conductor ampacity could be calculated at the maximum permitted loss-of-strength (L-O-S) value. Calculation of conductor

*Pennsylvania cities within the test utility's service territory.

PP&L-PJM METHOD RADIATED HEAT LOSS EQUATIONS

$$Q_r = 0.138\ De\ \left[\left(\frac{T_c + 273.16}{100}\right)^4 - \left(\frac{T_a + 273.16}{100}\right)^4\right] \ldots\ldots \text{equation 1}$$

NIGHTTIME EQUATION

$$Q_r = 0.069\ De\ \left[1.7\left(\frac{T_c + 273.16}{100}\right)^4 - \left(\frac{T_a + 273.16}{100}\right)^4\right] \ldots \text{equation 2}$$

DAYTIME EQUATION

Where:

T_a = ambient temperature in °C,

T_c = conductor temperature in °C,

Q_r = radiated heat loss in watts per foot,

D = conductor diameter in inches, and

e = coefficient of emissivity of conductor - dimensionless.

TABLE 1

L-O-S using the T-44 method would not be as simple, nor straightforward. Both methods did employ an electrical loading cycle, though, as part of the L-O-S determination.

Basically, the 1973 PP&L-PJM method was more refined than the T-44 report. It incorporated the latest "state-of-the art" ideas and equations. With a revised heat balance equation; an improved, integral weather model and loading cycle; and a greater flexibility to input the various parameters, the PP&L-PJM method was the most logical and best suited method to use for the distribution ampacity rating study.

When the original PJM Interconnection computer program was duplicated by this test utility, certain programming changes and updating occurred. The PP&L-PJM computer program was rearranged into two operating modes:

CEØEA10 PRINT(SYSØUT)
(Batch run or card input and
Communications terminal input)

CEØEA10 TYPERUN(NØLØSS) PRINT(SYSØUT)
(Communications terminal input, only)

The first operating mode provides ampacity calculations while also computing L-O-S. The second mode provides ampacity calculations without computing L-O-S,[12] and produces a "matrix type" output of ampacities at various wind speeds and ambient temperatures for a selected conductor temperature (Tables 11A, 11B, and 10A, pages 118, 119, and 115).

Before the PP&L-PJM computer program could be used to calculate distribution conductor ampacities, there were a few program difficulties to overcome. The original PJM Interconnection program was not designed to run for conductor temperatures below 45°C (113°F) nor higher than 180°C (356°F). The PJM Task Force was mainly interested in a temperature range between 100°C (212°F) and 200°C (392°F)[13], since transmission conductors are required to transmit large magnitudes of power and therefore operate at temperatures much higher than distribution conductors. So there was no need to refine the PJM program to calculate ampacity ratings in the lower temperature range. The PP&L-PJM computer program had this identical problem, since it was a copy of the PJM version.

The validity of the PP&L-PJM program was in doubt for conductor temperatures below 50°C (122°F). The left side of the heat balance equation is determined by adding the solar heat gain (Q_s) and the product of the conductor current squared and conductor resistance (I^2R). The right side sums the convected heat loss (Q_c) plus the radiated heat loss (Q_r).

The program mode, which does not consider L-O-S, calculates ampacity ratings over an ambient temperature range of -20 to +35°C (-4 to 95°F). As the conductor temperature is set lower than 50°C (122°F), the ambient and conductor temperature difference becomes smaller, approaching zero. When this occurs, the convected and radiated heat loss equation values become very small in magnitude since both depend on the size of the temperature difference. The right side of the equation approaches zero while the two values on the left side remain greater than zero. Solving for the current results in taking the square root of a negative number. This problem occurred in the PP&L-PJM program even before the conductor temperature equaled the ambient temperature.

The practical explanation of this problem is that on a hot, sunny day no current can be passed through the conductor, in addition to the solar heat gain received, and yet maintain a conductor temperature which nearly equals the ambient temperature.

A copy of the PP&L-PJM "CEØEA10 TYPERUN(NØLØSS) mode" program was used to test the programming changes necessary to overcome this problem[14,15]. Checks within the program were established to recognize when Q_r and Q_s became negative numbers at temperatures under 50°C. At these conditions of wind and temperature, no ampacity ratings were generated.* The upper temperature limit was not adjusted since L-O-S would be a boundary condition on this temperature (180°C).

Before the program changes were made, the basic heat loss equations were investigated to determine their validity in the lower anticipated temperature ranges. The research did not indicate any restrictions on the heat loss equations[16,17] were necessary.

Other miscellaneous changes were incorporated[14,15], including the day-night radiated heat loss (Q_r) equations, the annealing curves, and the necessary equations to calculate temperature drop through a covering material over a bare conductor surface.

*Program copied and revised under DISTAMP.PLI name.

The PJM Interconnection and PP&L-PJM computer programs were basically bare transmission conductor ampacity rating methods. However, most distribution utility systems, including the test utility, use covered* AAC or ACSR conductors where tree or clearance problems would hinder effective use of bare conductors. These covered conductors are also used near substations where the large magnitude short circuit currents and resulting forces could cause phases to swing together. Coverings in use by the test utility have included cross-linked polyethylene (XLP) and triple-braided weatherproof (TBWP) material.

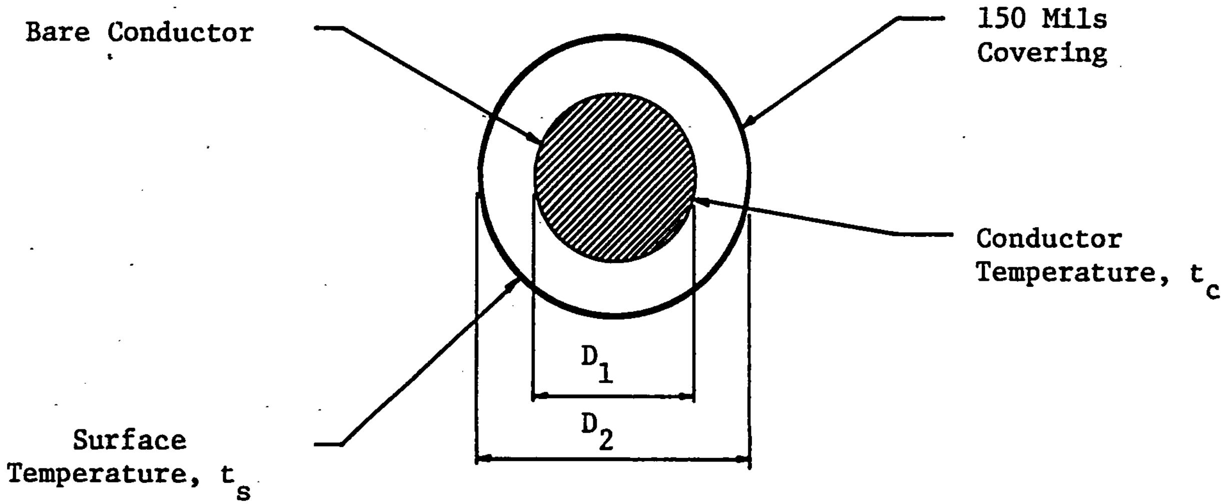
To overcome the problem of calculating covered conductor ampacity, the PP&L-PJM computer program was altered to include an equation which determined temperature drop through the conductor covering. This equation is given in Figure 1, page 22 along with a diagram. The terms in equation 3 are:

D_2 = overall conductor diameter including covering, in inches,

D_1 = conductor diameter without covering, in inches,

*A covered conductor is one encased within material of composition or thickness that is not recognized by national[18] electrical codes as electrical insulation.

TEMPERATURE DROP THROUGH A COVERED CONDUCTOR



$$\Delta t = t_c - t_s = I^2 R \rho_c \,(0.00522)\, [\log_e \frac{D_2}{D_1}] \text{ --- equation 3}$$

FIGURE 1

R = AC resistance at conductor temperature, in ohms per foot,

ρ_c = thermal resistivity of the covering, using 375 for polyethylene, in °C/watt/cubic centimeter,

I = current at that conductor temperature.

The temperature drop (Δt) is assumed, and then the surface temperature of the conductor (t_s) calculated. With this information known, the ampacity is calculated using t_s in place of t_c in the equations. A check is then made on the assumed temperature drop, using equation 3. This calculated Δt is compared to the assumed Δt. If the assumed Δt is less than the calculated Δt, then the ampacity is recalculated with a larger assumed Δt. If the assumed Δt is greater than the calculated Δt, a smaller Δt is assumed for the recalculation. Through this iterative process, the exact conductor surface temperature is determined and finally the ampacity[19,20,21]. Since maximum insulation temperatures were below the annealing temperatures for AAC and ACSR conductors, any check for L-O-S in these covered conductors was unnecessary.

The original PJM study, report, and computer program addressed only aluminum conductors --ACSR, AAC, AAAC, and ACAR. Since some copper transmission conductors and considerably more copper distribution conductors are still in service, there was an interest in determining copper conductor ampacity ratings.

The copper annealing curves were obtained from a copper conductor manufacturer. This family of curves was to be representative of all copper conductor sizes, and provided a percent L-O-S versus time at specific conductor temperature[22]. Each temperature curve of the family was translated using a point-by-point method, and loaded into the program's annealing model.

Even though the test utility had copper-clad steel and copper-clad steel with copper* conductors on its distribution system, no annealing curves were placed into the program annealing model. Discussions with the manufacturer revealed that annealing curves were not presently available for these two types of conductor material. Furthermore, it may even be possible that annealing curves were never prepared at any time during the introduction and subsequent use of this material on utility systems[23].

*Usually referred to by their tradenames, Copperweld (CW) and Copperweld-Copper (CWC).

The probable reason for not preparing annealing curves was due to copper-clad steel being composed mostly of steel, which has a very high annealing temperature. This temperature is outside of any practical maximum conductor operating temperature. Therefore, the L-O-S would not have to be considered.

For these reasons, the CW and CWC conductors were not permitted to exceed the temperatures recommended by the manufacturer when ampacity calculations were made[24]. The MCOT was limited to 125°C (257°F) for CW and 75°C (167°F) for CWC. Any clearance problems caused by sag limitations would reduce these maximum temperatures.

In the Introduction (page 6) it was noted that maximum conductor operating temperature (MCOT) for various types of conductors differed according to their use on transmission, substation, or distribution facilities. It will be shown that even for the distribution conductors of the same material type (i.e. - copper, or aluminum), the MCOT values selected by the ampacity rating method will differ with each conductor size.

The reason for this variation was due to the sag limitations imposed on each phase and neutral conductor combination.

The conductor weight and diameter, span lengths, pole framing, and stress-strain characteristics affect the sag limitations, and thus, the MCOT value.

It might be argued that an identical conductor, serving both as drop leads which span the short distance between a 12 kV power circuit breaker and line dead-end structure, and as an overhead terminal getaway line, should have the same MCOT values. However, the criteria for determining MCOT and ampacity would usually differ between substation and distribution engineering design. Distribution engineering would be concerned with:

- longer span lengths under tension,
- maximum conductor tension, and
- loss-of-strength,

all of which affect the MCOT and ampacity. The substation engineering criteria would not be quite as concerned with these three factors. The conductor would not be under any significant tension. L-O-S would not be as critical. This would permit higher MCOT values to be selected, resulting in much higher ampacity ratings. Similar reasoning can be applied to a transmission-substation comparison. There appeared to be no valid reason for selecting identical MCOT values for transmission, substation, and distribution conductors. A conductor's MCOT, and hence its ampacity, must be based on the specific design criteria under which the conductor will be operated.

Past practice by the test utility was not to operate distribution conductors at their thermal limits. This distribution thermal ampacity study was the first step in re-evaluating conductor loading practices. It was precipitated by the need to comply with new utility code requirements and to assure the most economical use of the conductors.

CHAPTER 2

OVERVIEW OF ALL TEST UTILITY ASSUMPTIONS USED IN THE DISTRIBUTION AMPACITY RATING METHOD

The numerous assumptions made by the test utility in developing the distribution ampacity rating method will be detailed and explained in this chapter[25]. Briefly, they included:

- the distribution ampacity (Dist-Amp) rating method was developed from the PP&L-PJM transmission conductor ampacity rating method,

- conductor ampacity was not derated because of:
  (1) poor quality or aging of line splices and connectors,
  (2) aging of the conductor,
  (3) line sectionalizing devices,

- the maximum assigned ampacity would not produce a reduction in conductor life,

- voltage drop and I^2R losses were not considered,

- the PP&L-PJM load cycle was not modified,

- the maximum conductor operating temperature (MCOT) was limited by:
  - (1) maximum permissible conductor insulation temperature,
  - (2) loss-of-tensile strength (L-O-S) in the conductor,
  - (3) National Electrical Safety Code (NESC) phase-to-neutral clearance requirements,
  - (4) maximum sag increase permitted in the phase conductor which factored in:
    - (a) utility sagging practices,
    - (b) neutral current,
  - (5) pole framing,

- The PP&L-PJM weather model was valid for the test utility territory,

- summer and winter ambient temperatures were selected at 25°C (77°F) and -10°C (14°F), respectively,

- a 3 knot wind speed was chosen, and

- the distribution ampacity (Dist-Amp) rating method allowed allowed up to an 8½ percent probability that "critical" weather conditions could be exceeded.

PP&L-PJM Method

Parts of the distribution ampacity (Dist-Amp) rating method criteria were similar to the criteria established by the PJM Task Force[1]. The Dist-Amp ampacity ratings were to be limited only by:

- vertical clearance requirements, between the ground level and overhead conductors,
- a maximum loss-of-tensile strength (L-O-S) over the conductor's life, not to exceed 10 percent, and
- maximum allowable sag increase in the phase conductor before national safety code clearance requirements between the phase and neutral conductors would be violated.

One assumption was that the PP&L-PJM transmission conductor ampacity rating method and background information in the PJM Interconnection report[1] could form the basis for the distribution conductor ampacity rating method. Use of the PP&L-PJM computer program and rating method equations appeared to be valid, and it would significantly reduce the manhours to perform the calculations compared with a manual calculation method. Since the background research, equations, and other related subject material had already been examined by the PJM Task Force, the test utility could take advantage of the accomplished basic research. Nevertheless, certain items and procedures in the PP&L-PJM method were investigated to assure its validity and completeness for the Dist-Amp rating method application.

Line Splices and Connectors

There was no derating of conductor ampacity to recognize that poor quality or aging of conductor splices and connectors might result in more failures as line loadings approached the maximum conductor ampacity. It was anticipated that by using infrared inspection, these faulty splices and connectors could be indentified before failure. Furthermore, a derating factor to recognize possible defective connections would be difficult to define without available, historical operating data.

Line Age

Line (conductor) age was not considered either. A useful conductor lifetime was assumed identical to the 35 years fixed in the load cycle. Deterioration of the conductor material could be caused by many factors, such as:

- atmospheric contamination,
- severity of yearly weather conditions,
- manufacturers' quality control, and
- construction crew installation practices.

Most would be difficult to meaure with any reasonableness. It would have been impractical to develop a line age derating factor.

Sectionalizing Devices

Since the major objective of this Dist-Amp rating method was to develop conductor thermal ampacity ratings, line sectionalizing devices* were not a restriction to the maximum conductor ampacity. These devices, however, could limit circuit ampacity. If a device was the limiting factor in a line section, it could be replaced. To apply a derating factor to all conductor ampacity ratings would have penalized

*oil circuit reclosers, oil and air switches.

those lines which did not contain any sectionalizing devices. These devices were studied separately to determine their current ratings.

Conductor Useful Life

Another assumption was that the distribution conductor's useful life should not be reduced from established, expected values by operating the conductor under conditions which would cause conductor loss of life. The PP&L-PJM method load cycle related the total hours that the conductor would spend during the day and night, at three different current ratings, to a 35 year transmission conductor life.

A 35 year period is also a reasonable assigned conductor lifetime for distribution conductors in standard weather and atmospheric conditions within the test utility's service territory. There was no past operating experience which suggested a change in this assumed conductor lifetime.

Operating a conductor at extremely high temperatures will cause an accelerated progressive annealing and a condition called elevated temperature creep (ETC)[26-28]. Annealing causes a loss-of-tensile strength (L-O-S) in the conductor, while the latter condition (ETC) results in significantly increased sag in a conductor's lifetime.

With appreciable L-O-S it would be impossible, after a certain point, to remove excess sag. This would result in safety code clearance violations, and the conductor would be more susceptible to wind and ice loading damage. The end result would be more "out-of-service" lines, effectively shortening the conductor's lifetime.

With ETC, the increased sag would produce actual clearances less than the design clearances which were based on a 15.6°C (60°F) creep rate, and may subject the conductor to more exposure from mechanical damage, again resulting in a shortened lifetime.

Voltage Drop and Line Losses

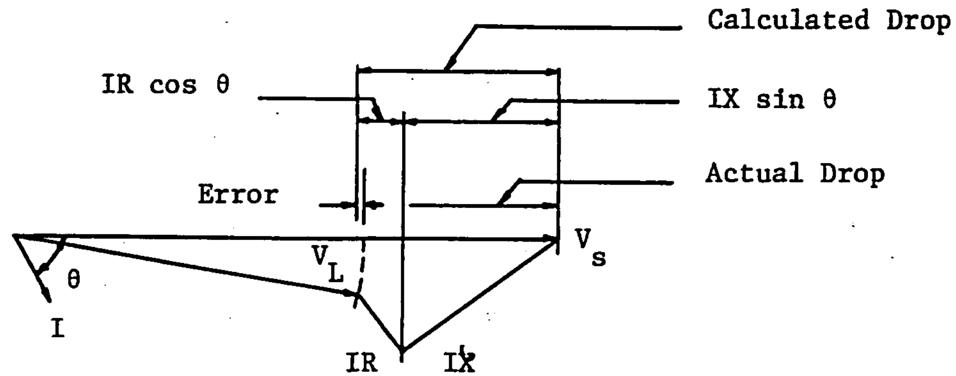
Voltage drop and line losses (I^2R) were also not considered as limitations during the calculation of a conductor ampacity. As the Introduction stated on page 4, this was a thermal current-carrying capability rating method. These two restrictions could be applied anytime, under specific circumstances. To control voltage drop on a line, the amount of current flowing through the conductor would have to be changed. For a given size and type conductor, the more current flowing, the higher the voltage drop[29] (Figure 2, page 36). There are more effective means for control of voltage drop (i.e. - capacitors, larger size conductors for a given load). The optimum I^2R losses should be determined by an economic analysis before reducing conductor ampacity ratings.

Load Cycle

The load cycle in the PP&L-PJM method was one item which initially caused some concern. (Figures 3A and 3B, pages 37 and 38) This cycle is a step function representation which specifies the percent of normal rated current carried by the conductor over a 24 hour period. During the weekday daylight hours, the conductor carries 100 percent of normal rated current. During weekday nighttime hours and all weekend hours the conductor is loaded to 70 percent of rated normal current. The load cycle in the PP&L-PJM method can be changed for a particular ampacity calculation[1,12].

The main objection to the PP&L-PJM load cycle was that it is more representative of lines (conductors) which are

VOLTAGE DROP DIAGRAM



Three Phase, Line-to-Line Voltage Drop $= \sqrt{3} \cdot I \cdot (R \cos \theta + X \sin \theta)$ ---- equation 4

Where:

I = rated current in amperes,
R = total resistance of one conductor in ohms,
X = total reactance of one conductor in ohms, and
θ = power factor at concentrated load in degrees.

FIGURE 2

PP&L-PJM METHOD LOAD CYCLE

Load Cycle
(Summer And Winter)

Weekday

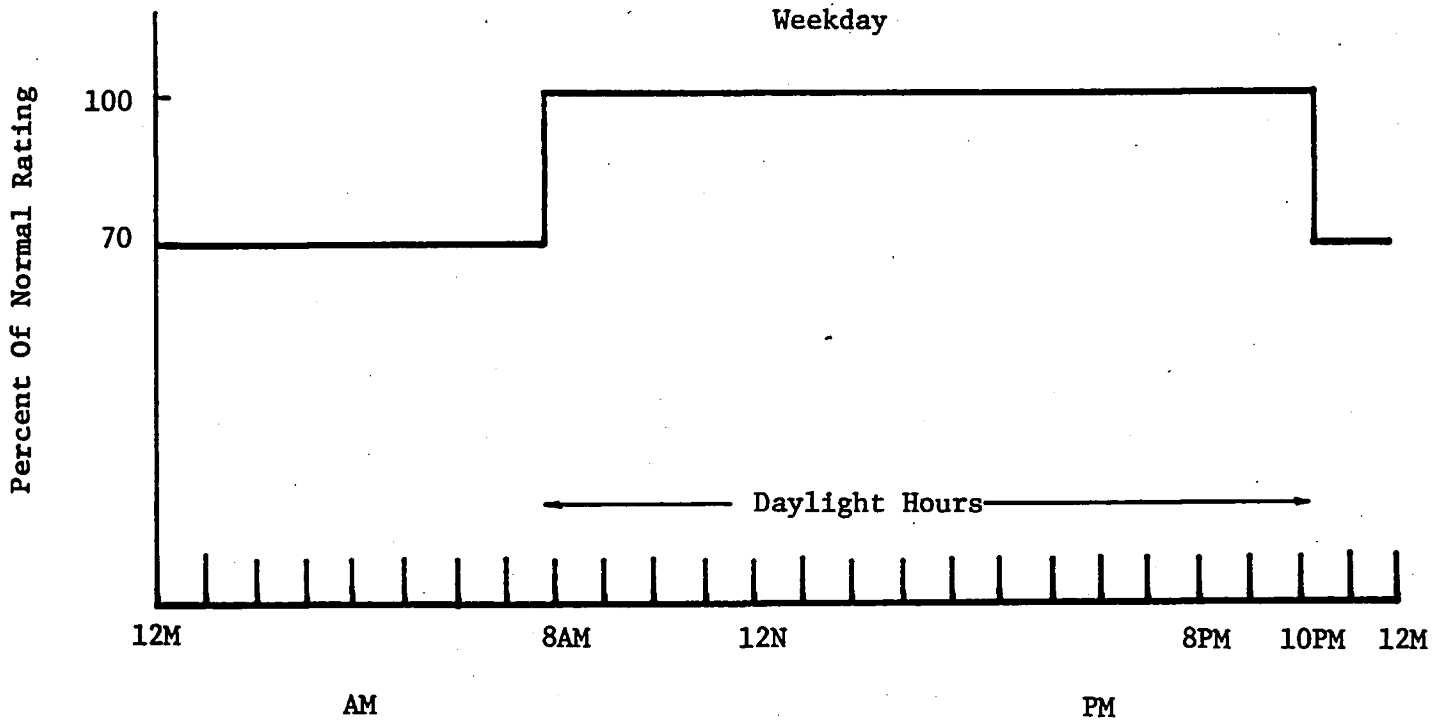


FIGURE 3A

PP&L-PJM METHOD LOAD CYCLE

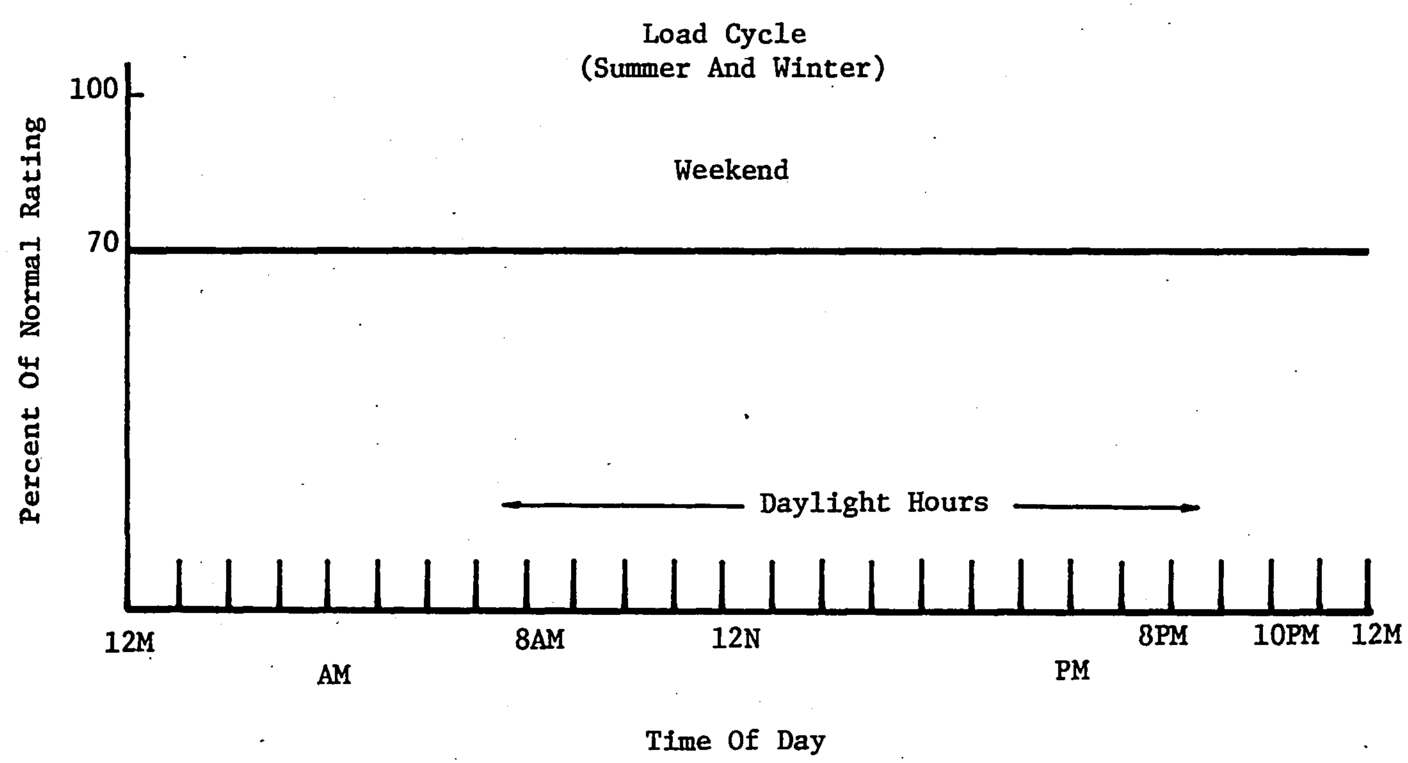


FIGURE 3B

"base" loaded. These "base" loaded lines* carry a certain level of demand load, usually determined by economically scheduled generation output or interconnection load transfer requirements between different utility systems. Their loading level is independent of ambient temperatures, and even a particular utility system daily load[9,30]. Distribution system lines would be loaded according to the daily demand, which usually is tied closely to the ambient temperature. On extremely hot or cold days, the air-conditioning or heating load produces a peak demand on the distribution system, but the PP&L-PJM load cycle did not represent this type of conductor loading.

A related concern was how to differentiate between urban versus rural, or even an express industrial feeder circuit versus a general residential circuit, and whether any load cycle could represent these type conductor loadings with any degree of accuracy.

A lack of adequate, readily available data to confirm the loading levels predicted in the above cases was the basic problem in constructing a new load cycle for the

*This concept applies mainly to three phase circuits.

Dist-Amp rating method. A suggestion to investigate var-watt recordings, which are recorded periodically at distribution substations, to possibly determine a new load cycle was rejected. The estimated versus available manhours required to prepare this data in a usable form was the principle reason for not pursuing this matter, and the cost-to-benefit ratio did not appear to justify this action. Furthermore, there was no way to verify that the outcome of this var-watt study would produce a more representative load cycle.

The PP&L-PJM load cycle could have been changed to have the conductor carry 100 percent of normal rated current for a 24 hour period, 5 or 7 days a week. This would have lowered the final calculated conductor ampacity, and it still would not be a very representative load cycle of an actual distribution line (conductor). It would have been more logical to lower the load cycle values of 70 and 100 percent.

Due to the many possible conductor loading cases, the absence of usable data, the high cost-to-benefit ratio of assigning additional manhours to this particular item, and the unverifiable outcome which would result, the load cycle in the PP&L-PJM method was not changed. Furthermore, this load cycle was used only in the L-O-S calculations, with other factors limiting the actual assigned ampacity ratings.

Maximum Conductor Operating Temperature

The maximum conductor operating temperature (MCOT) is the highest temperature attained by the conductor at maximum ampacity and at the highest ambient temperature predicted on the test utility system.

To illustrate this definition of MCOT:

- conductor --- 336.4 KCMIL 19 strand AAC
- maximum ampacity --- 640 amperes
- maximum ambient temperature --- 35°C (95°F);

then the maximum conductor operating temperature would be 84°C (183°F). Five factors which affected the MCOT are discussed next.

Maximum Conductor Insulation Temperature

The maximum conductor insulation temperature was limited to 90°C (194°F) for the XLP type conductor covering. This was based on recommendations in the cable standards of

IPCEA*[31]. While the "emergency" temperature might have been used, the more conservative "normal" temperature was chosen to assure no degradation of the covering material. Copper conductors originally covered with triple-braided, weather-proof material were considered as bare conductors, because the years of exposure to the weather had already made the covering ineffective.

Loss-Of-Tensile Strength

A 10 percent loss-of-tensile strength (L-O-S) in the conductor over its lifetime, as set by the PP&L-PJM method, was accepted for the Dist-Amp rating method. The PJM Task Force selected 10 percent because it represented a tolerable loss level and had general consensus among electric utilities and conductor manufacturers[32]. Some conductor rating methods had selected L-O-S values of 7 to 8 percent[3]. While a higher L-O-S could have been used, the conductor strength safety margin would have become smaller, and the possibility of violating national safety codes would become more likely[33].

*Insulated Power Cable Engineers Association, (IPCEA).

Loss-of-tensile strength (L-O-S) in a conductor means that the conductor loses its ability to resist breaking when placed in tension. Annealing causes this reduction in conductor tensile strength. Conductors used on primary distribution line construction are hard drawn, occasionally 3/4 hard drawn. This annealing and L-O-S effectively reduces hard drawn into soft drawn conductors.

There were many calculations in this Dist-Amp rating method where the L-O-S restricton never became a factor in the final assigned ampacity. The allowable sag increase limitations, which will be discussed shortly, prevented many conductors from attaining temperatures so high that L-O-S governed. Since this L-O-S did not represent the limiting factor for many ampacity ratings, the idea of increasing the 10 percent limit was not pursued.

National Electrical Safety Code

The 1977 edition of the National Electrical Safety Code[34] (NESC) governs the design and operation of the test utility distribution system. Company policy is to apply the NESC as the minimum standard for design and construction of distribution lines. Therefore, distribution conductor ampacities had to be chosen such that minimum NESC conductor clearances and strengths would be met or exceeded using present and future line designs.

In the past the vertical clearance of a conductor above ground usually was determined by the final sag at:

15.6°C (60°F), bare, no wind (1973 NESC requirement);

but maximum sag could occur at other loading conditions, and clearances above ground at these sags had to be checked when designing a line:

0°C (32°F), 1/2 inch radial ice, no wind (1973 NESC);
48.9°C (120°F), bare, no wind (1973 NESC);
93.3°C (200°F), bare, no wind (former distribution "thermal" loading condition).

Rule 232 of the 1977 NESC requires that the vertical clearance above the ground, for conductors operating at temperatures above 48.9°C (120°F) be measured using the final sag at:

(a) 0°C (32°F), 1/2 inch radial ice, no wind; or,

(b) the maximum conductor temperature for which the line is designed to operate;

whichever condition produces the greatest sag. When the 1977 Code was issued, the test utility determined that all distribution lines would operate above 48.9°C (120°F), or else very little ampacity would be attainable in the various conductor sizes.

Rule 235C requires that conductors located at different levels on the same supporting structure (pole) shall have a minimum vertical clearance of 30.48 centimeters (12 inches). The 30.48 centimeters is measured when:

(a) the upper conductor is at its final, unloaded sag at the maximum temperature for which the conductor is designed to operate (MCOT), and,

(b) the lower conductor is at its final, unloaded sag at 15.6°C (60°F).

All clearances are measured in a straight, vertical direction. Offsets in phase and neutral conductors due to pole framing do not enter into this clearance measurement --- only vertical direction between the upper phase and lower neutral conductor can be used to comply with Rule 235C.

Tables 9A and 9B, pages 112 and 113 have been developed to show the relationship between maximum phase conductor temperature, sag, ampacity, loss-of-strength in the conductor, varying span lengths, and types of framing. It is a portion of the total calculations made on the phase and neutral combinations. The Dist-Amp method attempted to optimize ampacity while maintaining required clearances and acceptable conductor loss-of-strength.

Maximum Sag Increase

The maximum sag increase allowable in the phase conductor is the additional sag required at a certain ambient temperature which would cause the phase conductor to move within 30.48 centimeters (12 inches) of the neutral conductor. At any constant ambient temperature, current passing through the unloaded conductor increases the conductor temperature. Since sag is directly proportional to conductor temperature, the higher the conductor temperature, the more sag that appears in the conductor span length. This may result in reduced clearances above ground level which then pose a safety hazard, cause violations of the national safety code clearance requirements, and increase the probability of a phase and neutral conductor contacting each other.

Due to the 10 percent L-O-S restriction, some of the copper conductors could not be operated at the temperatures determined for each one when the allowable sag increase was calculated. The L-O-S temperature instead of the maximum sag increase temperature value restricted the MCOT. Two examples for copper conductors are #4/0 solid and stranded.

The maximum temperature at which 10 percent L-O-S occurs was determined in conjunction with the load cycle in Figures 3A and 3B, pages 37 and 38. If this load cycle was changed for distribution conductor representation, the conductors examined in this method could have reached 10 percent L-O-S at higher or lower temperatures.

This effect would have been most pronounced on the copper conductors, since many of them had MCOT values nearly equal to the present L-O-S temperature limits. Some conductor temperatures determined by the maximum sag increase permitted even had to be reduced because of the L-O-S temperature restrictions.

To determine the MCOT by considering the 10 percent L-O-S temperature, each size and type conductor examined by this method was run through the PP&L-PJM method computer program in the mode designated CEØEA10. The program calculated L-O-S at various temperature ranges which the user selected, until a temperature was found at which 10 percent L-O-S occurred. This temperature was recorded for that particular conductor size and material. All conductors were checked in this manner for the L-O-S temperature.

The maximum sag increase permitted in the phase conductor set the other temperature value for the comparison. If the conductor temperature due to this sag limitation was less than the L-O-S temperature for that particular conductor, the former temperature was used to calculate that conductor's MCOT. If the opposite was true, then the L-O-S temperature was used as a starting point to calculate the MCOT. Using the ampacity rating and conductor temperature assigned from the sag or L-O-S limitation, and the highest ambient temperature predicted on the test utility system, the conductor's MCOT was calculated. By using a 10 percent L-O-S value, some conductor ampacities were restricted to less ampacity than the clearance between phase and neutral conductor would have permitted.

Conductor Sag

All conductor sags used in the calculations are at a loading condition of final, unloaded, bare, no wind --- computed with the transmission department sag and tension (S&T) program[35]. The test utility distribution conductors are sagged at a maximum design tension of 50 to 60 percent of the conductor rated breaking strength (RBS)*, or 2000 pounds, whichever is the lesser[36]. When the sag limitations were calculated, the various tensions normally used by the test utility were chosen for the calculations. If a phase conductor did not have a listed maximum design tension, or one could not be determined from historical records, then 60 percent of the conductor RBS was used. This occurred frequently for various small copper and CW conductors. The NESC does not allow more than 60 percent of RBS to be used for a maximum design tension.

If the initial (stringing) or final sag of the <u>neutral</u> conductor at any given temperature was less than the initial (stringing) or final sag of the phase conductor at the same

*Test utility uses 1/2 inch ice and 8 pounds per square feet wind for the distribution maximum design condition.

temperature, the neutral was resagged to the same value as the phase conductor. If the initial or final sag of the neutral at a given temperature was more than the phase conductor initial or final sag at the same temperature, no adjustment was made to the neutral sag. In the calculations, all resagging of conductors was determined at 4.44°C (40°F), bare, no wind. The same temperature/loading condition was used as the reference base for the determination of sag increases in the phase and neutral conductor. The reason for choosing 4.44°C (40°F) as a reference base instead of another temperature was due to:

- the S&T program calculating creep at 15.6°C (60°F), bare, no wind loading --- this condition could not be used to run the sag restriction procedure* of the program,

- the next lower or higher temperature conditions, which were standard output of the program, were approximately 11 centigrade degrees (20F°) degrees apart from 15.6°C (60°F). Since 26.7°C (80°F) appeared high, especially

*The sag restriction procedure allowed the user to resag the neutral conductor to the phase conductor; see discussion in previous paragraph.

for the winter, only 4.44°C (40°F) remained as a choice.

The NESC previously measured vertical clearances above ground and under other situations at the 15.6°C (60°F), bare, no wind loading condition; and this would have been used, except for the creep check.

The probability of exceeding a 4.44°C (40°F) ambient temperature, based on the PP&L-PJM weather model, is 90.1 percent for a summer day and 32.7 percent for a winter day[37,38].

<u>Neutral Current</u>

It was agreed that unbalanced loading existed on the distribution system, but that this condition did not produce a significant magnitude of neutral current that would affect the sag calculations, nor could it be realistically determined. Therefore, the effect of neutral current was not considered in this rating method, and for maximum sag increase calculations the neutral conductor was assumed to be at ambient temperature.

While this ampacity rating method was only applied to three phase construction, and the negligible neutral current can only be valid for this case, the single phase line construction should not present any problems. Most of the neutral current for this case would return through the ground and by other available paths, so the neutral conductor should carry little current. Even if the neutral conductor current in the single phase line was significant, the ampacity determined by this method would be conservative, as a result of the neutral conductor sag increase following somewhat closely the phase conductor sag increase as conductor temperatures became higher. The phase-to-neutral clearance would not be reduced as quickly as it normally would in three phase construction since the method assumes a fixed ambient temperature for the neutral. Because of neutral conductor movement away from the phase conductor, the actual ampacity could be even higher than the ampacity rating determined with the method. The negligible neutral conductor current assumption produced conservative ampacity results.

Pole Framing

The distribution poles are framed in a way that conserves pole length, and results in phase and neutral conductors being relatively close together and without excessive clearance above ground. These are economical restraints on pole framing. There is not much extra clearance space available on a pole for the conductor sag to increase appreciably, which would occur if very high current loadings and conductor temperatures were the only consideration.

There were three basic types of pole framing used on the test utility distribution system[39]. These are shown in Figures 4, 5, and 6, pages 55 through 60.

Case A ----

Three-phase 2.44 meter (8 foot) crossarm construction, clearances are:

89.54 centimeters (35-1/4 inches) --- outside phase-to-neutral (Ø-N.).

106.68 centimeters (42 inches) --- center Ø-N.

Case B ----

Close spaced plastic bracket construction, clearances are:

68.58 centimeters (27 inches) --- outside Ø-N.

132.08 centimeters (52 inches) --- center Ø-N.*

*Not applicable to Method 2.

Case C ----

Vertical pin standoff bracket construction, clearances are:

88.90 centimeters (35 inches) --- outside Ø-N.*

124.46 centimeters (49 inches) --- center Ø-N.*

*Not applicable to Method 2.

TEST UTILITY POLE FRAMING - CASE A

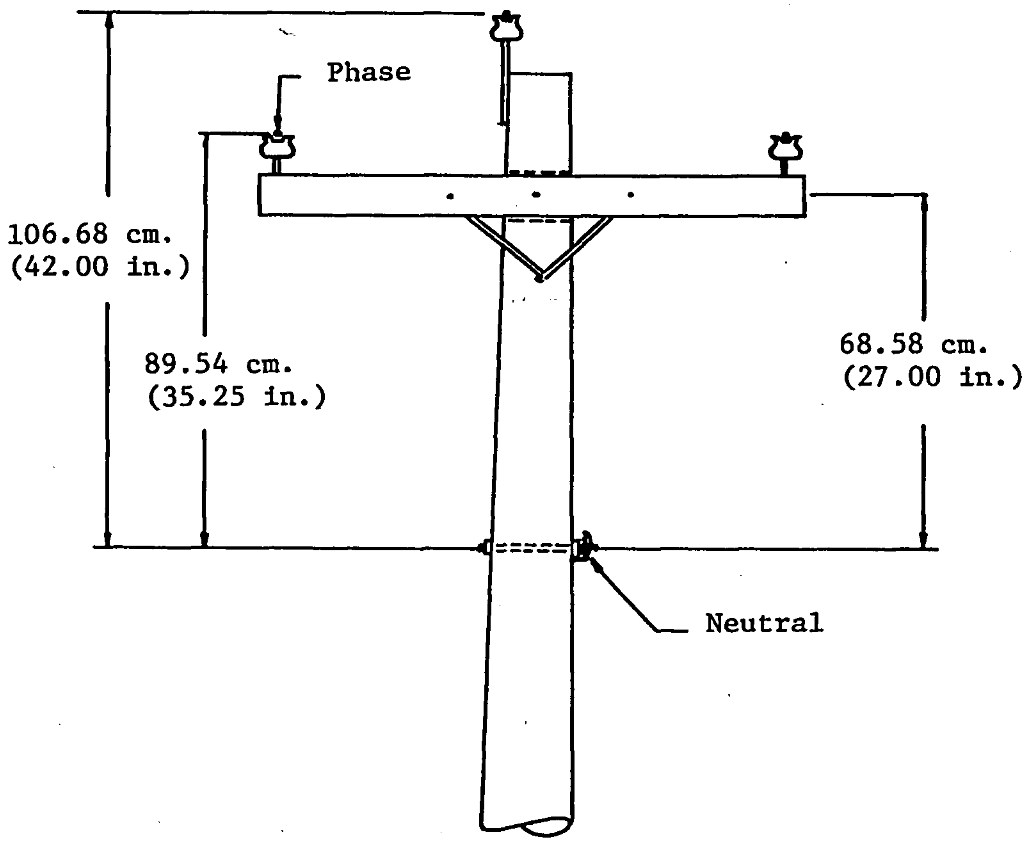
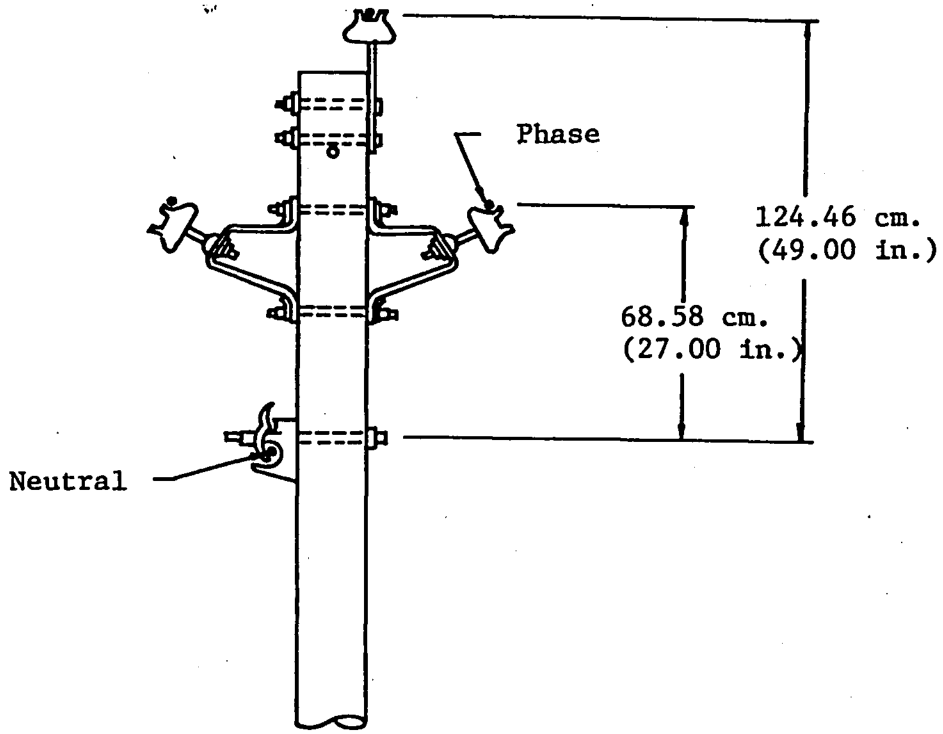


FIGURE 4

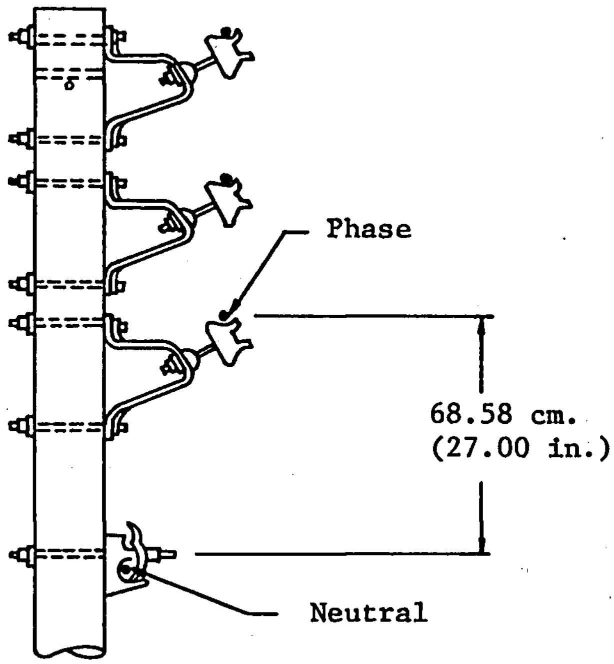
TEST UTILITY POLE FRAMING - CASE B



Method 1

FIGURE 5A

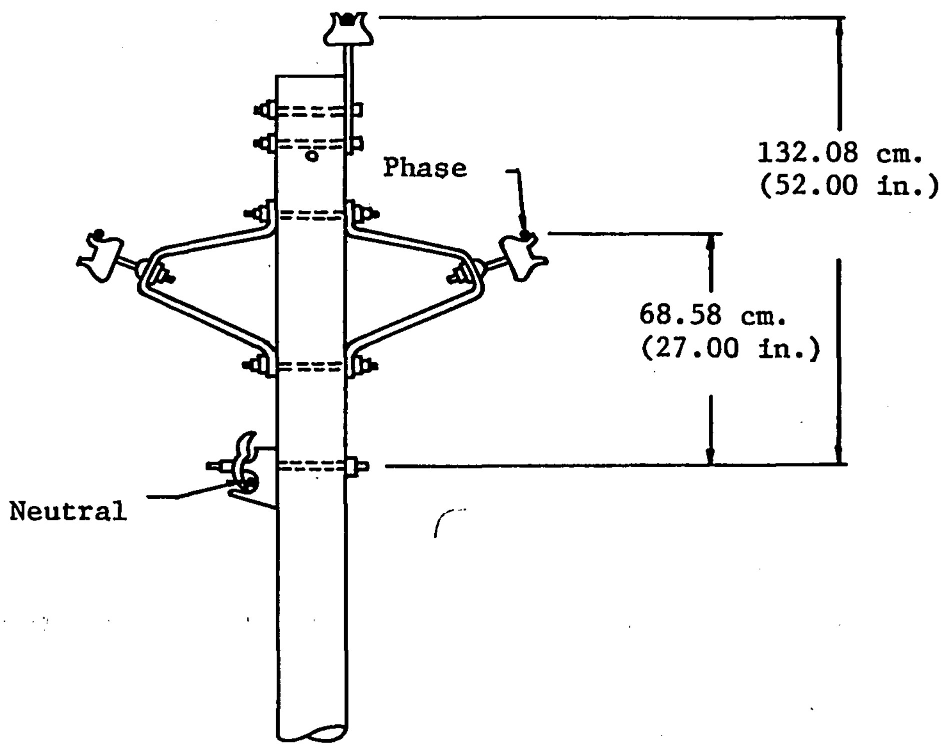
TEST UTILITY POLE FRAMING - CASE B



Method 2

FIGURE 5B

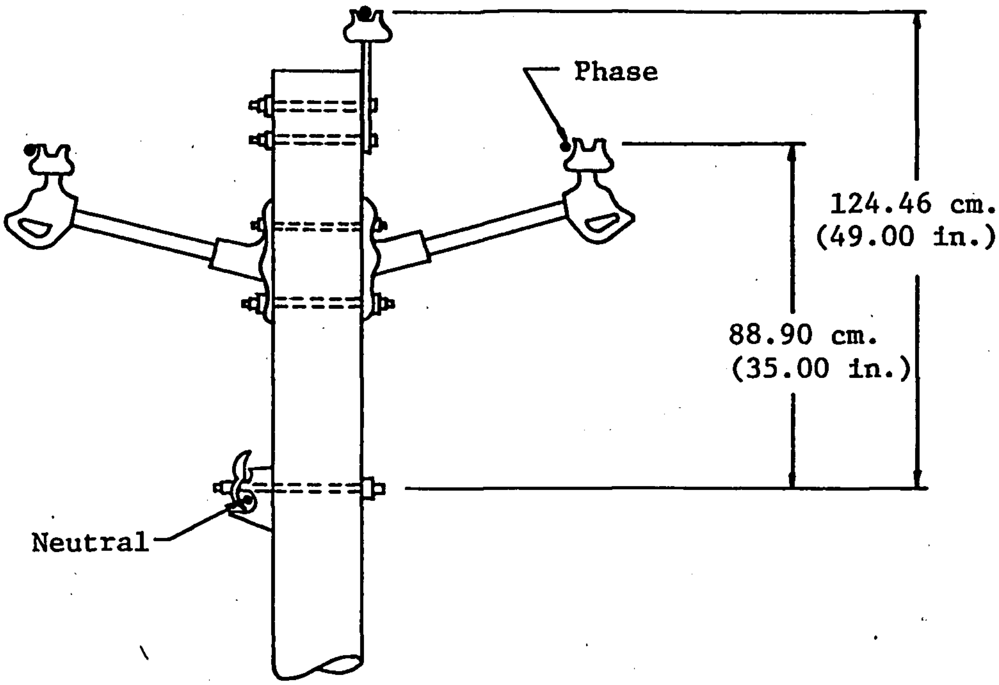
TEST UTILITY POLE FRAMING - CASE B



Method 3

FIGURE 5C

TEST UTILITY POLE FRAMING - CASE C



Method 1

FIGURE 6A

TEST UTILITY POLE FRAMING - CASE C

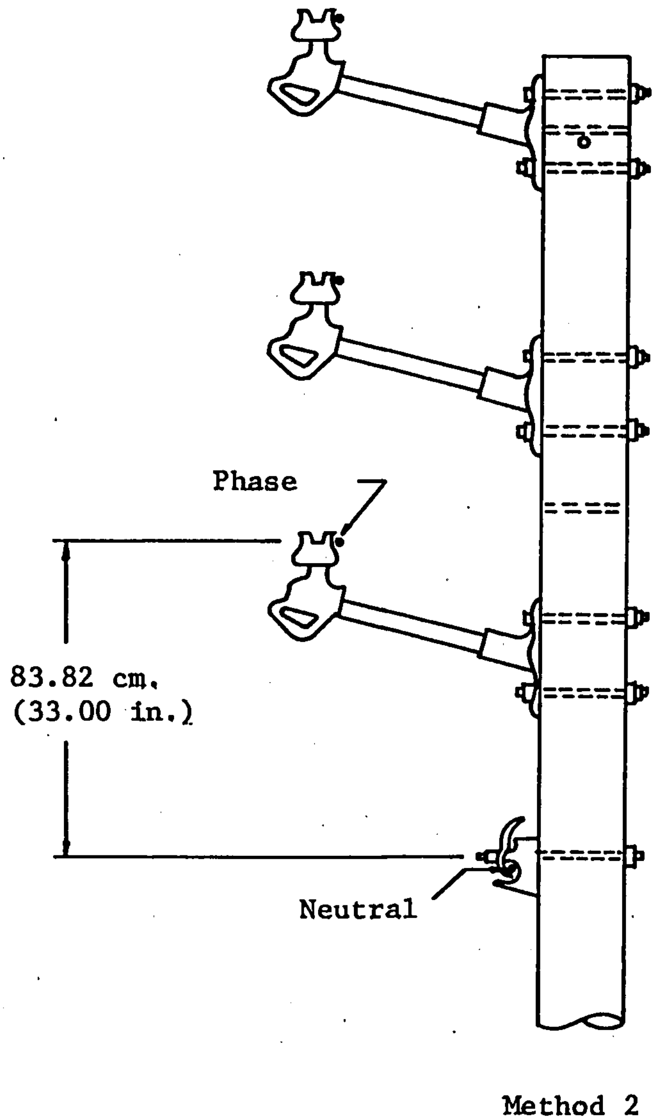


FIGURE 6B

Tables 7, 8, and 9, pages 99 through 114 were prepared by using these outside phase-to-neutral clearance values and allowing the phase and neutral conductors to sag within 30.48 centimeters (12 inches) vertically of each other.

To conform with the National Electrical Safety Code, all phase-to-neutral clearances (outside pin and ridge pin position) were measured vertically, not diagonally.

Method 1 and Method 2 of Case B were not considered in the method's calculations. Method 1 could be used only with copper, or XLP covered ACSR, or covered aluminum. There were very few copper lines constructed with Method 1, and for covered conductors it was believed that incidental phase-to-neutral or phase-to-phase contact would not cause significant problems. Method 2 was eliminated as it can be used only with covered conductor, and the same reasoning for eliminating Method 1 covered conductor construction applied in this case. Case C, Method 2 was eliminated for the same reason. In the covered conductor construction, the 30.48 centimeters outside phase-to-neutral final clearance was not a limiting condition on MCOT because of Rule 235C1, Exception 3[34]. Temperature limitations on the covering material, however, were considered.

Case B framing, Method 3 which is the close spaced 14 inch plastic bracket construction was eliminated from consideration when the final ampacities were chosen. It produced the lowest ampacity ratings of the 3 types of framing, due to the 68.58 centimeters (27 inches) outside phase-to-neutral vertical clearance. Justification for this decision:

- Case B framing was not used for new construction,
- Case B framing was estimated to be a small percentage of total distribution circuit miles, and
- a program could be developed to identify existing Case B framing, and through reconstruction, the neutral conductor lowered on the pole an additional 20.32 centimeters (8 inches).

The increase in ampacity, as a result of eliminating Case B framing, demonstrated the advantage in initiating this policy (see Tables 9A and 9B, pages 112 and 113).

The maximum span for three-phase 2.44 meter (8 foot) crossarm construction was 76.20 meters (250 feet). Spans equal to 80 percent of the maximum were investigated for this type of framing to determine the effects of span length on MCOT. The maximum allowable span lengths for all the types of framing are given in Table 2, pages 64, 65, and 66, and were used to produce Table 9, on pages 112, 113, and 114.

Throughout the rating method only the three-phase line framings were examined for sag limitations and to calculate ampacity ratings. This was done because:

- single phase lines were usually constructed in the test utility with phase and neutral conductor separations, at the pole, greatly exceeding those shown in Cases A, B, or C,

- single phase lines were not expected to be loaded to capacity, so the ampacity rating of a specific conductor which was used in this manner was not of major importance.

- the neutral conductor changed sag with the phase conductor in some instances, as discussed on page 52, providing additional final separation clearance.

When longer span lengths are used for either single or three phase lines by the test utility, special framing

TEST UTILITY ALLOWABLE MAXIMUM SPANS

Conductor Type & Size	1 Phase	Case A 8' X-Arm	Case B Method 1 (6-13-61)	Case B & C Method 2 (6-13-61) (6-13-91)	Case B Method 3 (6-13-61)	Case C Method 1 (6-13-91)
#4/0 HD AAC	*	250 ft.	-	-	150 ft.	150 ft.
336.4 KCMIL HD AAC	*	250 ft.	-	-	160 ft.	160 ft.
#2 ACSR, 6/1	200 ft.	200 ft.	-	-	-	-
#2 ACSR, 6/1	350 ft.	250 ft.	-	-	-	-
#1/0 ACSR, 6/1	350 ft.	250 ft.	-	-	250 ft.	250 ft.
#4/0 ACSR, 6/1	*	250 ft.	-	-	190 ft.	190 ft.
336.4 KCMIL ACSR, 26/7	*	250 ft.	-	-	180 ft.	180 ft.
#4 HD Solid Copper	250 ft.	250 ft.	225 ft.	-	-	250 ft.
#2 HD Solid Copper	*	250 ft.	250 ft.	-	-	250 ft.
#2 HD 3-Strd. Copper	250 ft.	250 ft.	250 ft.	-	-	250 ft.
#1/0 HD Strd. Copper	*	250 ft.	250 ft.	-	-	250 ft.
#2/0 HD Strd. Copper	*	250 ft.	225 ft.	-	-	250 ft.
#2/0 HD Strd. Copper	*	250 ft.	250 ft.	-	-	250 ft.

TABLE 2A

TEST UTILITY ALLOWABLE MAXIMUM SPANS (cont'd)

Conductor Type & Size	1 Phase	Case A 8' X-Arm	Case B Method 1 (6-13-61)	Case B & C Method 2 (6-13-61) (6-13-91)	Case B Method 3 (6-13-61)	Case C Method 1 (6-13-91)
#3/0 HD Strd. Copper	*	250 ft.	250 ft.	-	-	250 ft.
#4/0 HD Strd. Copper	*	250 ft.	250 ft.	-	-	250 ft.
#2 TBWP HD Solid Copper	*	250 ft.	180 ft.	-	230 ft.	230 ft.
#1 TBWP HD Solid Copper	*	250 ft.	200 ft.	-	250 ft.	250 ft.
#1/0 TBWP SD Strd. Copper	*	225 ft.	150 ft.	-	190 ft.	190 ft.
#2/0 TBWP SD Strd. Copper	*	250 ft.	200 ft.	-	250 ft.	250 ft.
#4/0 TBWP SD Strd. Copper	*	210 ft.	190 ft.	-	200 ft.	200 ft.
#1/0 XLP Covered ACSR	225 ft.	225 ft.	225 ft.	225 ft.	-	225 ft.
#1/0 XLP Covered ACSR	225 ft.	225 ft.	225 ft.	225 ft.	-	225 ft.
#4/0 XLP Covered ACSR	*	225 ft.	225 ft.	225 ft.	-	225 ft.
336.4 HD 19S XLP AAC	*	225 ft.	225 ft.	225 ft.	-	225 ft.

*Not normally used on single-phase lines

TABLE 2B

TEST UTILITY ALLOWABLE MAXIMUM SPANS (cont'd)

The ruling span of the sag chart selected should be as close as possible to the ruling span of the line being designed. If there is more than one sag chart to choose from, use the one with the highest load tension-unless conditions such as limited guying or uplift make the lower tension more practical.

The maximum span in any line is limited to the lesser of 1) spans listed above, or 2) 125% of the sag chart ruling span.

Reference 36.

TABLE 2C

designs are used, and greater phase and neutral conductor separation at the pole is provided, along with a longer crossarm, if needed.

Weather Model

The weather model in the PP&L-PJM method contained wind speed versus ambient temperature frequency of occurrence tables for summer and winter, which were based on historical weather data from Washington, DC and Pittsburgh, PA[1] (Tables 3 and 4, pages 68 through 71).

Ambient temperatures below 2½°C were lumped under the 0°C temperature row at all wind speeds. This accounted for any negative °C temperatures. Values at 37.5°C and higher were lumped at the "over 35°C" row, and were represented by 40°C in the computer program. By setting these weather tables up in this manner, they produce conservative results when ampacity ratings are calculated[13,38].

The original weather data were recorded on magnetic tape by the Task Force. The National Airport* data were

*Washington, DC

PP&L-PJM METHOD COMPOSITE WINTER WEATHER DATA

Pittsburgh and Washington D.C.
Pittsburgh 1/1/49 - 12/31/58 - 10 Years
National Airport 1/1/49 - 12/31/64 - 16 Years
Total Composite Hourly Record - 26 Years

Frequency of Occurrence (Percent)

Winter Days

Wind Speed-Knots

Ambient Temp. °C	0	1	2	3	4	5	Over 5	Sum
0	0.105	0.321	0.541	0.751	1.315	1.649	22.146	26.828
5	0.233	0.695	1.184	1.633	2.380	2.912	31.418	40.455
10	0.118	0.354	0.600	0.875	1.079	1.351	16.749	21.126
15	0.046	0.134	0.230	0.282	0.344	0.433	7.302	8.771
20	0.007	0.023	0.039	0.062	0.062	0.082	2.164	2.439
25	0.000	0.000	0.000	0.003	0.000	0.003	0.348	0.354
30	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.007

TABLE 3A

PP&L-PJM METHOD COMPOSITE WINTER WEATHER DATA (cont'd)

Winter Days

Wind Speed-Knots

Ambient Temp. °C	0	1	2	3	4	5	Over 5	Sum
35	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Over 35	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum	0.509	1.527	2.594	3.606	5.180	6.430	80.134	99.980*

Winter Nights

(Data Not Shown)

Note: The number of recorded calm hours was adjusted for anemometer error, as indicated in Figure 2, page A-6, Reference 1.

*Round-off error

TABLE 3B

PP&L-PJM METHOD COMPOSITE SUMMER WEATHER DATA

Pittsburgh and Washington D.C.
Pittsburgh 1/1/49 - 12/31/58 - 10 Years
National Airport 1/1/49 - 12/31/64 - 16 Years
Total Composite Hourly Record - 26 Years

Frequency of Occurrence (Percent)

Summer Days

Wind Speed-Knots

Ambient Temp. °C	0	1	2	3	4	5	Over 5	Sum
0	0.009	0.025	0.042	0.024	0.059	0.070	1.830	2.059
5	0.038	0.115	0.195	0.247	0.326	0.427	6.455	7.803
10	0.059	0.176	0.299	0.345	0.519	0.634	8.811	10.843
15	0.070	0.209	0.355	0.484	0.741	0.955	11.147	13.961
20	0.103	0.311	0.528	0.655	1.049	1.401	14.559	18.606
25	0.109	0.324	0.550	0.791	1.405	1.743	17.949	22.871
30	0.059	0.178	0.302	0.496	0.962	1.381	14.708	18.086

TABLE 4A

PP&L-PJM METHOD COMPOSITE SUMMER WEATHER DATA (cont'd)

Summer Days

Wind Speed-Knots

Ambient Temp. °C	0	1	2	3	4	5	Over 5	Sum
35	0.012	0.034	0.058	0.127	0.261	0.389	4.650	5.531
Over 35	0.000	0.001	0.001	0.003	0.009	0.010	0.187	0.211
Sum	0.459	1.373	2.330	3.172	5.331	7.010	80.296	99.971*

Summer Nights

(Data Not Shown)

Note: The number of recorded calm hours was adjusted for anemometer error, as indicated in Figure 2, page A-6, Reference 1.

*Round-off error.

TABLE 4B

tabulated by the Washington area representative* of the Task Force and the other weather data by the Task Force chairman. The existence and whereabouts of these data are in doubt.

The suggestion that a new weather model should be constructed using weather data from the test utility territory was prompted by the fact that the Washington data produced a warmer summer model. These data also biased the Pittsburgh data which would have normally produced a colder winter model, since both data sources were combined. A new weather model supposedly would be more representative of the test utility system weather. If the summer conditions resulted in being the limiting factor on maximum ampacity, the argument was that the test utility could get additional ampacity by using this revised weather model.

However, with the Dist-Amp rating method factoring into the calculations the conductor sag, the winter ambient temperature determined the maximum conductor ampacity. Also, the weather model was only used in the L-O-S calculation. When running the second mode of the PP&L-PJM computer program**, the weather model had no effect on the ampacity calculations.

*Potomac Electric Power Company
**See Chapter 1, page 18.

The major obstacle to this suggestion was the lack of an adequate source of weather data over a long time period for the whole 29 counties served by the test utility. Whatever information that was available from local weather stations most likely would have to be coded onto cards and processed before the two new weather model tables could be constructed. The use of this revised weather model suggestion was rejected because of (1) the unjustified large number of manhours required to produce a new model, and (2) the dramatic effect on the sag limitation temperature (and indirectly on the ampacity rating) of the winter ambient temperature.

Ambient Temperatures

The Dist-Amp rating method used ambient temperatures of 25°C (77°F) and -10°C (14°F) to represent "summer" and "winter" weather conditions, respectively, in the sag limitations part of the method. At these two temperatures, the neutral conductor sag served as a reference to compare the phase conductor sag increase at its higher operating temperature.

The planning department of the test utility used a -4°C (24.8°F) winter ambient temperature and a 29°C (84.2°F) summer ambient temperature in their technical studies. The two values were somewhat representative of temperatures when peak loading could be expected to occur. The ambient temperatures used in this distribution ampacity method will produce conservative ampacities and final phase-to-neutral conductor clearances. The winter peak load might occur at a temperature lower than -4°C, but the conductor ampacity was determined at -10°C in the Dist-Amp method, with the final phase-to-neutral clearance also determined at -10°C. Even if a peak load would occur below -4°C, the ampacity selected still maintained the 30.48 centimeters (12 inches) vertical clearance down to -10°C. In the summer, the lower ambient temperature used in this method, 25°C versus 29°C, also provided a margin in the final clearance. Since the peak load might occur above 25°C, at the selected ampacity the 30.48 centimeters vertical clearance would still be maintained, due to the greater sag in the neutral conductor at temperatures above 25°C --- the value at which final phase-to-neutral clearance and ampacity were calculated.

Though the -10°C and 25°C temperatures did not exactly represent peak load versus ambient temperature, they provided a reasonable basis on which conductor ampacities could be based.

If a 25°C ambient temperature would have been used in the last steps of assigning the final conductor ampacity rating, using the 30.48 centimeters final phase-to-neutral clearance value, MCOT, and ampacity calculated under these conditions, Rule 235C would probably have been violated. The NESC requires that the 30.48 centimeters separation be maintained with the neutral conductor sagged at 15.6°C (60°F) under bare, no wind, final sag loading conditions, while the phase conductor is at its maximum operating temperature. It was after some initial sag limitations were calculated that this point was noted. By using an ambient temperature of -10°C, instead, to calculate MCOT and assign the final ampacity, while maintaining the 30.48 centimeters separation, the Dist-Amp rating method was more conservative than the NESC required. This was permissible since the code intent was met by equalling or exceeding this clearance requirement. Also, since one year-round temperature/ampacity was going to be selected, the 25°C value would have been a little warm to be representative of both summer and winter ambient temperatures.

In previous test utility ampacity studies the winter ampacities exceeded the summer values. Table 9, pages 112 through 114, shows this is not always so when sag and clearance are included in the determination.

The maximum ambient temperature predicted on the test utility system was selected as 35°C (95°F). The PP&L-PJM weather model indicated that the probability of exceeding 35°C was 0.2 percent in the summer and 0.0 percent in the winter. While a 35°C ambient temperature may appear low for conductors located in sheltered areas (through alleys between buildings), distribution engineering believed that the probability of simultaneously experiencing a 35°C ambient temperature with maximum ampere loading on the conductor, with only minimal phase-to-neutral clearance at the pole, would be much less than the 0.2 percent value. Thus, the MCOT would still remain within its limits and safety code clearances would be maintained for that particular conductor.

PP&L-PJM Weather Definitions

The ambient temperatures and wind speeds selected by the PJM Task Force (PP&L-PJM method), at which ampacity ratings were calculated, resulted in a probability of less than 1 percent of ever experiencing weather conditions which would exceed the severity of the "critical" conditions[1]. During both the normal and emergency operations, the conductor's temperature should not exceed the maximum temperature specified at which the ampacity rating calculation would be evaluated. These PP&L-PJM method terms are defined[40] in Table 5, page 77.

PP&L-PJM METHOD WEATHER CONDITIONS

	"Critical" Conditions	"Most Severe" Conditions
Winter emergency (W/E)	10°C ambient temperature and 1 knot wind	*
Winter normal (W/N)	*	20°C ambient temperature and 0 knot wind
Summer emergency (S/E)	20°C ambient temperature and 1 knot wind	*
Summer normal (S/N)	*	35°C ambient temperature and 0 knot wind

Equivalent terms: 1) "most severe" conditions, most severe ambient conditions, most severe set of ambient conditions, 2) "critical" conditions, critical set of ambient conditions.

TABLE 5

The "most severe" condition is the highest ambient temperature and lowest wind speed combination that had a frequency of occurrence greater than zero on the summer and winter weather tables. The "critical" condition is the ambient temperature and wind speed combination, which the PP&L-PJM computer program determined, that had a frequency of occurrence of less than 1 percent of ever experiencing any other wind speed and ambient temperature which would exceed the severity of this "critical" condition.

Based on these definitions, during both normal and emergency operations, the conductor's maximum design temperature should not be exceeded, unless a random emergency* would occur during an ambient temperature and wind speed combination more severe than the "critical" condition[1,30].

<u>Wind Speed</u>

Initially, ampacity calculations were made for a few selected conductors, using the PJM Task Force and PP&L-PJM method criteria for "most severe" and "critical" weather conditions, along with the 1 percent probability value[1]. The

*Based on 10 hours per year for a 35 year period.

resulting ampacities were low compared to values presently being used by the test utility, which were supported by operating experience and determined by past rating methods.

It was reasoned that since present conductor loading practices exceeded these initially calculated "maximum ampacities", the "critical" and "severe" weather conditions used by the PP&L-PJM method had to be excessively restrictive for distribution line application. Otherwise, the test utility would be experiencing a significant amount of line outages because of this "overloading" which supposedly would be occurring, at least according to these initial ampacity calculations. The planning, operating, and distribution departments did not have any knowledge that this type of problem existed. A distribution line, in general, would be less critical as a supply line, compared to a transmission line. So, the risk of exceeding the "critical" condition was increased to a 5 to 10 percent range for these reasons.

After the ambient temperatures were selected for winter and summer, the PP&L-PJM method weather tables (Tables 3 and 4, pages 68 through 71) were examined to determine a wind velocity at these selected distribution ambient conditions that would result in a probability within this range. From this examination, the 3 knot wind speed was chosen. The planning, operating, and distribution engineering departments agreed that the 3 knot wind speed was better than the 4 knot speed, which would also have given a summer probability within the 10 percent range, because the resulting ampacities would then be conservative, rather than extended to the limit.

<u>Wind and Temperature Probabilities</u>

In the distribution ampacity method these weather condition definitions were a factor only when L-O-S calculations were run to determine the temperatures at which 10 percent L-O-S would occur.

Since -10° and 25°C ambient temperatures and 3 knot wind speed values determined the "distribution critical" conditions, the Dist-Amp rating method probabilities varied between 4½ and 8½, instead of 1 percent.

These different wind and ambient temperature conditions used in the Dist-Amp rating method resulted in a probability of less than 4.788 percent of ever experiencing weather conditions which exceed the severity of a 25°C ambient temperature and 3 knots wind during the summer months, and a probability of less than 4.630 percent during the winter months; a probability of less than 7.334 percent of ever experiencing weather conditions which exceed the severity of a -10°C ambient temperature and 3 knots wind during the summer months, and a probability of less than 8.236 percent during the winter months. December, January, and February are defined as the winter months. These probabilities of weather conditions which exceed, in severity, the selected ambient temperature and wind speed were calculated by summing the rows and columns of Tables 3 and 4 for temperatures and wind speeds greater than the "distribution critical" conditions[37]. While this was not a rigorous approach, a similar method of row/column summation was used by the PJM Task Force* to calculate the 1 percent probability[1].

The winter "distribution critical" condition probability value will be derived as an example.

- o wind = 3 knot
- o ambient temperature = -10°C

*PP&L-PJM method, also.

The "winter days" portion of Table 3, pages 68 and 69 will be used.

A higher ambient temperature results in a higher conductor operating temperature if the conductor current remains constant. A 35°C ambient temperature would produce a higher conductor operating temperature than a 20°C value, for constant current. Likewise, a 1 knot wind speed would produce a higher conductor operating temperature than a 5 knot value, because of less convective heat loss.

The probabilities in the wind speed columns less than 3 knots are summed (i.e. 0, 1, 2 knots). This probability value is 4.630 percent (0.509 + 1.527 + 2.594). Next, all ambient temperature rows greater than -10°C at all wind speeds up to and including 3 knots are summed row by row, but since most of this was done when the wind speed columns were summed, only the 3 knot column needs to be totaled at all temperatures greater than -10°C (in this example, the whole column). These probability values added to 4.630 percent result in 8.236 percent (4.630 + 3.606).

The four probabilities given on pages 80 and 81 were calculated in this manner. The "summer days" table was used for -10°C to determine the effect on probability if one year round ambient temperature would be selected. This calculation may be academic.

With an understanding, now, of the method's various assumptions, Chapter 3 will detail the steps in the Dist-Amp rating method, from selecting the phase and neutral combinations through the sag limitations and L-O-S checks, to the final assigned ampacity rating.

CHAPTER 3

METHOD USED TO CALCULATE

DISTRIBUTION CONDUCTOR AMPACITY RATINGS

The distribution ampacity (Dist-Amp) rating method is based on determining the amount of sag increase allowable in the phase conductor relative to its neutral conductor at certain ambient temperatures with no ice or wind loading on either conductor, noting the final phase conductor temperature when that sag condition is attained, and comparing the loss-of-tensile strength (L-O-S) temperature with the maximum sag phase conductor temperature (Figure 7, page 85) to select the conductor temperature value at which the initial ampacity rating will be calculated. After examining all phase and neutral conductor combinations, a series of steps are used to determine the maximum conductor operating temperature (MCOT) and assign the final ampacity rating for that particular size phase conductor. The details of this method applied to one conductor size are given in the following steps.

Step 1. All phase and neutral combinations that would be used in designs for that <u>one</u> phase conductor size were determined (see Chapter 4, pages 130 through 146).

Step 2. For the phase and neutral combinations determined

MAXIMUM PERMITTED SAG INCREASE

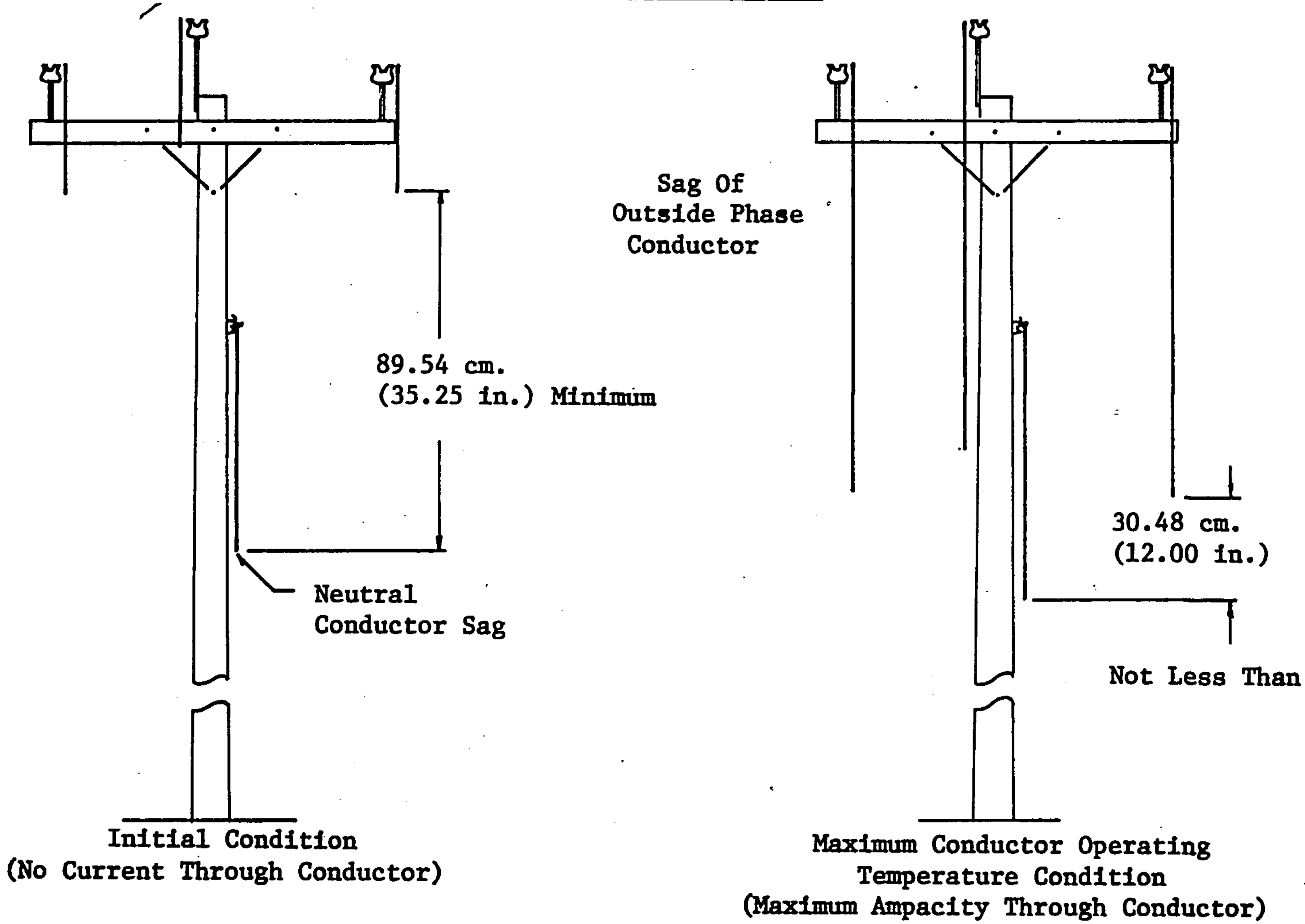


FIGURE 7

in Step 1, the following design parameters must be selected:

- o maximum design tension in the phase and neutral conductors,
- o ice and wind maximum loading conditions,
- o span lengths --- usually maximum allowable,
- o pole framing style (i.e. - Case A, B, or C; Figures 4, 5 or 6, pages 55 through 60).

One phase and neutral combination of the group was selected and used in the following steps.

Step 3A. The phase conductor sags were calculated for each span length, maximum design tension, and ice and wind loading parameter combination using a sag and tension computer program[35]. The program is called on the TSO communications terminal by the command CEØAE41. Seven separate program runs for the phase conductor were required to produce sag values at all bare, no wind °F. temperature-loading conditions so that sag limitations could be calculated. The 34 temperatures were: -10, 20, 25, 29, 35, 40°C (14, 68, 77, 84.2, 95, 104°F) and by 5°C (9°F) increments thereafter, including 180°C (356°F).

Step 3B. The neutral conductor sags were calculated for the same design parameter combinations as the phase conductor sags. Only one program run was necessary initially for the neutral, entering -10, 20, 25, 29, 35, 40°C temperatures. All sags in Steps 3A and 3B were under a bare*, no wind, final sag loading condition.

Step 4A. The top half of the Sag Limitation Data Sheet (Table 6A or 7A, pages 97 or 99) was completed from sag data obtained in Steps 3A and 3B. This information consisted of the phase and neutral final sag at 4.44°C (40°F), versus the various selected span lengths, for <u>one</u> phase and neutral combination for the design parameters used in Steps 2 & 3.

Note: Reader should continue to refer to Tables 7 through 12, pages 99 through 120 for a listing and example of these various Steps.

Step 4B. If the neutral conductor sag was equal to or greater than the phase conductor sag at 4.44°C (40°F), then the neutral sag at -10, 15.6, and 25°C (14, 60, and 77°F) from Step 3B was listed on the Sag Limitation Data Sheet

*No ice.

(SLDS). Step 4C would be disregarded for this case. If the neutral sag was less than the phase sag, the test utility sagging practice explained in Chapter 2, under "Conductor Sag", was simulated by executing Step 4C.

Step 4C. The sag and tension computer program[35] was run for the neutral conductor a second time, as in Step 3B, using the "sag restriction" feature. The neutral sag value entered in the program was identical to the phase sag at 4.44°C (40°F), for a span length, with all other design parameters unchanged. The -10, 15.6, and 25°C bare, no wind sag values produced from this re-run were used to complete the SLDS. When there are more than one span length, this Step must be repeated for each span.

Step 5A. With the basic sag values now listed on the SLDS, the actual "sag limitations" were calculated. The sag limitation process involved the determination of a phase conductor sag at some temperature that would bring it within 30.48 centimeters (12 inches) of the neutral conductor, which was fixed at one of three ambient temperatures*. The following equations were used to determine these two values.

*-10, 15.6, or 25°C (14, 60, 77°F)

$N_x + C_p - 1.0$ = phase sag required -------------- equation 5

$N_x + C_p - S_y$ = (phase-to-neutral clearance)$_x$ --- equation 6

where:

x represents the ambient temperature of -10, 15.6, or 25°C.,

y = 1, 2, 3, ... or 34,

C_p = phase-to-neutral conductor separation at the pole, in feet,

N_x = the neutral conductor sag at one of the three ambient temperatures represented by "x", in feet, and

S_y = the phase conductor sag from the sag and tension program, at one of the thirty-four temperatures ranging between -10 and 180°C (14 and 356°F).

Equations 5 and 6 were derived for values given in English system units, since the sag and tension program[35] was arranged for this type of data. All examples have sag values in English units for the same reason. If the correct phase conductor sag at some temperature, S_y, was chosen from the sag output in Step 3A, then:

$(\text{phase-to-neutral clearance})_x \geq 30.48$ centimeters (12 inches) .... equation 7.

A clearance value less than 30.48 centimeters meant that the chosen phase conductor sag (S_y) temperature-loading condition was too high, and a value much greater than 30.48 centimeters indicated that it was too low, and a higher phase conductor sag temperature-loading condition should have been used for S_y. This Step determined a phase conductor temperature.

Step 5B. After calculating a phase-to-neutral clearance which satisfied equation 7, noting the phase conductor temperature at that sag, Step 5A was repeated for the ambient temperatures of 15.6 and 25°C. The SLDS for one phase and neutral conductor combination was completed in this manner (Tables 7A through 7D, pages 99 through 102).

Step 6. If there were more than one phase and neutral conductor combination noted in Step 1, or more than one maximum design tension or ice and wind maximum loading condition in Step 2, at this point another SLDS was prepared similar to Table 7, pages 99 through 102 for the remaining combinations, until all combinations of phase and neutral and design parameters were included. Steps 3 through 5 were repeated in each combination case as required to provide complete sag information. The examples illustrate this point (Tables 7 and 8, pages 99 through 111).

Step 7. Data on every phase and neutral combination for the one phase conductor which was examined in the above steps were transferred to a Design Parameter Summary Sheet as shown in Table 13, page 121. The data listed in this table were:

- o phase and neutral combinations,
- o phase conductor temperatures,
- o various span lengths,
- o maximum design tension with ice and wind loading, and

o all pole framing possibilities.

Step 8. The various phase conductor temperatures determined in Step 5 and listed in Table 9A, page 112 under columns 2-4 were entered as part of the input data for this one phase conductor. The PP&L-PJM ampacity rating computer program, as modified for distribution conductors, was executed by calling: CEØEA10 TYPERUN(NØLØSS)*. This produced an output sheet of ampacity calculations, shown in Table 10A, page 115, for each phase conductor temperature on Table 9A, page 112. The phase conductor temperature referred to here results from the maximum sag increase calculations, and should not be confused with maximum conductor operating temperature (MCOT), which still must be determined for this phase conductor.

Step 9. The ampacity value was read from the output sheet, Table 10A on page 115, for the given phase conductor temperature at which the ampacity ratings were determined. The 3 knot

Program similar to CEØEA10 TYPERUN(NØLØSS) was actually used; called DISTAMP.PLI wind speed row and the -10, 15, or 25°C column intersection determined the desired value. This value was entered on Table 9A, page 112, under columns 7-9.

This step was repeated for other similar output sheets (Table 10B, page 116) generated for each phase conductor temperature determined and noted in Steps 5 and 8 (Table 9A and 9B, pages 112 and 113) at the three ambient temperatures.

Step 10. The PP&L-PJM ampacity rating computer program was executed in the L-O-S mode by calling CEØEA10 for this phase conductor size being examined. A group of conductor temperatures, by trial and error, were entered in the program, and the conductor temperature which produced a 10 percent L-O-S value was recorded. A copper conductor example is shown in Table 11, pages 118 and 119. For copper this temperature was entered in Table 9C, page 114, columns 2-4, under any phase conductor temperatures which exceeded it in magnitude. This did not occur for 336.4 AAC.

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*The Column 3 temperature was exactly 15.6°C (60°F) when sag increase and MCOT were computed. The exact temperature in Column 8 was 15°C (59°F), at which the conductor ampacity was determined, instead of exactly 60°F. Programming restrictions prevented more precise calculations. The small temperature variations and their effects on the final results in Column 8 appeared to be negligible.

Step 11A. The elimination process to select the ampacity of this phase conductor size for all phase and neutral combinations was next, after Tables 9A and 9B, pages 112 and 113 were completed from Steps 9 and 10.

If a 25°C (Table 9A, page 112, column 2) ambient temperature was used to determine the phase conductor ampacity, Rule 235C of the NESC might have been violated. This rule requires that when the neutral conductor is at 15.6°C (60°F), and the phase conductor is at its maximum conductor operating temperature (MCOT), then a 30.48 centimeter phase and neutral conductor separation must be maintained. However, the weather model demonstrated that winter temperatures below 15.6°C (60°F) would be experienced, making a 25°C ambient temperature unrealistic. The -10°C (14°F) ambient temperature would not violate the NESC, since 30.48 centimeters (12 inches) would be maintained or exceeded.

Referring to Table 9A, page 112, columns (2, 7) and (3, 8) were eliminated from any further consideration for these reasons. Columns 4 and 9 remained from which to select the phase conductor ampacity.

Step 11B. An exception to using columns 4 and 9 occurred in cases where the phase conductor temperature was restricted by the 10 percent L-O-S temperature value (Step 10). The phase conductor temperatures on Table 9C, page 114, columns 2-4, were adjusted downward because of this annealing limit. The ampacity was chosen from column 9 in this L-O-S restriction case, but at a lower conductor temperature. This occurred for #2 AWG, 7 strand H.D. copper (Table 9C, page 114). By decreasing the phase conductor temperature to 100°C, the phase-to-neutral clearance was increased to some value greater than 30.48 centimeters.

Ampacity ratings in Tables 9A and 9B, pages 112 and 113, column 4 were examined for only one phase conductor type and size (i.e. - 336.4 AAC) at a time. Case B framing ampacity ratings were eliminated (see Chapter 2, page 62) next, and the smallest magnitude of the remaining ampacity ratings chosen as that size conductor's thermal ampacity rating.

Step 12A. The ampacity and phase conductor temperature selected in Step 11 were then entered in a conductor temperature determination computer program[41]. This program calculated the conductor temperature over the ambient temperature range of -15 through 50°C at that ampacity (Table 12, page 120). The maximum ambient temperature on the test utility system, from Chapter 2, page 75, was determined as 35°C (95°F). The phase conductor temperature was examined under this ambient temperature column in the program.

Step 12B. If this conductor temperature exceeded the L-O-S temperature, even though Step 11B was performed, the phase conductor temperature from Step 11A was reduced by a 5°C increment. Both the new, reduced phase conductor temperature and lower ampacity were entered again (Step 12A) in the conductor temperature determination computer program[41], and the conductor temperature re-calculated over the ambient temperature range. This process was repeated until the phase conductor temperature at the 35°C ambient temperature was reduced below the L-O-S temperature from Step 10, for that particular size conductor.

Step 13. This 13 step procedure was repeated for all distribution conductors rated and listed in Chapter 4, starting with Step 1 for <u>each</u> (phase) conductor size. Where annealing was not a limitation (i.e. - CW, covered conductor), the temperature restriction due to the conductor material or insulation covering was applied in Step 10.

The complete conductor list and related ampacity ratings, along with each MCOT and L-O-S temperature are presented in Chapter 4.

SAG LIMITATION DATA SHEET

Ruling Span -----

Ø (#) Sag @ 40°F. ---

N. (#) Sag @ 40°F. ---

Neutral Sag _____ Ø Sag; Resag Neutral? Yes No

Adj. N. (#) Sag @ 40°F. ---

N. (#) Sag @ 14°F. ---

N. (#) Sag @ 60°F. ---

N. (#) Sag @ 77°F. ---

CASE _____

Outside (Pin) Ø - N. Clearance At Ambient Temperature =

R.S. = ; use N. Sag @ 14°F.;

Look For Ø Sag =

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance (Conductor on Outside Insulator)

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

R.S. = ; use N. Sag @ 60°F.;

Look for Ø Sag =

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

R.S. = ; use N. Sag @ 77°F.;

Look For Ø Sag =

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

TABLE 6A

SAG LIMITATION DATA SHEET (cont'd)

CONDUCTOR COMBINATION: ____________________

CASE _____

Outside (Pin) Ø - N. Clearance At Ambient Temperature =

R.S. = ; use N. Sag @ 14°F.;

Look For Ø Sag = ;

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance (Conductor on Outside Insulator)

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

R.S. = ; use N. Sag @ 60°F.;

Look For Ø Sag = ;

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

R.S. = ; use N. Sag @ 77°F.;

Look For Ø Sag = ;

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

Ø Sag @ °F. = ; Check; Final Ø - N. Clearance

TABLE 6B

SAG LIMITATION DATA SHEET - 336.4 AAC Ø & #4/0 ACSR N.

		Feet	Feet	Feet	
Steps 2. & 4.	Ruling Span ---	250	200	160	
336.4 AAC Ø (2000#)	Sag @ 40°F =	5.7	3.5	2.1	Step 2.
#4/0 ACSR N. (2000#)	Sag @ 40°F =	4.9	2.9	1.7	Step 3A.
Adj. #4/0 ACSR N. (2000#)	Sag @ 40°F =	5.7	3.5	2.1	Step 3B. & 4B.
	Sag @ 14°F =	5.1	2.9	1.6	
	Sag @ 60°F =	6.1	3.9	2.5	
	Sag @ 77°F =	6.4	4.2	2.8	
Neutral Sag < Ø Sag; Re-sag Neutral? Yes					Step 4C.

CASE 'A' Step 2.

Outside Ø - N. Clearance At Ambient = 35.25 Inches;

	Feet	Inches	
R.S. = 250 Feet; use N. Sag @ 14°F; Step 5A.			
Look For Ø Sag =	7.0375 Feet;		
Ø Sag @ 95°F =	6.9;	Check; 13.65	Final Ø - N. Clearance (Conductor On Outside Insulator) (Step 5A.)
Ø Sag @ 104°F =	7.1;	Check; 11.25	Final Ø - N. Clearance
R.S. = 250 Feet; use N. Sag @ 60°F; Step 5B. (Step 5A.)			
Look For Ø Sag =	8.0375 Feet; Step 5B.		
Ø Sag @ 149°F =	8.0;	Check; 12.45	Final Ø - N. Clearance
Ø Sag @ 158°F =	8.1;	Check; 11.25	Final Ø - N. Clearance
R.S. = 250 Feet; use N. Sag @ 77°F; Step 5B. (Step 5A. & 5B.)			
Look For Ø Sag =	8.3375 Feet;		
Ø Sag @ 167°F =	8.3;	Check; 12.45	Final Ø - N. Clearance
Ø Sag @ 176°F =	8.5;	Check; 10.05	Final Ø - N. Clearance

TABLE 7A

SAG LIMITATION DATA SHEET - 336.4 AAC Ø & #4/0 ACSR N. (cont'd)

CONDUCTOR COMBINATION: 336.4 AAC Ø (2000#) with #4/0 ACSR N. (2000#)

CASE 'A'

	Feet	Inches	
R.S. = 200 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 4.8375 Feet;			
Ø Sag @ 95°F =	4.7; Check;	13.65	Final Ø - N. Clearance
Ø Sag @ 104°F =	4.9; Check;	11.25	Final Ø - N. Clearance
R.S. = 200 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 5.8375 Feet;			
Ø Sag @ 158°F =	5.8; Check;	12.45	Final Ø - N. Clearance
Ø Sag @ 167°F =	6.0; Check;	10.05	Final Ø - N. Clearance
R.S. = 200 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 6.1375 Feet;			
Ø Sag @ 176°F =	6.1; Check;	12.45	Final Ø - N. Clearance
Ø Sag @ 185°F =	6.2; Check;	11.25	Final Ø - N. Clearance

CASE 'B'

Outside Ø - N. Clearance At Ambient = 27.00 Inches;

R.S. = 160 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 2.85 Feet;			
Ø Sag @ 68°F =	2.8; Check;	12.60	Final Ø - N. Clearance
Ø Sag @ 77°F =	2.9; Check;	11.40	Final Ø - N. Clearance

TABLE 7B

SAG LIMITATION DATA SHEET - 336.4 AAC Ø & #4/0 ACSR N. (cont'd)

CONDUCTOR COMBINATION: 336.4 AAC Ø (2000#) with #4/0 ACSR N. (2000#)

	Feet	Inches	
R.S. = 160 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 3.75 Feet;			
Ø Sag @ 122°F =	3.7; Check;	12.60	Final Ø - N. Clearance
Ø Sag @ 131°F =	3.9; Check;	10.20	Final Ø - N. Clearance
R.S. = 160 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 4.05 Feet;			
Ø Sag @ 140°F =	4.0; Check;	12.60	Final Ø - N. Clearance
Ø Sag @ 149°F =	4.1; Check;	11.40	Final Ø - N. Clearance

CASE 'C'.

Outside Ø - N. Clearance At Ambient = 35.00 Inches;

R.S. = 160 Feet; use N. Sag @ 14°F;			
Look for Ø Sag = 3.5167 Feet;			
Ø Sag @ 104°F =	3.4; Check;	13.40	Final Ø - N. Clearance
Ø Sag @ 113°F =	3.6; Check;	11.00	Final Ø - N. Clearance
R.S. = 160 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 4.4167 Feet;			
Ø Sag @ 167°F =	4.4; Check;	12.20	Final Ø - N. Clearance
Ø Sag @ 176°F =	4.5; Check;	11.00	Final Ø - N. Clearance

TABLE 7C

CONDUCTOR COMBINATION: 336.4 AAC Ø (2000#) with #4/0 ACSR N. (2000#)

	Feet	Inches	
R.S. = 160 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 4.7167 Feet;			
Ø Sag @ 194°F = 4.7; Check;		12.20	Final Ø - N. Clearance
Ø Sag @ 203°F = 4.9; Check;		9.80	Final Ø - N. Clearance

TABLE 7D

SAG LIMITATION DATA SHEET-
#2,7 STRD. H.D. COPPER Ø &
#4,7 STRD. H.D. COPPER N.

	Feet	Feet	Feet
Ruling Span ---	250	200	150
#2,7 Strd. CU. Ø (1560#) Sag @ 40°F ---	3.3	1.9	1.1
#4, 7 Strd. CU. N. (980#) Sag @ 40°F ---	6.3	3.3	1.2
Neutral Sag > Ø Sag; Resag Neutral? No			
Adj. N. (#) Sag @ 40°F ---	-	-	-
#4,7 Strd. CU. N. (980#) Sag @ 14°F ---	5.8	2.8	0.9
N. (980#) Sag @ 60°F ---	6.6	3.6	1.4
N. (980#) Sag @ 77°F ---	6.8	3.9	1.7

CASE 'A'

Outside Ø - N. Clearance At Ambient Temperature = 71.25 Inches;

	Feet	Inches	
R.S. = 250 Feet; use N. Sag 14°F;			
Look For Ø Sag = 7.7375 Feet;			
Ø Sag @ 293°F =	7.7; Check;	12.45	Final Ø - N. Clearance (Conductor on Outside Insulator)
Ø Sag @ 302°F =	7.8; Check;	11.25	Final Ø - N. Clearance
R.S. 250 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 8.5375 Feet;			
Ø Sag @ 356°F =	8.5; Check;	12.45	Final Ø - N. Clearance
Ø Sag @ - °F =	- ; Check;		Final Ø - N. Clearance

TABLE 8A

CONDUCTOR COMBINATION: #2,7 STRD. H.D. COPPER Ø (1560#) with
#4,7 STRD. H.D. COPPER N.(980#)

	Feet	Inches	
R.S. = 250 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 8.7375 Feet;			
Ø Sag @ 356°F = 8.5; Check;		14.85	Final Ø - N. Clearance
Ø Sag @ - °F = - ; Check;			Final Ø - N. Clearance

CASE 'A'

Outside Ø - N. Clearance At Ambient Temperature = 52.05 Inches;

R.S. = 200 Feet; use N. Sag @ 14°F;

Look For Ø Sag = 4.7375 Feet;

Ø Sag @ 212°F = 4.7; Check; 12.45 Final Ø - N. Clearance

Ø Sag @ 221°F = 4.9; Check; 10.05 Final Ø - N. Clearance

R.S. = 200 Feet; use N. Sag @ 60°F;

Look For Ø Sag = 5.5375 Feet;

Ø Sag @ 275°F = 5.5; Check; 12.45 Final Ø - N. Clearance

Ø Sag @ 284°F = 5.7; Check; 10.05 Final Ø - N. Clearance

R.S. = 200 Feet; use N. Sag @ 77°F;

Look for Ø Sag = 5.8375 Feet;

Ø Sag @ 293°F = 5.8; Check; 12.45 Final Ø - N. Clearance

Ø Sag @ 302°F = 5.9; Check; 11.25 Final Ø - N. Clearance

TABLE 8B

#2,7 STRD. H.D. COPPER Ø &
#4,7 STRD. H.D. COPPER N.

CONDUCTOR COMBINATION: #2,7 STRD. H.D. COPPER Ø (1560#) with
#4,7 STRD. H.D. COPPER N.(980#)

CASE 'A'

Outside Ø - N. Clearance At Ambient Temperature = 36.45 Inches;

	Feet	Inches	
R.S. = 150 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 2.8375 Feet;			
Ø Sag @ 158°F =	2.8; Check;	12.45	Final Ø - N. Clearance
Ø Sag @ 167°F =	2.9; Check;	11.25	Final Ø - N. Clearance
R.S. = 150 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 3.3375 Feet;			
Ø Sag @ 203°F =	3.3; Check;	12.45	Final Ø - N. Clearance
Ø Sag @ 212°F =	3.4; Check;	11.25	Final Ø - N. Clearance
R.S. = 150 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 3.6375 Feet;			
Ø Sag @ 230°F =	3.6; Check;	12.45	Final Ø - N. Clearance
Ø Sag @ 239°F =	3.7; Check;	11.25	Final Ø - N. Clearance

TABLE 8C

SAG LIMITATION DATA SHEET- (cont'd)
#2,7 STRD. H.D. COPPER Ø &
#4,7 STRD. H.D. COPPER N.

CONDUCTOR COMBINATION: #2,7 STRD. H.D. COPPER Ø (1560#) with
#4,7 STRD. H.D. COPPER N.(980#)

CASE 'B'

Outside Ø - N. Clearance At Ambient Temperature = 63.00 Inches;

	Feet	Inches	
R.S. = 250 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 7.05 Feet;			
Ø Sag @ 239°F = 6.9; Check;		13.80	Final Ø - N. Clearance
Ø Sag @ 248°F = 7.1; Check;		11.40	Final Ø - N. Clearance
R.S. = 250 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 7.85 Feet;			
Ø Sag @ 302°F = 7.8; Check;		12.60	Final Ø - N. Clearance
Ø Sag @ 311°F = 8.0; Check;		10.20	Final Ø - N. Clearance
R.S. = 250 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 8.05 Feet;			
Ø Sag @ 311°F = 8.0; Check;		12.60	Final Ø - N. Clearance
Ø Sag @ 320°F = 8.1; Check;		11.40	Final Ø - N. Clearance

TABLE 8D

SAG LIMITATION DATA SHEET- (cont'd)
#2,7 STRD. H.D. COPPER Ø &
#4,7 STRD. H.D. COPPER N.

CONDUCTOR COMBINATION: #2,7 STRD. H.D. COPPER Ø (1560#) with
#4,7 STRD. H.D. COPPER N.(980#)

CASE 'B'

Outside Ø - N. Clearance At Ambient Temperature = 43.80 Inches;

	Feet	Inches	
R.S. = 200 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 4.05 Feet;			
Ø Sag @ 158°F =	3.9; Check;	13.80	Final Ø - N. Clearance
Ø Sag @ 167°F =	4.1; Check;	11.40	Final Ø - N. Clearance
R.S. = 200 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 4.85 Feet;			
Ø Sag @ 212°F =	4.7; Check;	13.80	Final Ø - N. Clearance
Ø Sag @ 221°F =	4.9; Check;	11.40	Final Ø - N. Clearance
R.S. = 200 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 5.15 Feet;			
Ø Sag @ 239°F =	5.1; Check;	12.60	Final Ø - N. Clearance
Ø Sag @ 248°F =	5.2; Check;	11.40	Final Ø - N. Clearance

TABLE 8E

SAG LIMITATION DATA SHEET- (cont'd)
#2,7 STRD. H.D. COPPER Ø &
#4,7 STRD. H.D. COPPER N.

CONDUCTOR COMBINATION: #2,7 STRD. H.D. COPPER Ø (1560#) with
#4,7 STRD. H.D. COPPER N.(980#)

CASE 'B'

Outside Ø - N. Clearance At Ambient Temperature = 28.20 Inches;

	Feet	Inches	
R.S. = 150 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 2.15 Feet;			
Ø Sag @ 104°F = 2.1; Check;		12.60	Final Ø - N. Clearance
Ø Sag @ 113°F = 2.2; Check;		11.40	Final Ø - N. Clearance
R.S. = 150 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 2.65 Feet;			
Ø Sag @ 140°F = 2.6; Check;		12.60	Final Ø - N. Clearance
Ø Sag @ 149°F = 2.7; Check;		11.40	Final Ø - N. Clearance
R.S. = 150 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 2.95 Feet;			
Ø Sag @ 167°F = 2.9; Check;		12.60	Final Ø - N. Clearance
Ø Sag @ 176°F = 3.0; Check;		11.40	Final Ø - N. Clearance

TABLE 8F

SAG LIMITATION DATA SHEET- (cont'd)
#2,7 STRD. H.D. COPPER Ø &
#4,7 STRD. H.D. COPPER N.

CONDUCTOR COMBINATION: #2,7 STRD. H.D. COPPER Ø (1560#) with
#4,7 STRD. H.D. COPPER N.(980#)

CASE 'C'

Outside Ø - N. Clearance At Ambient Temperature = 71.00 Inches;

	Feet	Inches	
R.S. = 250 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 7.7167 Feet;			
Ø Sag @ 293°F = 7.7; Check;		12.20	Final Ø - N. Clearance
Ø Sag @ 302°F = 7.8; Check;		11.00	Final Ø - N. Clearance
R.S. = 250 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 8.5167 Feet;			
Ø Sag @ 356°F = 8.5; Check;		12.20	Final Ø - N. Clearance
Ø Sag @ - °F = - ; Check;			Final Ø - N. Clearance
R.S. = 250 Feet; use N. Sag @ 77°F;			
Look for Ø Sag = 8.7167 Feet;			
Ø Sag @ 356°F = 8.5; Check;		14.60	Final Ø - N. Clearance
Ø Sag @ - °F = ; Check;			Final Ø - N. Clearance

TABLE 8G

CONDUCTOR COMBINATION: #2,7 STRD. H.D. COPPER Ø (1560#) with
#4,7 STRD. H.D. COPPER N.(980#)

CASE 'C'

Outside Ø - N. Clearance At Ambient Temperature = 51.80 Inches;

	Feet	Inches	
R.S. = 200 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 4.7167 Feet;			
Ø Sag @ 212°F =	4.7; Check;	12.20	Final Ø - N. Clearance
Ø Sag @ 221°F =	4.9; Check;	9.80	Final Ø - N. Clearance
R.S. = 200 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 5.5167 Feet;			
Ø Sag @ 275°F =	5.5; Check;	12.20	Final Ø - N. Clearance
Ø Sag @ 284°F =	5.7; Check;	9.80	Final Ø - N. Clearance
R.S. = 200 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 5.8167 Feet;			
Ø Sag @ 293°F =	5.8; Check;	12.20	Final Ø - N. Clearance
Ø Sag @ 302°F =	5.9; Check;	11.00	Final Ø - N. Clearance

TABLE 8H

SAG LIMITATION DATA SHEET- (cont'd)
#2,7 STRD. H.D. COPPER Ø &
#4,7 STRD. H.D. COPPER N.

CONDUCTOR COMBINATION: #2,7 STRD. H.D. COPPER Ø (1560#) with
#4,7 STRD. H.D. COPPER N.(980#)

CASE 'C'

Outside Ø - N. Clearance At Ambient Temperature = 36.20 Inches;

	Feet	Inches	
R.S. = 150 Feet; use N. Sag @ 14°F;			
Look For Ø Sag = 2.8167 Feet;			
Ø Sag @ 158°F = 2.8; Check;		12.20	Final Ø - N. Clearance
Ø Sag @ 167°F = 2.9; Check;		11.00	Final Ø - N. Clearance
R.S. = 150 Feet; use N. Sag @ 60°F;			
Look For Ø Sag = 3.3167 Feet;			
Ø Sag @ 203°F = 3.3; Check;		12.20	Final Ø - N. Clearance
Ø Sag @ 212°F = 3.4; Check;		11.00	Final Ø - N. Clearance
R.S. = 150 Feet; use N. Sag @ 77°F;			
Look For Ø Sag = 3.6167 Feet;			
Ø Sag @ 230°F = 3.6; Check;		12.20	Final Ø - N. Clearance
Ø Sag @ 239°F = 3.7; Check;		11.00	Final Ø - N. Clearance

TABLE 8I

DESIGN PARAMETER SUMMARY SHEET - 336.4, 19 STRD. H.D. AAC

Sheet 1 of 2 — Loading Conditions: 1/2 Inch Ice & 8 Lbs./Sq. Ft. Wind — Date: 11/79

Wind Speed = 3 Knots for Columns 7-9 — SAO/TW-18

Column 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10
	Phase Conductor Temperature With Neutral Conductor Sag:					PP&L-PJM Program Calculations Phase Conductor Ampacity (Amperes)			
Phase & Neutral Conductor	@ 25°C Summer Ambient	@ 15°C N.E.S.C. Ambient	@ -10°C Winter Ambient	Span Length (Feet)	Framing Method (Case)	@ 25°C Summer Ambient	@ 15°C N.E.S.C. Ambient	@ -10°C Winter Ambient	Max. Design Tension
336.4 AAC Ø	167°F (75°C)	149°F (65°C)	95°F (35°C)	250	A	653	658	640	2000#
Step 7. & #4/0 ACSR N.	176°F (80°C)	Steps 7. & 8. 158°F (70°C)	95°F (35°C)	Step 7. 200	A	683	Step 9. 688	640	Step 7. 2000#
	140°F (60°C)	122°F (50°C)	68°F (20°C)	160	B	547	550	517	
	194°F (90°C)	167°F (75°C)	104°F (40°C)	160	C	738	717	674 Step 11.	

TABLE 9A

DESIGN PARAMETER SUMMARY SHEET - 336.4, 19 STRD. H.D. AAC (cont'd)

Phase & Neutral Conductor	@ 25°C Summer Ambient	@ 15°C N.E.S.C. Ambient	@ -10°C Winter Ambient	Span Length (Feet)	Framing Method (Case)	@ 25°C Summer Ambient	@ 15°C N.E.S.C. Ambient	@ -10°C Winter Ambient	Max. Design Tension
336.4 AAC Ø Step 6. &	212°F (100°C)	194°F (90°C)	149°F (65°C)	250	A	786	792	810	2000#
336.4 ACSR N.	212°F (100°C)	194°F (90°C)	140°F (60°C)	200	A	786	792	786	2000#
	167°F (75°C)	149°F (65°C)	104°F (40°C)	160	B	653	658	674	
	221°F (105°C)	203°F (95°C)	149°F (65°C)	160	C	809	815	810	
336.4 AAC Ø &	167°F (75°C)	149°F (65°C)	95°F (35°C)	250	A	653	658	640	2000#
336.4 AAC N.	185°F (85°C)	158°F (70°C)	95°F (35°C)	200	A	711	688	640	2000#
	149°F (65°C)	122°F (50°C)	60°F (15°C)	160	B	586	550	465	
	194°F (90°C)	176°F (80°C)	104°F (40°C)	160	C	738	743	674 Step 11.	

TABLE 9B

DESIGN PARAMETER SUMMARY SHEET - #2, 7 STRD. H.D. COPPER

Sheet 1 of 1 | Loading Conditions: 1/2 Inch Ice & 8 Lbs./Sq. Ft. Wind | Date: 11/79
Wind Speed = 3 Knots for Columns 7-9 | SAO/TW-18

Column 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10
	Phase Conductor Temperature With Neutral Conductor Sag:					PP&L-PJM Program Calculations — Phase Conductor Ampacity (Amperes)			
Phase & Neutral Conductor	@ 25°C Summer Ambient	@ 15°C N.E.S.C. Ambient	@ -10°C Winter Ambient	Span Length (Feet)	Framing Method (Case)	@ 25°C Summer Ambient	@ 15°C N.E.S.C. Ambient	@ -10°C Winter Ambient	Max. Design Tension
#2 Copper Ø & #4 Copper N.	347°F (175°C) / 212°F (100°C)	320°F (160°C) / 212°F (100°C)	266°F (130°C) / 212°F (100°C)	250	A	467 / 354	464 / 377	467 / 427	1560# 980#
	347°F (175°C) / 212°F (100°C)	320°F (160°C) / 212°F (100°C)	266°F (130°C) / 212°F (100°C)	250	C	467 / 354	464 / 377	467 / 427	
	Step 10.							Step 11B.	

TABLE 9C

SAMPLE OUTPUT OF CEØEA10 TYPERUN(NØLØSS)

Conductor Thermal Ratings - Daytime

Conductor	Rating	Wind Speed Knots	Step 8. Condr Max Temp Deg C	Conductor Current Amperes Ambient Temperature Degrees Celsius -20	-15	Step 9. -10	-5	0	5	10*	Step 9. 15	20+	Step 9. 25	30	35%
336.4-19 STRD. ALUMINUM															
	Normal	0.0	35	391	.	335	.	.	.	190	137	43	0	.	0
	Emerg	1.0	35	531	.	473	.	.	.	329	280	222	139	.	0
	Emerg	1.5	35	591	.	529	.	.	.	372	321	260	178	.	0
	Emerg	2.0	35	638	.	572	.	.	.	406	352	288	205	.	0
	Emerg	3.0	35	713	.	640	.	.	.	459	401	332	245	.	0
	Emerg	4.0	35	772	.	694	.	.	.	500	438	366	276	.	0
	Emerg	5.0	35	822	.	739	.	.	.	535	470	394	301	.	0
	Emerg	6.0	35	866	.	778	.	.	.	565	497	419	322	.	0
	Emerg	7.0	35	905	.	814	.	.	.	592	522	440	340	.	0
	Emerg	8.0	35	940	.	846	.	.	.	616	544	460	357	.	0
	Emerg	9.0	35	973	.	876	.	.	.	638	564	478	373	.	0
	Emerg	10.0	35	1003	.	903	.	.	.	659	583	494	387	.	0

*PJM Winter Emergency Rating Occurs at this Temperature at 1 Knot Wind
+PJM Ratings for Winter Normal at 0 Knots Wind and Summer Emergency at 1 Knot Wind Occur at this Temperature
%PJM Summer Normal Rating Occurs at this Temperature at 0 Knots Wind
Calculations Based on Method in PJM Report November 1972.

Output condensed and edited.

TABLE 10A

SAMPLE OUTPUT OF CEØEA10 TYPERUN(NØLØSS)

Conductor Thermal Ratings - Daytime

Conductor	Rating	Wind Speed Knots	Condr Max Temp Deg C	-20	-15	-10	-5	0	5	10*	15	20+	25	30	35%
				Conductor Current Amperes Ambient Temperature Degrees Celsius											
336.4-19 STRD. ALUMINUM															
	Normal	0.0	85	595	.	561	.	.	.	487	468	448	427	.	383
	Emerg	1.0	85	723	.	689	.	.	.	614	594	572	550	.	502
	Emerg	1.5	85	794	.	756	.	.	.	673	651	627	603	.	550
	Emerg	2.0	85	850	.	809	.	.	.	720	696	671	645	.	589
	Emerg	3.0	85	939	.	894	.	.	.	795	768	741	711	.	649
	Emerg	4.0	85	1011	.	962	.	.	.	855	826	796	765	.	698
	Emerg	5.0	85	1071	.	1019	.	.	.	905	875	843	810	.	739
	Emerg	6.0	85	1124	.	1069	.	.	.	950	917	884	849	.	775
	Emerg	7.0	85	1171	.	1114	.	.	.	990	956	921	885	.	807
	Emerg	8.0	85	1215	.	1155	.	.	.	1026	991	954	917	.	836
	Emerg	9.0	85	1255	.	1193	.	.	.	1059	1023	985	947	.	863
	Emerg	10.0	85	1292	.	1228	.	.	.	1090	1053	1014	974	.	889

*PJM Winter Emergency Rating Occurs at this Temperature at 1 Knot Wind
+PJM Ratings for Winter Normal at 0 Knots Wind and Summer Emergency at 1 Knot Wind Occur at this Temperature
%PJM Summer Normal Rating Occurs at this Temperature at 0 Knots Wind
Calculations Based on Method in PJM Report November 1972.

Output condensed and edited.

TABLE 10B

SAMPLE OUTPUT OF CEØEA10 TYPERUN(NØLØSS)

Conductor Thermal Ratings - Daytime

Conductor	Rating	Wind Speed Knots	Condr Max Temp Deg C	-20	-15	-10	-5	0	5	10*	15	20+	25	30	35%
				Conductor Current Amperes Ambient Temperature Degrees Celsius											
2 AWG 7 STRD. COPPER															
	Normal	0.0	100	267	.	254	.	.	.	227	220	212	205	.	189
	Emerg	1.0	100	346	.	332	.	.	.	302	294	285	277	.	258
	Emerg	1.5	100	379	.	364	.	.	.	330	321	312	302	.	282
	Emerg	2.0	100	405	.	388	.	.	.	352	343	333	322	.	301
	Emerg	3.0	100	446	.	427	.	.	.	387	377	366	354	.	330
	Emerg	4.0	100	478	.	458	.	.	.	415	404	392	380	.	354
	Emerg	5.0	100	505	.	484	.	.	.	439	426	414	401	.	373
	Emerg	6.0	100	529	.	507	.	.	.	459	446	433	419	.	391
	Emerg	7.0	100	551	.	527	.	.	.	477	464	450	436	.	406
	Emerg	8.0	100	570	.	546	.	.	.	494	480	466	451	.	420
	Emerg	9.0	100	588	.	563	.	.	.	509	495	480	465	.	433
	Emerg	10.0	100	604	.	579	.	.	.	523	509	494	478	.	445

*PJM Winter Emergency Rating Occurs at this Temperature at 1 Knot Wind
+PJM Ratings for Winter Normal at 0 Knots Wind and Summer Emergency at 1 Knot Wind Occur at this Temperature
%PJM Summer Normal Rating Occurs at this Temperature at 0 Knots Wind
Calculations Based on Method in PJM Report November 1972

Output condensed and edited.

TABLE 10C

SAMPLE OUTPUT OF CEØEA10

PJM Rating Method For Bare Overhead Conductors

2 AWG 7 STRD. COPPER

Diameter	Aluminum Factor	Resistance at 25 Deg. C	Conductor Weight	Core Weight
0.292	0.0	0.166700	0.205	0.0

Step 10. Design Temperature 100. Degrees C

Summer Normal Rating is 164. AMPS Winter Normal Rating is 194. AMPS
Summer Emergency Rating is 285. AMPS Winter Emergency Rating is 302. AMPS

Five Minute Rating is 305. AMPS
Fifteen Minute Rating is 302. AMPS

Anticipated Loading History

.7 Normal		Normal		Emergency	
35588.	Summer Dayhours	88706.	Summer Dayhours	263.	Summer Dayhours
91706.	Summer Nighthours	13688.	Summer Nighthours	0.	Summer Nighthours
11862.	Winter Dayhours	29569.	Winter Dayhours	87.	Winter Dayhours
30569.	Winter Nighthours	4562.	Winter Nighthours	0.	Winter Nighthours

Overall Loss of Strength is 10.00 Percent

Temperature - Deg. C	Duration - Hours
5	17274.5
10	39274.2
15	45200.0
20	44770.5
25	45202.8
30	48400.2
35	32524.4

TABLE 11A

SAMPLE OUTPUT OF CEØEA10 (cont'd)

Temperature - Deg. C	Duration - Hours
40	22781.1
45	8308.5
50	1537.0
55	497.0
60	207.1
65	165.8
70	129.7
75	173.3
80	68.2
85	37.0
90	12.5
95	2.5
100	1.1
105	1.0
110	0.5
115	0.0
120	0.1
.	.
.	.
.	.
145	0.1
150	0.2
155	0.5
160	0.6
165	0.2
.	.
.	.
180	0.0

Output condensed and edited.

TABLE 11B

SAMPLE OUTPUT OF CTDP PROGRAM

Conductor Temperature Values in Degrees Celsius--Daytime

Wind Speed = 3.0 Knots

Conductor Description					Condr Max Current - Amps			Ambient Temperature in Degrees Celsius					
-15	-10?	-5	0	5	10*	15	20+	25&	30	35%	40	45	50
Step 12A.					Step 11.					Step 12A.			
336.4-19 STRD. AAC					640								
29.51	35.02	40.52	.	.	.	62.22	67.58	72.91	78.21	83.49	88.75	93.98	99.17
Step 13.													
4/0-6/1 STRD. ACSR					519								
37.80	45.04	52.21	.	.	.	80.22	87.06	93.82	100.52	107.15	113.69	120.18	126.60
1/0-6/1 STRD. ACSR					341								
38.33	45.00	51.64	.	.	.	77.69	84.10	90.46	96.76	103.03	109.24	115.39	121.51
2 AWG 7 STRD. COPPER					354					Step 12B.			
53.07	59.00	64.94	.	.	.	88.35	94.12	99.86	105.57	111.27	116.91	122.53	128.12

*PJM Winter Emergency Rating Occurs at this Temperature at 1 Knot Wind
+PJM Ratings for Winter Normal at 0 Knots Wind and Summer Emergency at 1 Knot Wind Occur at this Temperature
%PJM Summer Normal Rating Occurs at this Temperature at 0 Knots Wind
?Distribution Winter Normal and Emergency Rating Occurs at this Temperature
&Distribution Summer Normal and Emergency Rating Occurs at this Temperature
Day and Night Equations Used in Calculation of --QS--and --QR-- Values
Calculations Based on Method in PJM Report November 1972 and Ampacity Program called PJMRRR.PLI
Conductor Temperature Determined by Iterative Method; Program changes by S.A.Olinick, Sept. 1978

Output condensed and edited.

TABLE 12

DESIGN PARAMETER SUMMARY SHEET

Sheet ___ of ___ Loading Conditions: 1/2 Inch Ice & 8 Lbs./Sq. Ft. Wind Date:

Wind Speed = ___ Knots for Columns 7-9 SAO/TW-18

Column 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10
	Phase Conductor Temperature With Neutral Conductor Sag:					PP&L-PJM Program Calculations Phase Conductor Ampacity (Amperes)			
Phase & Neutral Conductor	@ 25°C Summer Ambient	@ 15°C N.E.S.C. Ambient	@ -10°C Winter Ambient	Span Length (Feet)	Framing Method (Case)	@ 25°C Summer Ambient	@ 15°C N.E.S.C. Ambient	@ -10°C Winter Ambient	Max. Design Tension

TABLE 13

CHAPTER 4

DISTRIBUTION CONDUCTOR AMPACITY RATING TABLE

Table 14, pages 126 through 128, lists the distribution conductor thermal ampacity ratings produced by the method described in Chapter 3. The first column in the table gives the conductor description. The table does not include compact round concentric-lay-stranded conductors since all bare, primary conductors used by the test utility were concentric-lay-stranded.

The explanation of other column headings is as follows:

SLT --- sag limitation temperature; the maximum phase conductor temperature permitted, with the neutral conductor at one of the three ambient temperatures, while maintaining a minimum 30.48 centimeters (12 inches) phase-to-neutral conductor clearance. If the SLT shown and used to calculate the initial ampacity rating did not maintain a conductor temperature less than the L-O-ST at 35°C, the reduced temperature used to recalculate the ampacity is given in parentheses.

L-O-ST --- loss-of-strength temperature; the maximum phase conductor temperature permitted such that 10 percent L-O-S would not be exceeded.

MCOT --- maximum conductor operating temperature; the highest temperature attained by the phase conductor when carrying the selected maximum amperes at the highest ambient temperature predicted on the test utility system.

Ampacity Rating --- the maximum conductor ampacity permitted without violating the distribution criteria and assumptions given in Chapter 2; determined by the SLT, L-O-ST, MCOT, and a 3 knot wind speed.

Table 16, pages 130 through 146, lists the phase and neutral conductor combinations which exist on the test utility distribution system. These combinations formed the basis on which conductor ampacity ratings were determined, using the distribution ampacity rating method (Chapter 3).

Maximum design tension in pounds is shown in parentheses after the conductor size. All sags were determined at a 1/2 inch, 8 pounds per square feet maximum ice and wind loading condition. Ruling spans with framing cases examined for each phase and neutral combination are listed under the column heading "Case & Ruling Span". The sag limitation data sheets (SLDS) on which the actual combination have been recorded[60] are given under the column "Page". Other column headings are self-explanatory.

When using Table 16, pages 130 through 146, the following points should be remembered:

- phase and neutral conductors used in present and past construction are paired and listed,

- strand data are omitted under the column "Neutral" if identical to the particular phase conductor stranding,

- Table 15, page 129 illustrates the phase and neutral conductor material combinations permitted on the test utility system, and

- copperweld combinations are based on limited historical data.

Example:

To use Table 16A, page 130, refer to the second phase conductor listed for stranded copper: #4, 7 strand. This phase conductor had sag values calculated at a maximum design tension of 980 pounds, and was paired with a #4, 7 strand and #6, 7 strand copper neutral. Each neutral had sag values calculated at a maximum design tension of 980 and 620 pounds, respectively. Ruling spans for both phase and neutral combinations were selected at 250, 200, and 150 feet for all three framing cases, A, B, and C (Chapter 2, pages 53 and 54). The sag limitations were recorded on pages 2.0 and 3.0 of the SLDS reference book[60].

DISTRIBUTION CONDUCTOR AMPACITY RATINGS

Bare, H.D., Stranded Copper	SLT (°C)	L-O-ST (°C)	MCOT (°C)	Ampacity Rating (Amperes)
#6, 7 strd.	85 (40)	95	91	172
#4, 7 strd.	55 (40)	95	91	229
#3, 7 strd.	45 (40)	95	91	265
#2, 7 strd.	40	100	91	306
#2, 3 strd.	40	100	90	315
#1, 7 strd.	40	100	90	354
#1/0, 7 strd.	40	100	90	409
#2/0, 7 strd.	45	105	96	495
#3/0, 7 strd.	50	105	101	596
#4/0, 7 strd.	60 (50)	105	100	689
Bare, H.D., Solid Copper				
#8	100 (30)	85*	80	114
#6	85 (30)	85*	80	152
#4	55 (35)	90	85	214
#3	40	95	91	259
#2	40	95	91	300
#1	40	100	91	346
#1/0	40	100	90	400

*Extrapolated value and reference 22.

TABLE 14A

DISTRIBUTION CONDUCTOR AMPACITY RATINGS (cont'd)

	SLT (°C)	L-O-ST (°C)	MCOT (°C)	Ampacity Rating (Amperes)
Bare, H.D., Solid Copper (cont'd)				
#2/0	45	105	96	484
#3/0	50	105	101	582
#4/0	60 (50)	105	101	673
Bare, H.D., Stranded Aluminum (AAC)				
#4/0, 7 strd.	29	115	78	444
336.4, 19 strd.	35	120	84	640
Bare, ACSR				
#4, 6/1 strd.	140 (110)	180	175	256
#2, 6/1 strd.	55	180	114	274
#1/0, 6/1 strd.	45	180	103	341
#2/0, 6/1 strd.	29	180	84	341
#3/0, 6/1 strd.	40	180	100	436
#4/0, 6/1 strd.	45	180	108	519
336.4, 26/7 strd.	65	180	117	835
Covered, Primary				
#1/0, 6/1 ACSR	35	90**	90****	280
#4/0, 6/1 ACSR	60 (30)	90**	88****	407

**L-O-ST determined by maximum permitted conductor covering temperature.
****Estimated value.

TABLE 14B

DISTRIBUTION CONDUCTOR AMPACITY RATINGS (cont'd)

	SLT (°C)	L-O-ST (°C)	MCOT (°C)	Ampacity Rating (Amperes)
Covered, Primary (cont'd)				
336.4, 19 strd. AAC	50 (40)	90**	89****	594
556.5, 19 strd. AAC	60 (40)	90**	87****	804
Bare, Copperweld (CW)				
#6, 30%	80 (55)	125***	122	99
#4, 30%	75 (55)	125***	121	132
Bare, H.D., 6201-T81 Aluminum (AAAC)				
#2, 7 strd.	35	135	84	237
#1/0, 7 strd.	35	135	84	317
#4/0, 7 strd.	25	135	72	429
394.5, 19 strd.	35	140	83	658

**L-O-ST determined by maximum permitted conductor covering temperature.
***L-O-ST determined by manufacturer's recommendations.
****Estimated value.

TABLE 14C

CONDUCTOR MATERIAL COMBINATIONS

Neutral Conductor	Phase Conductor: CU	ACSR	AAC	AAAC (6201-T81)
CU	X			
ACSR		X	X	X
AAC			X	
AAAC (6201-T81)				X

TABLE 15

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS

Bare, H.D., Stranded Copper (CU)

Phase	Neutral	Case & Ruling Span	Page
#6, 7 strd. (620#)	#6 (620#)	A250,A200,A150	1.0
		B250,B200,B150	
		C250,C200,C150	
#4, 7 strd. (980#)	#4 (980#)	A250,A200,A150	2.0
		B250,B200,B150	
		C250,C200,C150	
	#6 (620#)	A250,A200,A150	3.0
		B250,B200,B150	
		C250,C200,C150	
#3, 7 strd. (1240#)	#3 (1240#)	A250,A200,A150	4.0
		B250,B200,B150	
		C250,C200,C150	
	#4 (980#)	A250,A200,A150	5.0
		B250,B200,B150	
		C250,C200,C150	
	#6 (620#)	A250,A200,A150	6.0
		B250,B200,B150	
		C250,C200,C150	

TABLE 16A

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, H.D., Stranded Copper (CU) - cont'd

Phase	Neutral	Case & Ruling Span	Page
#2, 7 strd. (1560#)	#2 (1560#)	A250,A200	7.0
		C250,C200	
	#3 (1240#)	A250,A200,A150	8.0
		B250,B200,B150	
		C250,C200,C150	
	#4 (980#)	A250,A200,A150	9.0 & 12.0A
		B250,B200,B150	
		C250,C200,C150	
#2, 3 strd. (1560#)	#2 (1560#)	A250,A200	73.0
		B250,B200	
		C250,C200	
	#3 (1180#)	A250,A200,A150	74.0
		B250,B200,B150	
		C250,C200,C150	
	#4 (1125#)	A250,A200,A150	75.0
		B250,B200,B150	
		C250,C200,C150	
#1, 7 strd. (1970#)	#1 (1970#)	A250,A200	10.0
		C250,C200	

TABLE 16B

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, H.D., Stranded Copper (CU) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#2 (1560#)	A250,A200	11.0
		C250,C200	
	#3 (1240#)	A250,A200,A150	12.0
		B250,B200,B150	
		C250,C200,C150	
#1/0, 7 strd. (2000#)	#1/0 (2000#)	A250,A200	13.0
		C250,C200	
	#1 (1970#)	A250,A200	14.0
		C250,C200	
	#2 (1560#)	A250,A200	15.0
		C250,C200	
#2/0, 7 strd. (2000#)	#2/0 (2000#)	A250,A200	16.0
		C250,C200	
	#1/0 (2000#)	A250,A200	17.0
		C250,C200	
	#2 (1560#)	A250,A200	11.0A
		C250,C200	

TABLE 16C

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, H.D., Stranded Copper (CU) - cont'd

Phase	Neutral	Case & Ruling Span	Page
#3/0, 7 strd. (2000#)	#3/0 (2000#)	A250,A200	18.0
		C250,C200	
	#2/0 (2000#)	A250,A200	19.0
		C250,C200	
	#1/0 (2000#)	A250,A200	20.0
		C250,C200	
#4/0, 7 strd. (2000#)	#4/0 (2000#)	A250,A200	21.0
		C250,C200	
	#3/0 (2000#)	A250,A200	22.0
		C250,C200	
	#2/0 (2000#)	A250,A200	10.0A
		C250,C200	

Bare, H.D., Solid Copper (CU)

Phase	Neutral	Case & Ruling Span	Page
#8 (495#)	#8 (495#)	A225,A200,A150	79.0
		B225,B200,B150	
		C225,C200,C150	
#6 (620#)	#6 (620#)	A250,A200,A150	80.0
		B250,B200,B150	
		C250,C200,C150	

TABLE 16D

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, H.D., Solid Copper (CU) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#8 (495#)	A225,A200,A150	81.0
		B225,B200,B150	
		C225,C200,C150	
#4 (980#)	#4 (980#)	A250,A200,A150	82.0
		B250,B200,B150	
		C250,C200,C150	
	#6 (620#)	A250,A200,A150	83.0
		B250,B200,B150	
		C250,C200,C150	
	#8 (495#)	A225,A200,A150	84.0
		B225,B200,B150	
		C225,C200,C150	
#3 (1463#)	#3 (1463#)	A250,A200,A150	85.0
		B250,B200,B150	
		C250,C200,C150	
	#4 (980#)	A250,A200,A150	86.0
		B250,B200,B150	
		C250,C200,C150	

TABLE 16E

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, H.D., Solid Copper (CU) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#6 (620#)	A250,A200,A150	87.0
		B250,B200,B150	
		C250,C200,C150	
#2 (1560#)	#2 (1560#)	A250,A200,A150	88.0
		B250,B200,B150	
		C250,C200,C150	
#1 (1970#)	#1 (1970#)	A250,A200,A150	89.0
		B250,B200,B150	
		C250,C200,C150	
	#2 (1560#)	A250,A200,A150	90.0
		B250,B200,B150	
		C250,C200,C150	
#1/0 (2000#)	#1/0 (2000#)	A250,A200,A150	91.0
		B250,B200,B150	
		C250,C200,C150	
	#1 (1970#)	A250,A200,A150	92.0
		B250,B200,B150	
		C250,C200,C150	

TABLE 16F

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, H.D., Solid Copper (CU) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#2 (1560#)	A250,A200,A150	93.0
		B250,B200,B150	
		C250,C200,C150	
#2/0 (2000#)	#2/0 (2000#)	A250,A200,A150	94.0
		B250,B200,B150	
		C250,C200,C150	
	#1/0 (2000#)	A250,A200,A150	95.0
		B250,B200,B150	
		C250,C200,C150	
	#1 (1970#)	A250,A200,A150	96.0
		B250,B200,B150	
		C250,C200,C150	
#3/0 (2000#)	#3/0 (2000#)	A250,A200,A150	97.0
		B250,B200,B150	
		C250,C200,C150	
	#2/0 (2000#)	A250,A200,A150	98.0
		B250,B200,B150	
		C250,C200,C150	

TABLE 16G

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, H.D., Solid Copper (CU) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#1/0 (2000#)	A250,A200,A150	99.0
		B250,B200,B150	
		C250,C200,C150	
#4/0 (2000#)	#4/0 (2000#)	A250,A200,A150	100.0
		B250,B200,B150	
		C250,C200,C150	
	#3/0 (2000#)	A250,A200,A150	101.0
		B250,B200,B150	
		C250,C200,C150	
	#2/0 (2000#)	A250,A200,A150	102.0
		B250,B200,B150	
		C250,C200,C150	

Bare, H.D., Stranded Aluminum (AAC)

#4/0, 7 strd.	#4/0 ACSR (2000#)	A250,A200	44.0
(1795#)		B150	
		C150	
	#3/0 ACSR (2000#)	A250,A200,A150	45.0
		B150	
		C150	

TABLE 16H

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, H.D., Stranded Aluminum (AAC) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#2/0 ACSR (2000#)	A250,A200,A150	46.0
		B150	
		C150	
	#1/0 ACSR (2000#)	A250,A200	47.0
		B150	
		C150	
336.4, 19 strd. (2000#)	336.4 AAC (2000#)	A250,A200	3.0A
		B160	
		C160	
	336.4 ACSR (2000#)	A250,A200	2.0A
		B160	
		C160	
	#4/0 ACSR (2000#)	A250,A200	1.0A
		B160	
		C160	

Bare, ACSR

Phase	Neutral	Case & Ruling Span	Page
#4, 6/1 strd. (700#)	#4 (700#)	A250,A200	49.0
#2, 6/1 strd. (1000#)	#2 (1000#)	A200,A160	9.0A

TABLE 16I

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, ACSR - cont'd

Phase	Neutral	Case & Ruling Span	Page
#2, 6/1 strd. (1440#)	#2 (1440#)	A250,A200	8.0A
#1/0, 6/1 strd.	#1/0 (2000#)	A250,A200	7.0A
(2000#)		B250,B200	
		C250,C200	
	#2 (1584#)	A250,A200	6.0A
		B250,B200	
		C250,C200	
#2/0, 6/1 strd.	#2/0 (2000#)	A250,A200	51.0
(2000#)		B250,B200	
		C250,C200	
	#1/0 (1250#)	A250,A200	52.0
		B250,B200	
		C250,C200	
	#2 (1584#)	A250,A200	53.0
		B250,B200	
		C250,C200	
#3/0, 6/1 strd.	#3/0 (2000#)	A250,A200	54.0
(2000#)		B250,B200	
		C250,C200	

TABLE 16J

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, ACSR - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#2/0 (2000#)	A250,A200	55.0
		B250,B200	
		C250,C200	
	#1/0 (1250#)	A250,A200	56.0
		B250,B200	
		C250,C200	
#4/0, 6/1 strd.	#4/0 (2000#)	A250,A200	5.0A
(2000#)		B190	
		C190	
	#3/0 (2000#)	A250,A200	57.0
		B190	
		C190	
	#2/0 (2000#)	A250,A200	58.0
		B190	
		C190	
	#1/0 (2000#)	A250,A200	4.0A
		B190	
		C190	

TABLE 16K

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, ACSR - cont'd

Phase	Neutral	Case & Ruling Span	Page
336.4, 26/7 strd. (2000#)	336.4 (2000#)	A250,A200	59.0
		B180	
		C180	
	4/0 (2000#)	A250,A200	60.0
		B180	
		C180	

Covered, Primary, Single Conductor (AAC & ACSR)

Phase	Neutral	Case & Ruling Span	Page
#1/0, 6/1 ACSR (2000#)	#1/0 ACSR, bare (2000#)	A225,A180	61.0
		C225,C180	
	#2 ACSR, bare (1584#)	A225,A180	62.0
		C225,C180	
#4/0, 6/1 ACSR (2000#)	#4/0 ACSR, bare (2000#)	A225,A180	63.0
		B225,B180	
		C225,C180	
	#1/0 ACSR, bare (2000#)	A225,A180	64.0
		B225,B180	
		C225,C180	

TABLE 16L

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Covered, Primary, Single Conductor (AAC & ACSR) - cont'd

Phase	Neutral	Case & Ruling Span	Page
336.4, 19 strd. AAC	336.4 AAC, bare	A225,A180	65.0
(2000#)	(2000#)	B225,B180	
		C225,C180	
	336.4 ACSR, bare	A225,A180	67.0
	(2000#)	B225,B180	
		C225,C180	
	#4/0 ACSR, bare	A225,A180	68.0
	(2000#)	B225,B180	
		C225,C180	
556.5, 19 strd. AAC	556.5 AAC, bare	A225,A180	69.0
(2000#)	(2000#)	B225,B180	
		C225,C180	
	336.4 AAC, bare	A225,A180	70.0
	(2000#)	B225,B180	
		C225,C180	
	556.5 ACSR, bare	A225,A180	71.0
	(2000#)	B225,B180	
		C225,C180	

TABLE 16M

Covered, Primary, Single Conductor (AAC & ACSR) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	336.4 ACSR, bare	A225,A180	72.0
	(2000#)	B225,B180	
		C225,C180	

Bare, Copperweld (CW)

Phase	Neutral	Case & Ruling Span	Page
#6, 30% (1475#)	#6 (1475#)	A250,A200	76.0
		B250,B200	
		C250,C200	
#4, 30% (2161#)	#4 (2161#)	A250,A200	77.0
		B250,B200	
		C250,C200	
	#6 (1475#)	A250,A200	78.0
		B250,B200	
		C250,C200	

Bare, All Aluminum Alloy (6201-T81) Conductor (AAAC)

Phase	Neutral	Case & Ruling Span	Page
#2, 7 strd.	#2 AAAC (1440#)	A250,A200	103.0
(1440#)		B175	
		C175	

TABLE 16N

Bare, All Aluminum Alloy (6201-T81) Conductor (AAAC) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#2 ACSR (1440#)	A250,A200	104.0
		B175	
		C175	
#1/0, 7 strd.	#1/0 AAAC (2000#)	A250,A200	105.0
(2000#)		B250,B200	
		C250,C200	
	#1/0 ACSR (2000#)	A250,A200	106.0
		B250,B200	
		C250,C200	
	#2 AAAC (1440#)	A250,A200	107.0
		B250,B200	
		C250,C200	
	#2 ACSR (1440#)	A250,A200	108.0
		B250,B200	
		C250,C200	
#4/0, 7 strd.	#4/0 AAAC (2000#)	A250,A200	109.0
(2000#)		B190	
		C190	

TABLE 16Ø

PHASE AND NEUTRAL CONDUCTOR COMBINATIONS (cont'd)

Bare, All Aluminum Alloy (6201-T81) Conductor (AAAC) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#4/0 ACSR (2000#)	A250,A200	110.0
		B190	
		C190	
	#1/0 AAAC (2000#)	A250,A200	111.0
		B190	
		C190	
	#1/0 ACSR (2000#)	A250,A200	112.0
		B190	
		C190	
394.5, 19 strd. (2000#)	394.5 AAAC (2000#)	A250,A200	113.0
		B180	
		C180	
	#4/0 AAAC (2000#)	A250,A200	114.0
		B180	
		C180	
	336.4 ACSR (2000#)	A250,A200	115.0
		B180	
		C180	

TABLE 16P

Bare, All Aluminum Alloy (6201-T81) Conductor (AAAC) - cont'd

Phase	Neutral	Case & Ruling Span	Page
	#4/0 ACSR (2000#)	A250,A200	116.0
		B180	
		C180	

TABLE 16Q

CHAPTER 5

LIMITATIONS OF THE DISTRIBUTION AMPACITY RATING METHOD

The distribution ampacity (Dist-Amp) rating method had certain limitations, and these are discussed in this chapter. Recommendations and conclusions pertinent to these limitations will be presented in Chapter 7.

The numerous steps in the Dist-Amp rating method make it a laborious and time-consuming process, even though the sag values, ampacity values, and maximum conductor operating temperature (MCOT) for each conductor size were calculated by computer programs. Several steps in the method dictated that numerical values be read from computer output sheets, and this data transferred to other calculation sheets (Steps 3 through 12, Chapter 3) to produce all the necessary Sag Limitation Data Sheet (SLDS) and Design Parameter Summary Sheet (DPSS) records.

As a result of the many manual operations involved, the method could be used to examine only a limited number of design variations. For example, the span lengths used for each phase and neutral combination were usually the maximum allowable span lengths and 80 percent of those values for some pole framing cases. To select additional span lengths for study would have made the sag limitation calculations impossible to complete within a reasonable time frame. The sensitivity analysis, Chapter 6, then became the only way to selectively examine the effects on the ampacity ratings of varying the span length and other input parameters. Also, a higher probability of calculation error was introduced into the method's final results because of the reading and transferring of data to the various calculation sheets.

The Dist-Amp rating method was designed exclusively for rating distribution conductors --- specifically, those conductors used on distribution systems where the neutral conductor would be framed relatively close and underneath the phase conductors. Transmission line designs differ* entirely with respect to distribution line framing, and few substation designs incorporate any type of long conductor spans under tension. Therefore, this method could not be applied to determine ampacity ratings of conductors used in these designs.

*usually no neutral conductor

The ampacity ratings calculated by the Dist-Amp rating method were based partially on past operating experience, and historical weather and loading data (see assumptions, Chapter 2). The method can not use continuously monitored weather data and conductor temperature, which directly affect the ampacity rating calculations. Recently, there has been consideration given in the industry to the use of a "real-time" system to calculate conductor ampacity ratings[37,42]. The main result of this type of system would be substantially higher ampacity ratings, with estimates of a 20-70 percent, and possibly even 300 percent, increase over the conventional, fixed parameter rating methods.

There were no provisions made in the Dist-Amp rating method to determine, concurrently, economical line loadings compared to maximum ampacity ratings. This method was designed strictly as a thermal rating method and the results must be used with that understanding. Some technical papers have suggested that maximum conductor temperatures should not exceed a 25°C rise over ambient temperature[43-45], for economical operation. Upon examining the MCOT values in Chapter 4, it can be seen that there were no provisions in this Dist-Amp rating method to account for this type of constraint.

Chapter 2 explained how the method accounted for the effect of sag limitations on the final conductor ampacity ratings. This final ampacity rating should be examined from not only an economical loading standpoint (I^2R losses), but also against pole height and phase-to-neutral framing distances. There should be an optimum MCOT, pole height and framing distance with respect to a chosen ampacity rating for each conductor. This should reduce the effect of sag limitations on ampacity ratings. The method cannot examine this area.

The ampacity ratings produced by the Dist-Amp rating method were quite dependent on the selected phase and neutral combination used by the test utility. It may be possible that certain phase and neutral combinations would result in an increased ampacity rating of a certain size phase conductor. The method does not selectively rank these combinations.

Many of the conductor sag and ambient temperature values used in the method's various calculations were "digitalized" and were not produced as continuous values. The sag and tension program values were given at 5°C (9°F) intervals, except for some temperatures less than 35°C (95°F), and the final sags used in the calculations were not interpolated between selected temperatures (Table 17, pages 151 through

SAG & TENSION PROGRAM SAMPLE OUTPUT

Conductor Sag and Tension Table

394.5 KCMIL AAAC
Rated Strength -- 13300. Lbs. 35% Rated Strength -- 4655. Lbs. 25% Rated Strength -- 3325. Lbs.
Bare Weight -- 0.3703 Lbs./Ft.
Area -- 0.310 Sq. In.
Maximum Loading Condition: 0.50 In. Ice, 8. Lbs. Wind
Governing Condition(s): 250 Ft. Span -- 0. Deg. F., 0.50 Ice 8 Wind
180 Ft. Span -- 0. Deg. F., 0.50 Ice 8 Wind

Span Ft.		Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.
		0.50 Ice 8 Wind 0. Deg. F.		Bare No Wind 0. Deg. F.		Bare No Wind -20. Deg. F.		Bare No Wind 20. Deg. F.		Bare No Wind 32. Deg. F.		Bare No Wind 40. Deg. F.	
250.	Initial	2000.	6.3	599.	4.8	676.	4.3	542.	5.4	513.	5.7	497.	5.8
	Final	2000.	6.3	555.	5.2	620.	4.7	506.	5.7	482.	6.0	467.	6.2
180.	Initial	2000.	3.3	805.	1.9	1065.	1.4	639.	2.4	570.	2.6	533.	2.8
	Final	2000.	3.3	687.	2.2	915.	1.6	556.	2.7	503.	3.0	474.	3.2
		0.50 Ice 8 Wind 0. Deg. F.		Bare No Wind 60. Deg. F.		Bare No Wind 80. Deg. F.		Bare No Wind 100. Deg. F.		Bare No Wind 120. Deg. F.		Bare No Wind 212. Deg. F.	
250.	Initial	2000.	6.3	461.	6.3	431.	6.7	407.	7.1	386.	7.5	319.	9.1
	Final	2000.	6.3	436.	6.7	410.	7.1	389.	7.5	370.	7.9	309.	9.4
180.	Initial	2000.	3.3	462.	3.3	411.	3.7	373.	4.0	344.	4.4	263.	5.7
	Final	2000.	3.3	418.	3.6	378.	4.0	347.	4.3	322.	4.7	252.	6.0

TABLE 17A

SAG & TENSION PROGRAM SAMPLE OUTPUT (cont'd)

Span Ft.		Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.
		0.50 Ice 8 Wind 0. Deg. F.		Bare 4 Lb. Wind 0. Deg. F.		Bare 6 Lb. Wind 60. Deg. F.		Bare 9 Lb. Wind 60. Deg. F.		Bare 25 Lb. Wind 60. Deg. F.		0.5 Ice No Wind 32. Deg. F.	
250.	Initial	2000.	6.3	697.	5.0	627.	6.5	778.	6.6	1653.	7.3	1363.	6.5
	Final	2000.	6.3	652.	5.3	599.	6.8	750.	6.9	1641.	7.4	1340.	6.6
180.	Initial	2000.	3.3	892.	2.0	616.	3.4	753.	3.5	1516.	4.1	1338.	3.4
	Final	2000.	3.3	784.	2.3	569.	3.7	706.	3.8	1492.	4.2	1297.	3.5
		0.50 Ice 8 Wind 0. Deg. F.		0.50 Ice 4 Wind 0. Deg. F.		NESC Heavy 0. Deg. F.		Opt Ice 8 Wind 32. Deg. F.		0.50 Ice 2 Wind 32. Deg. F.		NESC Heavy 32. Deg. F.	
250.	Initial	2000.	6.3	1656.	6.0	1958.	6.3	890.	6.0	1400.	6.5	1791.	6.9
	Final	2000.	6.3	1639.	6.1	1956.	6.3	857.	6.3	1377.	6.6	1782.	6.9
180.	Initial	2000.	3.3	1713.	3.0	1965.	3.2	920.	3.0	1369.	3.5	1704.	3.7
	Final	2000.	3.3	1688.	3.0	1962.	3.2	859.	3.2	1330.	3.6	1686.	3.8

TABLE 17B

SAG & TENSION PROGRAM SAMPLE OUTPUT (cont'd)

Span Ft.		Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.	Tension Lbs.	Sag Ft.
		0.50 Ice 8 Wind 0. Deg. F.		Bare No Wind 104. Deg. F.		Bare No Wind 113. Deg. F.		Bare No Wind 122. Deg. F.		Bare No Wind 131. Deg. F.		Bare No Wind 140. Deg. F.	
250.	Initial	2000.	6.3	402.	7.2	393.	7.4	384.	7.6	376.	7.7	368.	7.9
	Final	2000.	6.3	385.	7.6	376.	7.7	368.	7.9	361.	8.1	354.	8.2
180.	Initial	2000.	3.3	367.	4.1	353.	4.3	341.	4.4	330.	4.6	320.	4.7
	Final	2000.	3.3	341.	4.4	330.	4.6	320.	4.7	311.	4.8	302.	5.0

Output edited.

TABLE 17C

153). The ambient temperatures and wind speeds in the ampacity rating program were incremented by 5°C (9°F) and 1 knot* values (Table 10A, page 115). This resulted in rounding down in the sag limitation calculations, since sags were calculated at only certain temperatures. Ampacity ratings were then calculated at only certain phase conductor temperature increments, such as 30°C instead of 31°C.

There was not a great deal of flexibility in the PP&L-PJM ampacity rating computer program, other than in the load cycle and maximum design temperature areas. This was reflected in the method, as the following items could not be readily changed, except through the services of the computer programming department:

- o weather model frequency of occurence values,
- o maximum loss-of-strength (L-O-S),
- o temperatures at which L-O-S was determined, and
- o emissivity.

---

*except for a 1.5 knot value.

This fact limited the method's ability to evaluate conductor ampacity ratings at alternate L-O-S values, or with weather data biased to represent colder or warmer weather conditions.

Copperweld-copper (CWC) conductors were not evaluated by the method. The necessary stress-strain curves could not be obtained from the conductor manufacturer. Also, since L-O-S curves did not exist, the CW conductor ampacity ratings were limited not by L-O-S restraints, but by sag limitations and manufacturer's maximum suggested operating temperatures (Chapter 2).

The method produced varying MCOT values for the various size and material type conductors. Most previous ampacity rating methods selected one maximum operating temperature for copper, aluminum, and ACSR.

There was a restriction on using the output from the ampacity rating program in the mode: CEØEA10 TYPERUN (NØLØSS). Due to the sag limitation assumption, this wind speed versus ambient temperature output matrix could be read only at the ambient temperature* which determined the phase conductor temperature (referred to as "Condr Max Temp Deg C", on Table 10A, page 115). This phase conductor temperature generates the table. As an example, since the -10°C ambient temperature determined the 35°C phase conductor temperature in Table 10A, ampacity ratings in the -10°C ambient temperature column would be the only valid ratings for 336.4 AAC. These ampacity ratings would not violate the method's assumptions on phase and neutral final clearances. Reading an ampacity rating under an ambient temperature to the left or right of -10°C would be invalid.

Keeping these limitations in mind will result in a proper perspective for the ampacity rating values given in Chapter 4, a restraint on using the Dist-Amp rating method incorrectly, and a better understanding of the conclusions and recommendations given in Chapter 7.

*(but at any wind speed value)

CHAPTER 6

METHOD SENSITIVITY TO VARIATIONS IN THE INPUT PARAMETERS

The distribution ampacity (Dist-Amp) rating method was examined to determine its sensitivity to variations in the input parameters. These input parameters include:

- maximum loss-of-tensile strength (L-O-S),
- maximum permitted conductor insulation temperature,
- ambient temperatures,
- conductor physical-electrical characteristics,
- pole framing,
- span length,
- maximum design tension,
- conductor ice loading,

- wind speed and resultant probability of exceeding "critical" conditions, and

- phase and neutral conductor combinations used by the test utility.

While many conductors could have been examined, the most commonly used size and material for a three phase express circuit was chosen. For the test utility, that conductor was 336.4 KCMIL 19 strand AAC. This conductor was examined in the following sensitivity analysis comparisons. In certain instances where 336.4 AAC was not affected by varying input parameters, other conductor sizes and materials are mentioned as examples. Tables 19 and 20, pages 164 through 166 summarize the discussion which follows.

Table 14A, page 126 in Chapter 4 illustrates that the loss-of-strength temperature (L-O-ST) was less than or equal to the sag limitation temperature (SLT) for only #6 and #8 AWG, bare, solid copper. Therefore, the ampacity ratings of only these two conductors were directly affected by the 10 percent L-O-S requirement. Sag limitations determined all other initial conductor ampacity ratings*. The SLT values for all covered, primary conductors were less than the maximum permitted conductor covering temperature.

However, when the maximum conductor operating temperature (MCOT) values were calculated, there were approximately a dozen conductors that had their ampacity ratings adjusted downward because the MCOT exceeded the 10 percent L-O-S temperature. Most of these conductors were small size copper. One exception was #4/0, 7 strand copper. If the L-O-ST could have been increased to 110°C, from 105°C, the ampacity rating would have been 715 amperes, or an increase of 26 amperes. The temperatures listed in parentheses in the SLT column of Table 14, pages 126 through 128, note those conductors whose MCOT values were affected by the 10 percent L-O-S requirement.

The effect of higher ambient temperatures on the ampacity ratings was examined. The -10°C and 25°C ambient temperatures used in this method for a 336.4 AAC phase with a #4/0 ACSR neutral produced a 640 ampere rating. A 5°C and 35°C "winter"

*Note special constraints listed in Chapter 2 on covered and CW conductors.

and "summer" ambient temperature were selected for comparison. These ambient temperatures resulted in a 663 ampere rating for the phase conductor --- an increase of 23 amperes.

The variation in conductor electrical characteristics among published literature was examined for 336.4 AAC. The AC resistances for this conductor, taken from three information sources[46-48], are listed in Table 18, page 160.

VARIATION IN AC RESISTANCES - THREE DATA SOURCES

Data Source	AC Resistance @ 25°C (77°F) (Ohms Per 1000 Feet)	AC Resistance @ 75°C (167°F) (Ohms Per 1000 Feet)
A	0.05275	0.06327
B	0.0528	0.0633
C	0.0527	0.0633

TABLE 18

The resistance variation from the highest to lowest value is negligible, and the ampacity ratings for 336.4 AAC vary by one ampere at the most. Using the heat balance equation,

$$I^2R = Q_{net} \text{ ----- equation 8}$$

it can be shown that for a given conductor temperature a 5 percent increase in resistance, over an assumed resistance would still produce an ampacity rating equal to 98 percent of the true rating. For 336.4 AAC this would be 624 instead of 640 amperes --- a reduction of 16 amperes.

When the Design Parameter Summary Sheets (DPSS) were examined for all conductors rated in Chapter 4, the longer spans for all conductors, except four, governed the SLT value selected for each size. The most noticeable change in SLT occurred for 150 and 160 versus 250 feet spans. If span lengths over 160 feet were not considered, the 336.4 AAC SLT for all its neutral combinations would become 40°C (104°F), producing an ampacity rating of 673 amperes --- a gain of 33 amperes.

Case B produced significantly lower SLT values. Cases A and C produced identical SLT values and ampacity ratings for the same span lengths. If Case B would not have been eliminated, the 336.4 AAC ampacity rating, for all neutral combinations, would have been 465 amperes --- a reduction of 175 amperes (Table 9B, page 113).

Higher maximum design tensions would have produced lower ampacity ratings. Examining only a 336.4 AAC phase and #4/0 ACSR neutral combination, a maximum design tension of 2500 pounds resulted in an ampacity rating of 595 amperes --- a reduction of 45 amperes. A 1500 pounds maximum design tension would have produced an ampacity rating of 760 amperes --- an increase of 120 amperes.

This same phase and neutral conductor combination for 300 and 400 feet spans, at a 2000 pounds maximum design tension produced an identical ampacity rating as the 250 feet span --- 640 amperes. Only Case A framing was examined, as Cases B and C would not be used for spans of these lengths.

If one inch radial ice loading had been used when calculating sags with the same phase and neutral combination, the SLT values would have been identical for Case A framing of 250, 300, and 400 feet span lengths. The resultant ampacity rating would have been 809 amperes.

A higher wind speed would increase the ampacity ratings of all conductors. For 336.4 AAC, a 4 knot wind would produce a rating of 693 amperes, but would have increased the probability of exceeding the "critical" condition by an additional 5 percent.

There would be no change in the ampacity rating of 336.4 AAC if the #4/0 ACSR neutral conductor combination could have been eliminated. (See Chapter 4, Table 16I, page 138) The elimination of the 336.4 AAC and #4/0 ACSR neutrals, however, would have increased the ampacity rating for 336.4 AAC to 786 amperes. The ampacity ratings were dependent on the phase and neutral combinations, and these selections had to be carefully considered (Tables 9A and 9B, pages 112 and 113).

The various points raised in this sensitivity analysis will be treated in Chapter 7, along with the conclusions and recommendations of this thesis.

SENSITIVITY ANALYSIS SUMMARY SHEET NO. 1

Column 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
Wind Speed = 3 Knots	Phase Conductor Temperature With Neutral Conductor Sag:				PP&L-PJM Program Calculations — Phase Conductor Ampacity (Amperes)			
Phase & Neutral Conductor	@ 5°C Winter Ambient	@ -10°C Winter Ambient	Span Length (Feet)	Framing Method (Case)	@ 5°C Winter Ambient	@ -10°C Winter Ambient	Max. Design Tension	Loading Condition
#4/0, 7 Strd. Copper & (All)	-	140°F (60°C)	250	A	-	715	2000#	1
336.4, 19 Strd. AAC & #4/0 ACSR N.	131°F (55°C)	95°F (35°C)	250	A	663	640 693*	2000#	1
336.4, 19 Strd. AAC & (All)	-	104°F (40°C)	160	C	-	673	2000#	1

Loading Condition 1 is 1/2 inch ice and 8 pounds per square feet wind. (All) indicates every neutral combination permitted with the phase conductor as listed in Chapter 4.
*Wind Speed - 4 Knots.

TABLE 19

SENSITIVITY ANALYSIS SUMMARY SHEET NO. 2

Column 1 Wind Speed = 3 Knots	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
	Phase Conductor Temperature With Neutral Conductor Sag:			PP&L-PJM Program Calculations Phase Conductor Ampacity (Amperes)		
Phase & Neutral Conductor	@ -10°C Winter Ambient	Span Length (Feet)	Framing Method (Case)	@ -10°C Winter Ambient	Max. Design Tension	Loading Condition
336.4, 19 Strd. AAC & #4/0 ACSR N.	84.2°F (29°C)	250	A	595	2500#	1
	131°F (55°C)	250	A	760	1500#	1
	95°F (35°C)	400	A	640	2000#	1
	95°F (35°C)	300	A	640	2000#	1
	95°F (35°C)	250	A	640	2000#	1

TABLE 20A

SENSITIVITY ANALYSIS SUMMARY SHEET NO. 2 (cont'd)

Phase & Neutral Conductor	@ -10°C Winter Ambient	Span Length (Feet)	Framing Method (Case)	@ -10°C Winter Ambient	Max. Design Tension	Loading Condition
336.4, 19 Strd. AAC &	167°F (75°C)	400	A	809	2000#	2
#4/0 ACSR N.	167°F (75°C)	300	A	809	2000#	2
	167°F (75°C)	250	A	809	2000#	2

Loading Condition 1 is 1/2 inch ice; Condition 2 is 1 inch ice; both with 8 pounds per square feet wind.

TABLE 20B

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

A method has been presented in this thesis to calculate the thermal ampacity ratings of bare and covered overhead distribution conductors. A table of ampacity ratings was produced for the distribution conductors used on the test utility system.

Based on the work described in this thesis, it is concluded that:

- past methods used to determine distribution conductor ampacity ratings are unacceptable since they were based on a limited group of input parameters,

- a procedure now exists to redetermine the ampacity ratings of distribution conductors, and rating tables in use by the planning and operating departments should be revised,

- existing distribution facilities, except Case B framing, should not and need not be replaced in rerating these distribution conductors, and

- recent revisions to the National Electrical Safety Code require that ampacity rating methods consider conductor sag, phase and neutral combination, and pole framing clearances, which past rating methods usually treated less rigorously.

By using a method such as outlined in this thesis, the actions described in these conclusions can be implemented.

The ratings in Chapter 4, Table 14, pages 126 through 128 should be adopted as the basis for deriving planning and operating distribution ampacity ratings. Factors such as voltage drop, line losses, load transfer capability, and system reliability will still have to be considered. The ratings in Chapter 4 provide only the conductor loading limit permissible without violating assumptions and criteria established in Chapter 2.

The sensitivity analysis in Chapter 6 raised various points which require some clarification and response. Only those points which could alter the ampacity ratings are mentioned here.

It is recommended that the load cycle and weather model be accepted as satisfactory for use in distribution conductor ampacity rating calculations and that no additional research in these areas be expended. The sensitivity analysis demonstrated that both parameters have minimum influence on the outcome of the ampacity ratings. Furthermore, the most pronounced effect was on small size copper conductors, which are no longer used for new construction.

Ambient temperatures selected for sag limitation calculations and ampacity ratings should be accepted. While higher ambient temperatures could produce higher ampacity ratings, the reasoning given in Chapter 2, for the values selected in the method, does not indicate this is a valid procedure to follow.

It is not recommended that maximum allowable span lengths be reduced to gain additional ampacity. The gain in ampacity would be outweighed significantly by the increased cost of short span construction and also negate conservation of plant resources (poles, insulators, crossarms, hardware). Span lengths longer than the maximum allowable lengths should be recognized as special framing cases, even though the analysis demonstrated that the effects on ampacity ratings to be insignificant.

It is recommended that all new pole framing designs be examined to ascertain the effect on ampacity ratings. The economics of pole height and phase-to-neutral conductor clearances should be balanced against the conductor ampacity rating. This pole framing examination should also include the selection of phase and neutral combinations which maximize ampacity ratings. While nothing can be done economically to existing Case A and C framing, it is recommended that a program be initiated to provide an additional 20.32 centimeters (8 inches) of phase-to-neutral clearance at the pole for all "in-place" Case B facilities where 68.58 centimeters (27 inches) presently exists.

The effect of higher or lower maximum design tensions should be disregarded. The test utility standardizes on pole framings and design tensions, as discussed in Chapter 2 and Chapter 4. These parameters were factored into the ratings in Chapter 4. For other than these standard distribution designs, increased pole framing is normally provided. Because of this, the maximum design tension effect on ampacity ratings is nullified. Also higher maximum design tensions require higher strength hardware to meet safety code requirements.

The effect of one inch radial ice loading, when required for mechanical reasons, will have a positive effect on the ampacity ratings. It should not be adopted for all line designs since the economic costs to the test utility for this mechanically stronger type of construction would greatly exceed any ampacity gains.

It is not recommended that a 4 knot wind speed be adopted. The 3 knot wind speed does not appear to be overly conservative. A 4 knot wind at a -10°C ambient temperature produces a probability of about 13.4 percent compared with 8.2 percent for a 3 knot wind that weather conditions may occur that would exceed in severity the "distribution critical" condition. This probability is believed to be unacceptable from an operating standpoint.

To complete the ampacity rating table, it is recommended that CWC conductors be examined, provided the required stress-strain curves can be obtained from some reliable source.

Finally, it is recommended that the Dist-Amp rating method be reorganized so that all computer programs interact with each other through one overall program.

This new program would examine all parameters which affect ampacity ratings. Certain parameters could be varied by the user, such as phase and neutral conductor combinations, or maximum design tension and ice loading. An in-depth sensitivity analysis would be performed by the program, and various pole framing and phase-neutral options would be listed in the output so that the user could select an optimum ampacity rating.

This integrated program would:

- free a considerable amount of time presently required of the method's user,

- greatly expand the number of parameter variations which could be examined,

- eliminate the possibility of error which can now occur in the manual steps of the method when values are read from computer output and transferred to other calculation data sheets,

- provide a higher degree of resolution in selecting the SLT, MCOT, and ampacity values, and

- enable a user to better optimize pole framing clearances, conductor span lengths, sizes, and combinations.

This thesis has provided, as an end result, the documentation of thermal ratings and maximum conductor operating temperatures required by the test utility and discussed in the Introduction. Also, the method provided herein should be useful to other electric utilities in calculating similar ampacity ratings for their distribution conductors.

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APPENDIX 1

PHYSICAL-ELECTRICAL CHARACTERISTICS OF CONDUCTORS

Tables 22 through 28, pages 192 through 204, provide a tabulation of the physical-electrical characteristics of the distribution size conductors examined in this ampacity rating method. Related problems in the determination, acquisition, and selection of these conductor characteristics will be discussed later in this appendix. Chapter 6 explored the sensitivity of the ampacity rating method to variations in these physical-electrical characteristics. These tables are provided so that a common base can be used for a comparision study by other interested individuals.

The choices from which to select these conductor parameters were numerous and somewhat confusing, since most sources listed differing data for identical conductor sizes, for not only AC but DC resistances. The main objective was to select these conductor parameters from as accurate a source as possible. When assembling Tables 22 through 28, pages 192 through 204, the preferred references were those which derived diameters, weights, and resistances from first-hand, basic data or empirical equations.

The National Bureau of Standards (NBS) has published two wire table booklets for copper and aluminum wire[49,50]. While these booklets contain in-depth background information on wire theory and methods of calculating conductor physical-electrical characteristics, both sources are incomplete.

These NBS wire tables have the following limitations:

- o AC resistances for stranded or solid wire were not listed, (copper and aluminum)
- o DC resistances for aluminum stranded wire were given at only 20°C,
- o DC resistances for <u>annealed</u> bare, concentric-lay copper were given at 25 and 65°C for only Class B and C stranding*,
- o only solid wire DC resistances were given at 20°C and other selected temperatures. (copper and aluminum)

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*distribution overhead conductors are class AA or A, and hard-drawn.

The EPRI research project book on UHV transmission was considered as a possible source; however, the book is directed toward transmission conductors[51]. It did not contain all of the distribution conductor sizes under examination, and the given physical-electrical data had been gathered from the Aluminum Association, ASTM, AIEE (IEEE) transaction papers, and manufacturers' product literature on the subject. The EPRI tables were not first-hand sources.

The American Society for Testing and Materials (ASTM) publishes standards which mainly provide conductor physical data, and these were used extensively to determine weights and diameters[52]. Many conductor manufacturers use these same ASTM standards as reference sources when they publish tables of conductor physical-electrical characteristics for their product catalogs.

The Aluminum Association has published an aluminum conductor handbook[46] which provides wire theory and numerous tables of the physical-electrical characteristics of aluminum conductors. This book provided some of the data needed in the calculations when more original data sources could not be found. ASTM standards and aluminum conductor manufacturers provided the Aluminum Association with the basic handbook data.

Most major conductor manufacturers have engaged in research to determine the physical-electrical characteristics of their conductors[24, 47, 48]. Some of the electrical data were obtained from these industry research papers and handbooks. E. Hazan's paper[47] provided most of the AAC electrical data, and the Aluminum Association's handbook[46] was used as a source for most of the ACSR electrical data. The CW and CWC manufacturer's catalogs[24] provided data on these type conductors.

ASTM standards could not readily be used to determine ACSR electrical characteristics, since all but one conductor in Table 26, pages 201 and 202 are single layer type ACSR. With this type of conductor construction, the effects of core magnetization must be considered when calculating AC resistances[53]. In nonmagnetic conductors, the resistance is affected by temperature and frequency because of the skin effect. In magnetic conductors (ACSR, CWC, CW) these two factors plus current density affect resistance. The current density determines the magnetic field intensity and flux density and the resulting iron or magnetic losses inside the conductor[54].

Alcoa's data book[48] would have simplified the determination of the AC resistances in the single layer type, but current magnitude had to be known to select the AC resistance from the plotted curves. Since current magnitude was still to be determined, this method of calculating resistances was unsatisfactory. The Aluminum Association's data book[46] was therefore used to construct the ACSR table. This reference assumed 10 percent of rated current was carried by the conductor at 25°C and 100 percent at 75°C.

E. Hazan's paper[47] provided a unique approach to electrical data determination. By providing the constants "x" and "y" for practically every conductor size and material, except copper, the user only needed to select the temperature (T) at which a resistance was desired, find the appropriate "constants table", and solve the equation:

$$R_{DC} \text{ or } R_{AC} = x + y \cdot T \text{ --- equation 9}$$

More details and the degree of accuracy of this equation can be found in the referenced paper. This method was used to produce the AAC table.

Copper-clad steel and copper-clad steel with copper conductors, better known by their tradenames copperweld (CW) and copperweld-copper (CWC), presented the same type problem as ACSR conductors. Both CW and CWC are magnetic. Also, usage on most utility distribution systems today is very low, and most technical data relating to these conductors dates back to 1946-1951[55]. AC resistance values were taken from the manufacturer's product literature. As with ACSR these resistances are a function of current density in addition to temperature and frequency. There are no published equations to calculate CW and CWC resistances from resistivity and cross-sectional area[23]. The product literature data were based on the manufacturer's tests on a selected number of CW and CWC samples. From these tests, empirical formulas were derived and then used to calculate the resistance of other size CW and CWC conductors[24].

The AAAC 6201-T81 conductor electrical characteristics were not computed using Hazan's paper[47], but were taken directly from a manufacturer's product literature. This is a relatively new conductor, therefore more complete AC resistance data are available[56].

Since there was limited AC resistance data available on copper conductors, the electrical characteristics were calculated using a computer program which incorporated the equations from ASTM B-193 and B-258[52,57].

ASTM B-1 and B-258[52] provided the conductor diameters. The resistance and weight for each size solid conductor listed in Table 22, pages 192, 193, and 194 were calculated first.

$$W = (d^2 \cdot \delta \cdot 0.34049) \div 1000 \text{ ------- equation 10}$$

$$RDC20 = \frac{\rho \cdot 105.35}{d^2 \cdot \delta} \text{ ---------------- equation 11}$$

where:

W = weight in pounds per 1000 feet,

RDC20 = DC resistance at 20°C in ohms per 1000 feet,

d = solid wire diameter in mils,

δ = copper wire density at 20°C in grams per cubic centimeters,

ρ = copper wire resistivity at 20°C in ohm - pounds per mile^2.

Resistivity is dependent on whether the wire is hard-drawn or soft-drawn. The resistance was then determined at a second temperature using:

$$RDC @ T2 = RDC20 \cdot (1 + \alpha T1 \cdot (T2 - T1)) \text{ ---------- equation 12}$$

where:

RDC @ T2 = DC resistance at second temperature T2, in ohms per 1000 feet,

RDC20 = DC resistance at 20°C, in ohms per 1000 feet,

$\alpha T1$ = temperature coefficient of resistance at and from temperature T1, in per °C, T2 = second temperature at which RDC @ T2 is to be determined, in °C,

T1 = temperature at which αT1 is known and RDC20 calculated.

For copper wire, the value of αT1 was determined by:

$$\alpha_x = \cfrac{1}{\cfrac{1}{n \cdot (0.00393)} + (T_x - 20)} \text{ ----------- equation 13}$$

where:

n = the percent conductivity expressed as a decimal,

α_x = temperature coefficient of resistance at the desired temperature "x",

T_x = temperature at which α_x is to be determined.

Hard-drawn copper ranges between 97.0 and 97.5% IACS. Using 97.5% to determine α_x at T_x = 20 resulted in:

$$\alpha_{20} = \cfrac{1}{\cfrac{1}{(0.975) \cdot (0.00393)} + (20-20)}$$

or,

α_{20} for 97.5% IACS = αT1 = 0.00383

In equation 12, the value 0.00383 was assigned to αT1, and RDC@T2 calculated at 50 and 100°C. This step provided the DC resistances for solid copper at 20, 50, and 100°C.

The AC resistance at each temperature was determined by:

$$RAC20 = RDC20 \cdot K \text{ ------------------------- equation 14}$$

where K is the skin effect ratio.

The skin effect ratio is greater than or equal to 1.0 and reflects the increased apparent resistance in a conductor carrying AC current due to the unequal current density throughout the conductor cross-section. A thorough treatment of this topic can be found in various engineering texts[54]. Using a National Bureau of Standards bulletin[58] which lists the skin effect ratio versus a variable called "X", equation 14 can be solved.

The variable "X" is given by:

$$X = 0.063598 \left(\frac{f \cdot \mu}{(RDC_x) \cdot (5.28)}\right)^{1/2} \text{ --------- equation 15}$$

where,

RDC_x = DC resistance at 20, 50, or 100°C,

f = frequency or 60 cycles,

μ = permeability of the wire, assumed constant.

For copper or other non-magnetic material, $\mu = 1.0$. Solving for "X" and then using the NBS bulletin tables determines the skin effect ratio value, K.

Equations 14 and 15 were was solved for temperatures at 20, 50 and 100°C for all solid conductors by the computer program. The stranded copper conductors had a stranding factor applied (i.e. 1.01 or 1.02) at equations 10 and 11, before the other equations were applied, for each size of stranded conductor. This stranding factor increment accounted for the extra weight and resistance in the wire strands due to their spiral wrapping around the center strand. This is in accord with ASTM practices.

Only class AA and A types were listed in these tables, since these conductors would be used in overhead lines[59].

NOTES AND ABBREVIATIONS FOR TABLES 22 THROUGH 28

Notes:

1) All base data values at 20°C.

2) Test utility catalog numbers given in parentheses under "Conductor" column.

3) Assumed 97.5% IACS for copper, Table 22; 61.0% IACS for 1350-H19 aluminum, Table 25; and 52.5% IACS for 6201-T81 aluminum alloy, Table 28.

Abbreviations:

1) Strd. --- strand
2) E.H.S. --- extra-high strength
3) H.S. --- high strength
4) 30% --- 30% conductivity
5) CW --- copperweld
6) CWC --- copperweld-copper
7) AAC --- all aluminum conductor
8) AAAC --- all aluminum alloy conductor
9) ACSR --- aluminum conductor, steel reinforced
10) Conc. --- concentric-lay
11) Comp. --- compact round concentric-lay
12) IACS --- International Annealed Copper Standard
13) H.D. --- hard drawn

TABLE 21

COPPER, HARD DRAWN
(97.5% IACS)

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 100°C (Ohms/1000 Ft.)
#8 AWG Solid	0.1285	49.98	0.6465	0.6465	0.8447
#6 AWG Solid (#147454)	0.1620	79.44	0.4067	0.4068	0.5314
#6 - 7 Strd. Conc.	0.1836	81.05	0.4149	0.4149	0.5421
#4 AWG Solid (#147455)	0.2043	126.3	0.2558	0.2558	0.3342
#4 -3 Strd. Conc.	0.2543	127.6	0.2583	0.2584	0.3375
#4 -7 Strd. Conc.	0.2316	128.9	0.2609	0.2610	0.3409
#3 AWG Solid	0.2294	159.3	0.2028	0.2029	0.2651
#3 -3 Strd. Conc.	0.2855	160.9	0.2049	0.2049	0.2678
#3 -7 Strd. Conc. (#147521)	0.2601	162.5	0.2069	0.2070	0.2704
#2 AWG Solid (#147456)	0.2576	200.9	0.1609	0.1610	0.2102
#2 -3 Strd. Conc. (#147502)	0.3204	202.9	0.1625	0.1626	0.2123

TABLE 22A

COPPER, HARD DRAWN (cont'd)
(97.5% IACS)

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 100°C (Ohms/1000 Ft.)
#2 -7 Strd. Conc. (#147522)	0.2922	204.9	0.1641	0.1642	0.2145
#1 AWG Solid	0.2893	253.3	0.1275	0.1277	0.1668
#1 -3 Strd. Conc.	0.3599	255.9	0.1288	0.1289	0.1684
#1 -7 Strd. Conc. (#147523)	0.3279	258.4	0.1301	0.1302	0.1701
#1/0 AWG Solid	0.3249	319.5	0.1011	0.1013	0.1322
#1/0 -7 Strd. Conc. (#147524)	0.3684	325.8	0.1031	0.1033	0.1349
#2/0 AWG Solid	0.3648	402.8	0.08021	0.08038	0.1049
#2/0 -7 Strd. Conc. (#147525)	0.4137	410.9	0.08182	0.08199	0.1070
#3/0 AWG Solid	0.4096	507.8	0.06362	0.06384	0.08330

TABLE 22B

COPPER, HARD DRAWN (cont'd)
(97.5% IACS)

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 100°C (Ohms/1000 Ft.)
#3/0 -7 Strd. Conc. (#147526)	0.4644	518.1	0.06490	0.06512	0.08497
#4/0 AWG Solid	0.4600	640.5	0.05045	0.05071	0.06613
#4/0 -7 Strd. Conc.	0.5217	653.3	0.05146	0.05172	0.06746

References: 19,49,52

TABLE 22C

COPPERWELD - COPPER

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 25°C *Small Currents* (Ohms/1000 Ft.)	AC Resistance @ T = 50°C *75% Ampacity* (Ohms/1000 Ft.)
#8A-3 Strd. (#149000)	0.199	74.27	0.6598	0.665	0.733
#7A-3 Strd. (#149001)	0.223	93.66	0.5232	0.527	0.581
#6A-3 Strd. (#149002)	0.230	101.6	0.4150	0.419	0.462
#4A-3 Strd. (#149003)	0.290	161.5	0.2610	0.264	0.293
#2F-6/1 Strd. (#149051)	0.308	222.8	0.1658	0.168	0.187
#1/0K - 3/4 Strd. (#149126)	0.475	512.0	0.1043	0.110	0.126
#2/0F - 6/1 Strd. (#149052)	0.436	446.8	0.08265	0.0848	0.0949
#2/0G - 5/2 Strd. (#149101)	0.463	496.6	0.08265	0.0869	0.0994

TABLE 23A

COPPERWELD - COPPER (cont'd)

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 25°C *Small Currents* (Ohms/1000 Ft.)	AC Resistance @ T = 50°C *75% Ampacity* (Ohms/1000 Ft.)
#3/0F - 6/1 Strd. (#149053)	0.490	563.2	0.06556	0.0678	0.0759
#4/0F - 6/1 Strd. (#149054)	0.550	710.2	0.05199	0.0544	0.0610

References: 24, 52, 55

TABLE 23B

COPPERWELD

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 25°C *Small Currents* (Ohms/1000 Ft.)	AC Resistance @ T = 75°C *75% Ampacity* (Ohms/1000 Ft.)
#8-Solid - E.H.S. - 30%	0.1285	45.81	2.136	-	-
#7-3 Strd. - E.H.S. - 30% (#148801)	0.311	174.7	0.5691	0.581	0.703
#6 - Solid - E.H.S. - 30% (#148701)	0.1620	72.85	1.343	1.37	1.63
#6-3 Strd. - H.S. - 40%	0.349	220.3	0.3385	0.347	0.420
#4 - Solid - E.H.S. - 30% (#148702)	0.2043	115.8	0.8447	0.860	1.02
#9 - 19 Strd. - E.H.S. - 30% (#148813)	0.572	700.0	0.1437	0.151	0.209
#9-7 Strd. - E.H.S. - 30% (#148802)	0.343	256.9	0.3886	0.400	0.500
#8-7 Strd. - E.H.S. - 30% (#148806)	0.385	323.9	0.3081	0.318	0.402

TABLE 24A

COPPERWELD (cont'd)

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 25°C *Small Currents* (Ohms/1000 Ft.)	AC Resistance @ T = 75°C *75% Ampacity* (Ohms/1000 Ft.)
#7-7 Strd. - E.H.S. - 30% (#148803)	0.433	408.4	0.2444	0.253	0.321
#6-7 Strd. - E.H.S. - 30% (#148804)	0.486	515.0	0.1938	0.201	0.258
#5-7 Strd. - E.H.S. - 30% (#148805)	0.546	649.4	0.1537	0.160	0.208

References: 24,52

TABLE 24B

ALL ALUMINUM CONDUCTOR, HARD DRAWN
(1350-H19 ALLOY, 61.0% IACS)

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 75°C (Ohms/1000 Ft.)
#4 AWG Solid	0.2043	38.41	0.4074	0.4074	0.4977
#4 - 7 Strd. Conc. Rose	0.2316	39.20	0.4154	0.4154	0.5088
#4 - 7 Strd. Comp.	0.2130	39.20	0.4154	0.4154	0.5088
#2 AWG Solid	0.2576	61.07	0.2562	0.2563	0.3131
#2 - 7 Strd. Conc. Iris (#147108)	0.2922	62.34	0.2613	0.2615	0.3203
#2 - 7 Strd. Comp.	0.2680	62.34	0.2613	0.2615	0.3203
#1 AWG Solid	0.2893	77.03	0.2032	0.2032	0.2483
#1 - 7 Strd. Conc. Pansy	0.3279	78.57	0.2072	0.2073	0.2532
#1 - 7 Strd. Comp.	0.2990	78.57	0.2072	0.2073	0.2532
#1/0-7 Strd. Conc. Poppy (#147110)	0.3684	99.09	0.1643	0.1643	0.2013

TABLE 25A

ALL ALUMINUM CONDUCTOR, HARD DRAWN (cont'd)
(1350-H19 ALLOY, 61.0% IACS)

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 75°C (Ohms/1000 Ft.)
#1/0 - 7 Strd. Comp.	0.3360	99.09	0.1643	0.1643	0.2013
#2/0 - 7 Strd. Conc. Aster	0.4137	125.0	0.1304	0.1304	0.1597
#2/0 - 7 Strd. Comp.	0.3760	125.0	0.1304	0.1304	0.1597
#3/0 - 7 Strd. Conc. Phlox (#147114)	0.4644	157.5	0.1034	0.1036	0.1269
#3/0 - 7 Strd. Comp.	0.4230	157.5	0.1034	0.1036	0.1269
#4/0 - 7 Strd. Conc. Oxlip	0.5217	198.7	0.08187	0.08206	0.1006
#4/0 - 7 Strd. Comp.	0.4750	198.7	0.08187	0.08206	0.1006
300 KCMIL - 19 Strd. Comp.	0.5700	281.8	0.05781	0.05801	0.07104
336.4 KCMIL-19 Strd. Conc. Tulip (#147117)	0.6655	316.0	0.05155	0.05170	0.06327
336.4 KCMIL-19 Strd. Comp.	0.6030	316.0	0.05155	0.05170	0.06327

References: 47,50,52

TABLE 25B

ACSR
(TYPE AZ OR GC, 61.0% IACS)

Conductor	Diameter (Inches)	Weight of Conductor & Core (Lbs./1000 Ft.)		DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 25°C (Ohms/1000 Ft.)	AC Resistance @ T = 75°C (Ohms/1000 Ft.)
#4 - 6/1 Strd. Conc. Swan (#147151)	0.250	39.0	18.4	0.4047	0.4125	0.5233
#4 - 6/1 Strd. Comp.	0.229	39.0	18.4	0.4134	0.4125	0.5233
#4 - 7/1 Strd. Conc. Swanate	0.257	39.0	28.0	0.4003	0.4080	0.5297
#4 - 7/1 Strd. Comp.	0.236	39.0	28.0	0.4134	0.4080	0.5297
#2 - 6/1 Strd. Conc. Sparrow (#147152 & 53	0.316	62.0	29.3	0.2543	0.2598	0.3377
#2 - 6/1 Strd. Comp.	0.290	62.0	29.3	0.2600	0.2598	0.3377
#2 - 7/1 Strd. Conc. Sparate	0.325	62.0	44.7	0.2515	0.2570	0.3407
#2 - 7/1 Strd. Comp.	0.298	62.0	44.7	0.2600	0.2570	0.3407
#1/0 - 6/1 Strd. Conc. Raven (#147154 & 55)	0.398	98.6	46.6	0.1598	0.164	0.2184
#1/0 - 6/1 Strd. Comp.	0.365	98.6	46.6	0.1635	0.164	0.2184

TABLE 26A

ACSR (cont'd)
(TYPE AZ OR GC, 61.0% IACS)

Conductor	Diameter (Inches)	Weight of Conductor & Core (Lbs./1000 Ft.)		DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 25°C (Ohms/1000 Ft.)	AC Resistance @ T = 75°C (Ohms/1000 Ft.)
#2/0 - 6/1 Strd. Conc. Quail	0.447	124.3	58.8	0.1268	0.130	0.177
#2/0 - 6/1 Strd. Comp.	0.410	124.3	58.8	0.1297	0.130	0.177
#3/0 - 6/1 Strd. Conc. Pigeon (#147156)	0.502	156.8	74.1	0.1007	0.103	0.143
#3/0 - 6/1 Strd. Comp.	0.461	156.8	74.1	0.1028	0.103	0.143
#4/0 - 6/1 Strd. Conc. Penguin (#147157)	0.563	197.7	93.4	0.0798	0.0822	0.117
#4/0 - 6/1 Strd. Comp.	0.517	197.7	93.4	0.0816	0.0822	0.117
336.4 KCMIL - 26/7 Strd. Conc. Linnet (#147205)	0.721	317.3	145.8	0.0507	0.05184	0.06205

References: 46,52

TABLE 26B

COVERED ACSR & ALUMINUM

Conductor	Diameter (Inches)	Weight of Conductor & Core (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 25°C (Ohms/1000 Ft.)	AC Resistance @ T = 75°C (Ohms/1000 Ft.)
#1/0 ACSR 6/1 Strd., 150 MILS XLP. Cvrd., (Compact) (#147395)	0.700	253.0	0.1635	0.164	0.2184
#4/0 ACSR 6/1 Strd., 150 MILS XLP. Cvrd., (Compact) (#147396)	0.845	429.0	0.0816	0.0822	0.117
336.4 KCMIL H.D. AAC. 19 Strd., 150 MILS XLP. Cvrd., (Compact) (#147399)	0.940	535.0	0.05155	0.05275	0.06327
556.5 KCMIL H.D. AAC. 19 Strd., 150 MILS XLP. Cvrd., (Compact) (#147400)	1.160	718.0	0.03116	0.03215	0.03856

References: 46, 47, 50, 52, 59

TABLE 27

ALL ALUMINUM ALLOY CONDUCTOR
(6201 - T81 ALLOY, 52.5% IACS)

Conductor	Diameter (Inches)	Weight (Lbs./1000 Ft.)	DC Resistance @ T = 20°C (Ohms/1000 Ft.)	AC Resistance @ T = 25°C (Ohms/1000 Ft.)	AC Resistance @ T = 75°C (Ohms/1000 Ft.)
#2 - 7 Strd. Conc. Ames	0.316	72.7	0.260	0.265	0.310
#1/0 - 7 Strd. Conc. Azusa	0.398	115.7	0.163	0.166	0.195
#4/0 - 7 Strd. Conc. Alliance	0.563	231.8	0.0816	0.0832	0.0973
394.5 KCMIL-19 Strd. Conc. Canton	0.721	370.3	0.0511	0.0522	0.0610

Reference: 56

TABLE 28

VITA

Stephen Andrew Olinick was born in Lebanon, Pennsylvania, on June 27, 1949. He is the son of Andrew and Lauretta E. Olinick of Tower City, Pennsylvania. The author entered the Pennsylvania State University (PSU) upon graduation in 1967 from Williams Valley High School, Reinerton, Pennsylvania. He was graduated from PSU in June 1971, with a Bachelor of Science Degree in Electrical Engineering. During the summer months between his sophomore and senior years at PSU, the author was employed by the Pennsylvania Power & Light Company (PP&L) as a laborer and cadet engineer. In July 1971 he accepted a full-time position with PP&L as an Engineer in the Substation Engineering Section of the System Power and Engineering Department at the Allentown General Office. In December 1975, he was promoted to Project Engineer-Substation within the same department. In April 1977 he transferred into the Distribution Development Section of the Division Operations Department in the position he currently holds, Project Engineer-Distribution Development. Except for a brief period of active duty military service, he has been employed by PP&L since 1971. During the course of his employment at PP&L, the author has been involved in substation engineering production design, distribution and substation standards, material evaluation, and distribution technical studies. The author is a member of Eta Kappa Nu and Tau Beta Pi. He resides in Allentown, Pennsylvania.