VI.A

BARE OVERHEAD TRANSMISSION CONDUCTOR RATINGS

GUIDE FOR DETERMINATION OF

BARE OVERHEAD TRANSMISSION CONDUCTORS

PJM INTERCONNECTION

December 2022

Heritage MAAC Group

A Special Session of the Transmission and Substation Subcommittee

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1. REVISION HISTORY

August 2000: Rev. 0 – Original Document

November 2011: Rev. 1 – General revision and document standardization and clarification of emergency and load dump ratings, revision of associated equations, and upgrade of associated Excel spreadsheet.

December 2022: Rev. 2 – General revisions, edits, and modifications to calculations for expanded temperature range. Revised calculation spreadsheet to produce results in Fahrenheit, expand temperature range, and move to 5F temperature bands. Sensitivity of environmental parameters to normal and short-term emergency ratings are also presented in the ratings calculation tool for illustration purposes.

2. SCOPE AND PURPOSE

In 2021, the PJM Transmission & Substation Subcommittee (TSS) determined that the existing Bare Overhead Transmission Conductor Ratings Guide was in at risk of becoming out-of-date and decided to pursue an update to the document. A Special Session was convened to address these updates outside of the routine TSS business meetings. The update was intended to be completed in two major Tasks: Task 1 covered minor updates and edits and tried to make the document more current with member practices, while Task 2 modernized the data behind the document and included topics such as climate change and dynamic line ratings (DLR). This document covers those items under Task 1 with Task 2 items to be addressed at a future date.

While scoping the effort for the Task 1 update, FERC finalized their Notice of Proposed Rulemaking (NOPR) RM20-16-000 into FERC Order 881 "Managing Transmission Line Ratings". Among other things, this Order requires all transmission owners to calculate ambient adjusted ratings for their transmission facilities, a detail already included in this Guide. However, the Order dictated that Ambient Adjusted Ratings (AAR) are provided in 5°F temperature increments and cover 10°F colder than the historically coldest ambient temperature and 10°F warmer than the historically warmest ambient temperature for a transmission owner. This Guide therefore also required revisions to comply with FERC Order 881 ratings requirements.

In addition to the updates to the Guide, the PJM Overhead Transmission (OHT) Ratings Spreadsheet requires modifications to produce ratings in the desired units, increments, and ranges compatible with FERC Order 881 requirements. Additional user enhancements and bug corrections were also performed under this Task 1 effort, including expanding the HTLS conductor options, allowing user overrides for various default inputs, and expanding the output tables.

The PJM Overhead Transmission (OHT) Ratings spreadsheet is intended to cover conductors rated 100 kV and above, which are considered part of the Bulk Electric System (BES) and are subject to the guidelines set forth in the PJM Operating Manuals. High Temperature Low Sag (HTLS) conductors such as aluminum conductor composite core (ACCC) and aluminum conductor composite reinforced (ACCR) were also added to the spreadsheet. Transmission owners also have the ability to add additional conductors to the spreadsheet as needed.

The OHT Ratings spreadsheet was previously updated to include a method for calculating the conductor load dump ratings and no changes were made to that process. All ratings in the spreadsheet are given in amperes and diligence should be used when converting to MVA when using nominal voltage (e.g. phase imbalances, operating voltage). Recent updates to the spreadsheet include bug fixes and adapting the resulting tables to the temperature units, ranges, and intervals specified in FERC Order 881.

This document addresses the issues associated with the rating of bare overhead conductors. Often these ratings are the most limiting ratings on a circuit or feeder, but not always. The ratings provided in this document must not be confused with circuit ratings; they are only one component in the analysis to determine the circuit rating. This document and the ratings spreadsheet are voluntary guidelines and may be applied at the transmission owner's discretion.

The committee was also charged with defining the transition point between transmission and substation ratings jurisdictions. Working in conjunction with the Outdoor Substations Conductor Ratings Ad Hoc Committee the following consensus was established:

"Regardless of the installation method, the point of demarcation is the connection of the insulator string to the overhead conductor at the dead end structure. The dead end referenced should be the structure that transitions the line to any type of substation equipment. Underground cable transition is at the end of the pot head."

However, the intent of the point of demarcation is to prevent a high temperature overhead conductor from overheating temperature sensitive substation equipment. Conductor drops from a take-off tower may be rated as line conductor if attached to non-temperature sensitive substation components.

3. BACKGROUND

This guide outlines a methodology for determining thermal ratings of overhead transmission conductors. This document resulted from the effort to update an earlier PJM guide: Bare Overhead Transmission Conductor (November, 2000 and October, 2009). The bulk of the work of the Special Session focused on the following:

- Accommodating the FERC Order 881 rules for Ambient Adjusted Ratings (AAR).
  - Expanded temperature range
  - Results in Fahrenheit (with conversions to Celsius)
  -
- Expanding discussion on high temperature conductors.
- Introducing discussion on Dynamic Line Ratings (DLR)
- Incorporating conductor coatings and their effects on ratings.
- Incorporating updated discussion on emissivity and absorptivity into the guide and calculations.

A major accomplishment was the update of the existing Microsoft Excel spreadsheet for determining overhead ratings. The spreadsheet was revised to produce ambient adjusted conductor ratings in 5F ratings bands and expanded the ambient temperature ranges to comply with FERC Order 881. The spreadsheet was thoroughly tested to ensure comparable performance to industry-standard programs for determining overhead conductor ratings. A how-to guide on the use of the new spreadsheet is provided in this document. A comparison table showing the output values of the spreadsheet and commercial software is also provided.

The assumptions regarding climatic and conductor conditions remain unchanged from the previous revision of the document. An engineer already familiar with overhead ratings and the previous versions of this document will not notice any significant changes in the core algorithm for determining the overhead ratings. Despite the ambient temperatures being in Fahrenheit, the base calculations are still performed using Celsius. All versions of this document dated prior to 2000 are included in the appendices as well.

It is assumed that power levels will be maintained and managed within the requirements of PJM Manual 3, Section 2, "Thermal Operating Guidelines". PJM operating philosophy strives to restore loads to below the Normal Rating in four hours or less. The intent of this guide is that equipment loading will not be above the Normal Rating for greater than four hours. It is understood that under a single event restoration, cumulative time of loading in excess of the Normal Rating beyond four hours may occur. Operating in excess of four hours above the Normal Rating for a single event restoration should be evaluated by the equipment owner.

4. DEFINITIONS

Following are definitions of terms used in this report for use in determining PJM switch ratings:

Continuous Duty
A duty that demands operation at a substantially constant load for an indefinitely long time.

Short Time Duty
A duty that demands operation at a substantially constant load for a short and definitively-specified time.

Normal Conditions
All equipment in normal configuration, normal ambient weather conditions.

Normal Rating
The maximum permissible constant load at normal conditions, at the maximum allowable conductor temperature for that conductor.

Emergency Conditions
Equipment has been operating at Normal Rating. The equipment is then exposed to an out of configuration condition and emergency ambient weather conditions.

Emergency Rating
The maximum permissible steady-state load at emergency conditions, at the maximum allowable conductor temperature for a period not to exceed 24 hours.

Load Dump Rating
The maximum permissible load at emergency conditions, at the maximum allowable conductor temperature for a period of 15 minutes as determined by the transient method.

Dynamic Line Rating
In FERC Order 881, the Commission defined Dynamic Line Rating (DLR) as a transmission line rating that: (1) applies to a time period of not greater than one hour; (2) reflects up-to-date forecasts of inputs such as (but not limited to) ambient air temperature, wind, solar irradiance intensity, transmission line tension, or transmission line sag; and (3) is calculated at least each hour, if not more frequently.

Weather Conditions
Ambient temperature, solar and sky radiated heat flux, wind speed, wind direction, and elevation above sea level.

Max. Allowable Conductor Temp.

The maximum temperature limit that is selected in order to minimize loss of strength, conductor sag, line losses, or a combination of the above.

Time Risk
The time during which the conductor is vulnerable to operation at temperatures greater than the design temperature.

Temperature Risk
The maximum increase in conductor temperature above design temperature which can be experienced if the conductor carries its rated current simultaneously with an occurrence of the most severe set of ambient conditions.

5. Non-thermal Rating Limitations

Situations may arise where limitations other than the thermal rating of the conductor will limit the maximum rating of the circuit. Other electrical devices such as wave traps, switches, transformers, disconnects, breakers, and relays could limit a transmission facility below the capability of the bare overhead transmission conductor. Legal or contractual limitations will sometimes restrict operating practices to limit magnetic fields due to field concerns. On shared rights-of-way, other entities (railroads, for example) may impose maximum current limits to minimize inductive interference.

Interference issues should always be addressed when determining loading on a line. Potential interference or inductive coupling may cause hazards to other utilities or other lines or objects within or near the right of way.

At times, system conditions may require a limit on the maximum amount of current flowing through a line. This may require the line being taken out of service or devices added which limit the amount of current carried through the line.

6. Weather

Ambient weather conditions have a major effect on the calculation of a conductor's thermal rating. Wind speed is the most widely varying parameter and the most important determinant of ratings. Careful selection of weather parameters for thermal rating calculations is as important as the selection of method of calculation itself and requires considerable engineering judgment.

Since the publication of "Ambient Adjusted Thermal Ratings For Bare Overhead Conductors" in May 1980 and its acceptance by the PJM companies, wind speed and ambient temperature became the major determining factor related to weather for the calculation of steady state thermal ratings of conductors for daily operation.

In the original PJM work, the weather data included 10 years of data from Pittsburgh (1/1/49 – 12/31/58) and 16 years of data from Washington D.C. National Airport (1/1/49 – 12/31/64). These were added together and used as being the total composite hourly record of wind data for 26 years. Any differences between the two different weather data sets were obscured by combining the data. This Special Session acknowledges that the weather data is old and not geographically diverse and has proposed that this data be updated and expanded to cover a wider geographical area more reflective of the current PJM Transmission Owners footprint. This will be performed under a future revision to the Guide.

6.1. Weather Model

Under actual operating conditions, conductors experience fluctuations in load and weather conditions. This complex relationship is not adequately represented by a set of fixed parameters. A probabilistic model, however, can utilize actual weather data and load cycle characteristics to represent the conductor's operating history. This model produces a time distribution of conductor temperature which can be used to calculate the loss of strength that a conductor would experience. This modeling technique allows conductors to be rated to meet the constraints of maximum allowable temperature and/or allowable loss of strength.

A weather model is the heart of the simulation. Weather conditions, especially wind, have a marked effect on conductor temperatures. For the PJM weather model, detailed weather data was gathered from several locations representative of the PJM area. Two of the locations had hourly recordings of weather data on magnetic tape for periods exceeding ten years. These hourly recordings were summarized in frequency distribution tables, called "wind roses" which tabulate the statistical distribution of wind speed for each five-degree range of ambient temperature. Wind roses were prepared from day and night data in order to allow the exclusion of solar heating during the night hours.

The hour-by-hour weather data used to make the wind roses was examined to determine whether prolonged periods of simultaneous still air and high temperature exist. No such prolonged periods were found; three successive hours at temperatures in excess of 25°C was the longest period recorded.

However, this examination of the wind roses for each of the locations revealed a higher than expected occurrence of recorded still air. The same data indicated few occurrences of one and two knot winds. The Environmental Sciences Services Administration (ESSA) was consulted for an explanation, and the wind roses were studied by their Science Advisory Group at the National Weather Records Center (NWRC.) The NWRC advised that due to bearing friction and inertia in the standard cup anemometers used by ESSA, many of these instruments will not begin to record until the wind speed exceeded two or three knots. A paper, "Bias Introduced by Anemometer Starting Speeds in Climatological Wind Rose Summaries" discussed this problem and concluded that there is indeed a strong measurement bias but offered no solution to the problem of how to overcome this bias. The NWRC suggested that the calm hours be apportioned over the zero, one, and two knot ranges. This reapportionment was made and the resulting adjusted weather data from several locations in PJM territory were combined into a single matrix. Computations using weather data from each individual location yielded results which were essentially identical to those computations made using the combined data. Based on this computation, it was decided that a single weather model can be used.

In order to complete the simulation of the operating experience of the conductor, it is necessary to determine the shape of the load cycle, which the conductors will experience.

A representative load cycle was prepared from studies of actual PJM line loadings. A step function approximation was made to represent this cycle.

The 2000 Task Force believed that if it had to purchase new weather data, the weather data would lead to the same conclusions, based on anecdotal information. Glenn Davidson, who did much of the original work as the Chair of the 1973 PJM Conductor Rating Task Force, and who attended the May 1999 meeting of this Task Force, also shared this opinion.

The 2009 Task Force accepted the assumptions made in the original PJM Conductor Rating calculations to remain valid and applicable. The 2022 Special Session team recognizes that the body of knowledge on climate change has exponentially increased in recent years. As such, it is recommended that the PJM TSS review applicable weather condition assumptions within the guideline and update with modern data reflecting a larger geographic area and account for the latest science around climate change. Given the level of effort expected of such a review, this task is not covered under this revision of the Rating Guide and is recommended for a subsequent effort so it does not hold up other critical revisions.

6.2. Definition of Planning and Seasonal Ratings Sets

For long-term system planning purposes, defined Summer and Winter planning ratings are needed to ensure adequate long-term system capacity. In this guide, the Summer season is defined as the nine-month period extending from March through November and having an ambient temperature of 35°C (95F). Winter is defined as the three-month period extending from December through February and having an ambient temperature of 10°C (50F). These values are very conservative as the winter temperatures are less than or equal to 10°C over 88% of the time. The actual summer temperatures are less than or equal to 35°C approximately 99% of the time. These are the values used by planners to determine the need to add transmission capacity.

FERC Order 881 now requires that operational "seasonal" ratings be defined for no less than 4 seasons with no single season lasting longer than 6 months for operational forecast ratings. This is not the same thing as conventional planning forecast ratings. In discussions with PJM Operating Committee representatives, the expectation is that PJM Operations may obtain any seasonal (or sub-seasonal) operating forecast ratings from the facility rating tables using the available ambient temperature bands calculated. Therefore, there is no expected immediate need to define a specific seasonal rating temperature in this guideline.

7. Maximum Conductor Temperature

Each Transmission Owner determines the maximum operating temperature for a conductor by consideration of several factors. Those factors include:

- The requirement to maintain clearance from the aerial line conductors to the ground and other features.

- The capability of the specific conductor type to operate at a given temperature without an unacceptable reduction in strength or corrosion protection.
- The compatibility of the conductor temperature with fittings and other line hardware and insulation and connected equipment limitations.

The National Electrical Safety Code (NESC) sets the minimum permissible clearance to ground and other features for aerial transmission lines. In some cases, the practice of Transmission Owners is to design and operate lines with a specified margin of clearance in excess of the NESC minimums. The PJM Transmission Owner Guidelines, Section V.A "PJM Design & Application of Overhead Transmission Lines 69kV and Above" recommends a 3-foot clearance buffer above the NESC requirements for most clearance calculations. The selected maximum operating temperature of line conductors shall be consistent with design and operating assumptions for maximum line sag and the Transmission Owners' design clearance to ground and other features and obstructions.

The minimum strength required for a conductor is set by the NESC and by specific requirements of the individual Transmission Owners. The strength requirement is a factored value of the design tension of the line. Application of high temperature to stranded conductors can reduce the strength of the conductor and could impact compliance with NESC and Transmission Owner requirements.

For conductors such as ACSR, ACAR, AAAC, and AAC that use hardened aluminum wires (1350-H19) or aluminum-alloy wires (6201-T81), the application of temperatures in excess of 100°C can result in annealing of the wires and loss of strength. The selection of the maximum operating temperature for these conductor types requires an assessment of the expected loss of strength over the expected life of the line compared to the required strength set by NESC or owner requirements. Section 6 examines the implications of elevated temperature operation and discusses risk assessment.

ACSS conductors use annealed aluminum wires (1350-0). The rated strength of ACSS conductors is primarily the strength of the steel core plus the small strength contribution of the annealed aluminum wires. Since the aluminum wires are already annealed, application of high temperature will not further reduce the strength of the wires or the overall conductor. In the case of ACSS conductors, the maximum temperature is limited by the temperature susceptibility of the protective coating of the steel core wires and temperature capability of dead-ends, spices, and other fittings. For newer ACSS conductors (>2000), the steel core wires typically use a zinc - 5% aluminum-mischmetal alloy coating (Galfan) instead of conventional galvanizing to permit operation up to 250°C. Older ACSS conductors likely still use a galvanized steel core and care should be taken when establishing the conductor maximum operating temperature as a result.

Conductor types with non-metallic cores (ACCC and ACCR, for example) use a composite material as the primary strength member of the conductor replacing the typical steel core wires. These conductor types use aluminum wires as the conductive component of the construction. The aluminum wires may be hardened, annealed, or may be a heat-resistant aluminum alloy (aluminum-zirconium, or Al-Zr). The maximum operating temperature of non-metallic core conductors or other conductors not covered above should be determined by the properties of the specific conductor materials, as set by the conductor manufacturer.

8. Effects of Elevated Temperature Operation

Operation of bare overhead conductors at elevated temperatures can have detrimental effects on the strength and sag characteristics of the conductor. Those effects can occur when operating temperatures exceed 100°C.

8.1. Loss of Strength due to Annealing

Annealing is the metallurgical process where applied temperature softens a hardened metal resulting in loss of tensile strength. As applied to bare, overhead conductors, annealing can degrade the strength of aluminum 1350-H19 wires: the wires used in ACSR and AAC conductors. About 70% of the strength of 1350-H19 aluminum is a result of hardening. Annealing of aluminum 1350-H19 begins at 93°C and is a function of both the magnitude of the temperature and the duration of the application. At lower temperatures (below 100°C), the effect is negligible. At higher temperatures (above 200°C), the effect can be significant and occur quickly.

The rated strength of a stranded conductor is the sum of the strengths of the individual wires, factored to account for stranding. An all-aluminum conductor (AAC) derives all its strength from the aluminum wires. In the case of AAC, the loss of strength of the conductor due to annealing is directly proportional to the degradation of the aluminum. Similarly, aluminum conductor, alloy reinforced conductors (ACAR) use both 1350-H19 wires and aluminum-alloy 6201-T81 wires. Both are subject to annealing, and the loss of strength for ACAR is directly proportional to the degradation of the aluminum and aluminum-alloy. For both AAC and ACAR conductors, the maximum allowable conductor temperature should not significantly exceed the annealing temperature of aluminum. Conductor operating temperatures of up to 100°C have a negligible risk of annealing the aluminum wires and are considered acceptable for AAC and ACAR conductors.

Aluminum conductor, steel reinforced conductors (ACSR) use a core of steel wires overlaid by one or more layers of aluminum 1350-H19 wires. The steel wires will not anneal at temperatures used for ACSR operation. For ACSR, the loss of strength of the conductor is a function of the loss of strength of the aluminum wire component of the conductor compared to the rated strength of both the aluminum and steel wires. A typical ACSR conductor derives about half it its strength from the steel wires and half from the aluminum wires. ACSR Drake (795kcmil 26/7), for example, derives 44% of its strength from the aluminum wires and 56% from the steel wires. If elevated temperature operation reduces the strength of the aluminum wires by 20%, the overall strength of the conductor will be reduced by 9%. Since the degradation of the aluminum wires only partially impacts the overall conductor strength, conductor temperature in excess of the annealing temperature of aluminum can be applied to ACSR such that the maximum loss of overall strength of the conductor is limited to 10%.

Some aerial conductor types are designed to eliminate or reduce the effect of annealing on conductor strength. Aluminum conductor, steel supported conductors (ACSS) use fully annealed aluminum 1350-0 wires over a core of steel wires. The strength of ACSS conductor is virtually all from the steel core. Since the aluminum wires are already annealed, elevated temperature operation has no effect on the strength of the aluminum wires or the conductor. Accordingly, the maximum temperature of ACSS conductors is set by the thermal capability of connectors and by the heat resistance of the protective coating on the steel wires.

New conductor constructions use composite core materials. These conductors also use aluminum wires surrounding the composite core that are either annealed or are heat resistant during high-temperature operation. The specific effects of temperature on these types of conductors should be obtained from the manufacturer.

Conductor Loss of Strength in % Based on PJM Weather Model

From the 1973 PJM Report

Conductor Size	Maximum Design Conductor Operating Temperature (°C)									
	100	110	120	125	130	140	150	160	170	180
2493 kcm 54/37 ACAR	2.83	3.76	5.77	7.56	9.72					
2312 kcm 76/19 ACSR	1.58	2.65	4.25	5.08	6.18	8.54				
2300 kcm 84/19 ACSR	0.00	0.68	1.95	2.76	3.55	5.57	7.77			
2167 kcm 72/7 ACSR	1.40	2.45	4.17	4.98	5.91	8.30				
2156 kcm 84/19 ACSR	0.00	0.18	1.49	2.26	2.96	4.90	7.11	9.93		
1780 kcm 84/19 ACSR	0.00	0.71	1.95	2.79	3.53	5.63	7.79			
1590 kcm 54/19 ACSR	0.00	0.00	0.00	0.20	0.80	2.30	4.20	6.40	8.40	
1590 kcm 45/7 ACSR	0.00	0.86	2.15	2.95	3.80	5.71	8.03			
1272 kcm 54/19 ACSR	0.00	0.00	0.00	0.18	0.86	2.43	4.19	6.24	8.30	10.47
1272 kcm 45/7 ACSR	0.00	0.85	2.25	2.94	3.87	6.09	8.17			
1033.5 kcm 54/7 ACSR	0.00	0.00	0.00	0.27	1.00	2.52	4.24	6.33	8.31	10.34
1033.5 kcm 45/7 ACSR	0.00	0.88	2.25	3.08	3.93	5.88	8.28			
795 kcm 30/19 ACSR	0.00	0.00	0.00	0.00	0.00	0.00	0.62	1.95	3.46	4.92
795 kcm 26/7 ACSR	0.00	0.00	0.00	0.00	0.00	1.20	2.80	4.40	6.20	8.00
634.9 kcm 12/7 ACAR	3.09	4.19	6.23	7.77	9.98					
556.5 kcm 24/7 ACSR	0.00	0.00	0.00	0.42	1.06	2.80	4.20	5.88	7.85	9.74
477 kcm 26/7 ACSR	0.00	0.00	0.00	0.00	0.26	1.68	2.94	4.34	6.07	7.92
336 kcm 26/7 ACSR	0.00	0.00	0.00	0.04	0.58	1.92	2.94	4.37	5.98	7.82
336.4 kcm 18/1 ACSR	1.30	2.56	4.78	5.83	6.98	9.03				
300 kcm 26/7 ACSR	0.00	0.00	0.00	0.08	0.74	2.02	2.94	4.32	6.08	7.87
300 kcm 19 str AAC	5.43	7.61	10.28							

Assumptions: Conductor operates for 35 years to PJM Load Cycle as shown in Appendix #3, Pg A-7, Figure #3
Conductor emissivity =0.7 and apsorptivity =0.9
Winter Rating Conditions: Normal 20 °C, no wind / Emerg 10 °C, 1 knot
Summer Rating Conditions: Normal 35 °C, no wind / Emerg 20 °C, 1 knot

Figure 8-1

8.2. Predicting Loss of Strength of Conductors due to Annealing

Calculating the projected loss of strength of ACSR and other conductors subject to annealing at elevated temperatures requires a complex analysis of the metallurgical aspects of the wires and the probability of weather and electrical power flow conditions. The operating temperature of the conductor is a function of several inter-related parameters that include wind and the current being carried. The line rating and the associated conductor operating temperature are based on electric current and weather parameters that are conservative to ensure safe and reliable system operation. However, actual wind speeds will generally be higher than that assumed for ratings, and actual electrical load will generally be less than the full line rating. Thus the conductor operating temperature of most lines will almost always be lower than the maximum temperature used for rating the line. Most lines will experience design-case conditions and operating temperatures for a few hours a year, at most.

The loss of strength due to annealing of the aluminum wires is a temperature and time dependent phenomenon. The key to determining the probable loss of strength over the expected life of the conductor is to predict the amount of time the conductor will experience temperatures that will result in annealing. That time prediction requires an assessment of the projected load patterns of the line and the predicted wind patterns. Once a matrix of load and wind is established, a tabulation of conductor temperatures and expected durations can be developed. From that tabulation the cumulative annealing effect can be calculated and the projected remaining strength of the conductor can be determined.

Appendix 2 provides guidance to the calculation of predicted loss of strength of conductors subject to annealing. The information and sample calculation in Appendix 2 is highly simplified and is not appropriate for all conditions.

For specific information regarding the effect of high temperature operation on bare overhead conductors see:

IEEE-1283-2004; *IEEE Guide for Determining the Effects of High-Temperature Operation on Conductors, Connectors, and Accessories*; Institute of Electrical and Electronics Engineers

8.3. Creep Effects of Elevated Temperature Operation

Operation of conductors at high temperature can increase the creep effect of conductors affecting sag. Creep is the non-elastic relaxation of material over time. The effect of creep on aerial conductors is to have line sag increase over years even in the absence of extreme loading events. Aluminum 1350-H19 wires are subject to creep. Lines designed for elevated temperature operation should have sags and tensions derived with creep as a consideration in order to ensure adequate clearance to ground and other obstructions over the long term.

8.4. Aluminum Wire Compression of ACSR Conductors Operating at Elevated Temperatures

Research has indicated that ACSR conductors exposed to high temperature operation can sag more than the values predicted by conventional sag-tension programs. This is the result of the aluminum wires going into compression at high temperatures. The coefficient of thermal expansion of aluminum wire is higher than that of steel wire. Subject to elevated temperatures, the aluminum wires of ACSR will attempt to lengthen more than the steel wires. Since the aluminum wires are held tightly to the steel wires by the stranding, the aluminum wires will be forced to the same elongation as the steel wires. The result is that the aluminum wires at high temperature will either buckle outward in an effect called “bird caging”, or the wires will go into a compressive stress state. If the aluminum wires go into compression, they will impose an equal tensile force on the steel wires. That additional tension will clause the steel wires to elongate more than predicted by conventional methods and will result in greater line sag. The greater sag could result in unexpected clearance issues.

The actual, real world impact of aluminum wire compression is not clear. Typically it is not an issue for operating temperatures up to 120°C. Even at higher temperature it may range from nothing, if the aluminum wires are assumed to birdcage and relieve compression, to 100% of theoretical aluminum wire compression. For a typical line using ACSR Drake conductor with 900-foot spans and operating at 140°C, the additional sag resulting from the assumption of aluminum wire compression is about 2 feet.

Most modern sag-tension calculation programs permit analysis assuming aluminum wire compression as an option. The decision to assume compression of the aluminum wires of ACSR should be governed by operating experience.

9. Fittings/Accessories/Hardware

Fittings used on a transmission line serve both electrical and mechanical functions. Conductor fitting must be compatible with the conductor type and the selected maximum operating conductor temperature.

Electrically, the fittings must establish and maintain low contact resistance, must not generate radio noise at the design voltage and must not exceed the temperature of the conductor.

Mechanically, full tension fittings must be capable of holding 95% of the conductor’s rated strength and non-tension fittings should be capable of holding at least 10% of the rated strength of the conductor.

Compression fittings, properly installed with the manufacturer’s recommended practice and appropriate joint compound, are capable of transferring the maximum current.

Fittings used with conductors operating at high temperature, shall be designed specifically for high temperature operation. Lines using conventional fittings should not be operated at temperatures in excess of the fitting capability regardless of the conductor type unless the hardware has been electrically shunted for reduced temperature operation. If the rating of an existing line is to be increased by increasing the maximum operating temperature, an assessment should be made to ensure the compatibility of the existing fittings with the proposed operation and appropriate mitigation completed before increasing the operating temperature of the line.

10. Risk

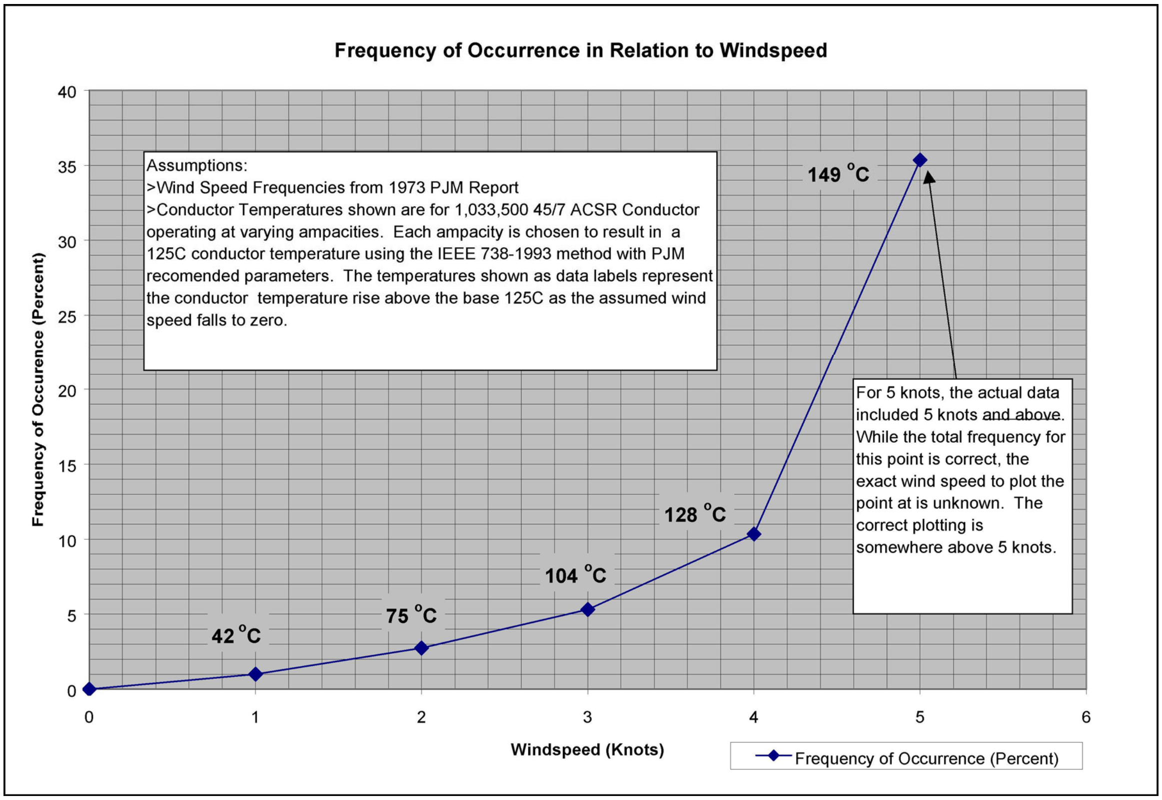
As discussed previously, overhead conductor ratings are affected by many factors, but the most significant of these many parameters is wind speed. But unlike many of the other factors such as absorptivity, ambient temperature, conductor resistance, etc., wind speed is truly variable in magnitude and direction. In the early PJM work, summarized by the "Determination of Thermal Ratings for Bare Overhead Conductor, 1973", weather data was collected from Washington DC over a period of 16 years, and from Pittsburgh over a 10 year period. These data were pooled to represent a 26-year span for an average PJM condition. The weather data were summarized on pages A18 and A19 in the 1973 Report in a table format for the frequency distribution of wind and ambient temperature conditions. The tables are reprinted in this report as Appendix 1, Tables 12-1 and 12-2. In these tables each row list the probability of occurrence of a given wind speed at a specified ambient temperature. Alternately, each row gives the probability of occurrence of different ambient temperatures given the particular wind speed.

When rating transmission conductors, the choice of wind speed is important due to the significant effect on the rating. While a higher wind speed is desired for the higher rating, there is a cost. What happens if the actual wind speed that occurs along the transmission line is less than the assumed value? As the original PJM work showed, the wind speed is characterized by a distribution of wind speeds with higher and lower values. A wind speed lower than assumed would drive a higher conductor temperature than assumed. For example, if a rating were based upon 100°C with 2 feet/sec. of wind and a lesser wind were to occur it would cause an increase in conductor temperature above 100°C. This risk of increase in conductor temperature is called temperature risk.

The duration of these lower wind speeds is also of concern. The acceptability of a temperature risk changes with the duration of that risk. For example, while a temperature overrun of 25°C would not be of major concern for 5 minutes, it would be more problematic if it were for 6 hours during mid-day. The risk due to the duration of an over temperature condition is called time risk.

Figure 10-1 shown below depicts these risks. On the horizontal axis are listed wind speeds, and on the vertical axis are the probabilities of wind speeds at or less than the listed values. For example wind speeds of 1 knot (1.69 ft./sec.) or less are likely 1% of the time, and this increases to 10% for 4 knots (6.76 ft./sec.) of wind.

Figure 10-1



This chart also details the temperature risk as the labels next to each data point. For example, with 3 knots of wind the temperature of an overhead transmission conductor would increase in temperature by up to 104°C at different combinations of ambient temperatures and lesser wind speeds. For this 3-knot condition, the temperature risk would be 104°C with the time risk equivalent to 5% of the time, or 438 hours per year.

The original PJM CRTF evaluated these risks and developed a reasonable approach to manage these risks. Normal ratings were to be based upon 0 knots of wind. This is a conservative approach since there is no risk that a lesser wind speed would occur. Therefore there is neither temperature nor time risk. The original PJM work determined that a conductor would operate under emergency conditions for 350 hours over its 35 year life (0.1%). As a result, this approach was chosen knowing that the normal rating applies 99.9% of the time. However, the original CRTF did acknowledge the need for an increased rating for an emergency condition. In an effort to provide this capability, an emergency rating based upon 1 knot of wind was selected. This condition resulted in a 1% risk of a lesser wind speed occurring (time risk) and this was believed to be acceptable for an emergency condition. Additionally, the temperature risk was calculated to be approximately 30°C for the commonly used PJM 230 kV Lapwing transmission conductor. While this is fairly significant, the resulting increase in conductor sag was calculated to be approximately 2 feet for a standard 230 kV span length and tension. This increase in sag was up to about 3 feet safety factor that all PJM companies added to the required ground clearance requirements. Therefore the temperature risk was actually of no effect since NESC clearances were not violated.

The recommendation of the 1999 CRTF and the 2009 Ad Hoc group regarding wind and weather assumptions for normal and emergency ratings is given in Section 11.0. The 2022 Special Session working group recommends future work and research on the appropriate wind speeds and risks within the PJM TO footprint.

10.1. Emergency Ratings

Emergency ratings are provided for abnormal out of configuration system conditions. These ratings allow the system operators to take advantage of ambient wind speed to ride through short time duties without endangering the public.

Since a 1% risk is accepted for emergency ratings, these ratings are limited to abnormal configurations and a very specific duration. The longer the short time duration, the more risk is assumed.

Emergency Rating periods are not to exceed 24 hours. Due to the thermal time constant of electrical conductors, all emergency ratings longer than 15 minutes are essentially the same. The only increase available is by assuming more risk.

10.2. Load Dump Ratings

Load dump ratings are calculated on a similar basis as Emergency Ratings except that the duration of the Load Dump period shall not exceed 15-minutes. The same conditions as stated in Section 10.1 for Emergency Ratings apply; however, initial conditions are based upon parameters set forth in section 11.

11.Parameters for Calculations

This section of the report summarizes the assumed program parameters for normal and emergency conditions. The user may select values that differ from the ones given below provided they have a sound engineering basis for the deviation(s).

11.1. Normal Conditions

Normal Operating Conditions assume that all equipment and conductors are available and in normal operating configuration. The normal weather conditions, as listed below, are assumed to exist during normal operating conditions. During normal weather conditions it is assumed that the conductor under consideration can operate at continuous duty. The normal ratings are based upon normal weather conditions and have insignificant risk of exceeding the conductor's design temperature since they incorporate a zero wind speed.

Typical Normal Conditions-Summer

Ambient Temperature:	**35°C (95F)**
Wind Speed:	0 feet per second
Wind Direction:	90° to conductor
Solar/ Sky:	Day -Industrial
Elevation:	200 ft above sea level
Max. Allowable conductor temp.:	100°-250°C(material dependent)
Latitude:	40° North
Sun Time:	14:00
Emissivity:	0.7
Absorptivity:	0.9

Typical Normal Conditions-Winter:

Ambient Temperature:	**10°C (50F)**
Wind Speed:	0 feet per second
Wind Direction:	90° to conductor
Solar/ Sky:	Day - Industrial
Elevation:	200 ft above sea level
Max. Allowable conductor temp.:	100-250°C(material dependent)
Latitude:	40° North
Sun Time:	14:00
Emissivity:	0.7
Absorptivity:	0.9

Note: The ambient temperatures above are used for long-term system planning. Ambient temperatures will be adjusted according to actual temperatures and forecast ambient temperatures for short-term future ratings (+10 days)..

11.2. Emergency & Load Dump Conditions

Emergency Operating Conditions require that the conductor under consideration operate for a short time above its normal rating. The weather conditions for conductor rating during emergency conditions are specified below. Therefore, this short time emergency rating is limited to no more than 24 hours per occurrence and 15 minutes for load dump ratings. These ratings are based upon a 1 % risk of exceeding the conductor's design temperature.

Typical Emergency Conditions-Summer:

Ambient Temperature:	**35°C (95F)**
Wind Speed:	1.5 Kt. (2.533 ft/sec.)
Wind Direction:	90° to conductor
Solar/ Sky Radiated Heat Flux:	Day - Industrial
Elevation:	200 ft above sea level
Max. Allowable conductor temp.:	100-250°C(material dependent)
Latitude:	40° North
Sun Time:	14:00
Emissivity:	0.7
Absorptivity:	0.9

Typical Emergency Conditions-Winter:

Ambient Temperature:	**10°C (50F)**
Wind Speed:	1.5 Kt. (2.533 ft/sec.)
Wind Direction:	90° to conductor
Solar/ Sky Radiated Heat Flux:	Day - Industrial
Elevation:	200 ft above sea level
Max. Allowable conductor temp.:	100-250°C(material dependent)
Latitude:	40° North
Sun Time:	14:00
Emissivity:	0.7
Absorptivity:	0.9

Note: The ambient temperatures above are used for long-term system planning. Ambient temperatures will be adjusted according to actual temperatures and forecast ambient temperatures for short-term future ratings (+10 days).

Discussion of Assumptions for Ampacity Calculations Using the Method of IEEE Std. 738-2012

Day and Night Ratings

Daylight hours are, for operating purposes, between sunrise and sunset. Night ratings should be used during all other periods.

Atmosphere

The task force evaluated the environmental conditions in the PJM service area and selected the "industrial" atmosphere.

Sun Time
The sun times available for use range between 10:00 am and 2:00 pm in hourly steps. The task force chose 2:00 p.m. because that time is nearest to the typical peak ambient temperature.

Latitude
The task force chose 40 degrees north as this latitude approximately divides the PJM service territory in half.

Conductor Direction
The task force studied a geographic map of the PJM service territory and determined that it became apparent that most lines are primarily oriented east-west. Therefore, this direction was chosen as the input for the program.

Wind Direction
The task force chose the wind angle of 90 degrees to the conductor, which is consistent with earlier PJM work. It also results in maximum cooling for any given wind speed.

Conductor Elevation
The task force discussed the various terrain and elevations within their respective areas and agreed to a conductor elevation of 200 feet above sea level as a good average value.

Conductor Resistance
Conductor AC resistance values are calculated by each manufacturer and these values may vary for the same conductor type and size. This can cause a variance in the rating calculation. ASTM committee B-1 is considering development of a standardize methodology for calculating AC resistance values. Until ASTM issues their methodology document it is recommended that each utility consistently use ac resistance values from one source. The AC resistance values used in the PJM rating spreadsheet are listed in the spreadsheet. Each utility is responsible to verify that the ac resistance values in the spreadsheet meet their standard.

Emissivity/Absorptivity
The Special Session has elected to maintain the emissivity and absorptivity values from prior report versions; however, the user is encouraged to adjust the values based on experience and engineering evaluations. In addition, the emissivity and absorptivity values must be adjusted for conductors with special coatings designed to change these values.

The values used are:

emissivity = 0.7,
absorptivity = 0.9 for daytime and 0.0 for nighttime.

For additional discussion, see Appendix C of the 1973 PJM Report. While these values are generally supported in Cigre TB 299, recent EPRI testing indicates that they may not be conservative. Using accurate emissivity data is important particularly when dealing with high temperature operation as the radiative heat loss is proportional to the emissivity times the conductor temperature raised to the 4^{th} power.

Conductor Temperature

Maximum conductor operating temperature should be between 100°C and 250°C.

12. IEEE Standard 738-2012 For Calculating the Current-Temperature of Bare Overhead Conductors

The 2022 Special Study working group was tasked with updating the existing "PJM OHT Conductor Rating Spreadsheet" to comply with FERC Order 881. This update required changing the output tables from 5C ambient temperature increments to 5F ambient temperature increments and to expand the minimum and maximum ambient temperature range to include a 10F margin above the highest recorded high temperature and below the lowest recorded low temperature in the PJM region.

The new "PJM OHT Conductor Rating" spreadsheet is based on the overhead conductor methodology as set forth in IEEE 738-2012, "Standard for Calculating the Current Temperature of Bare Overhead Conductors" which may be purchased by the user from a variety of sources at a nominal cost. Further, the method is based upon the 1958 work of House and Tuttle as modified by a group sponsored by the East Central Area Reliability Co-Ordination Agreement (ECAR) and is similar to the "PJM Method" of calculating bare overhead conductor ratings. Due to the iterative process of calculating load dump ratings, the spreadsheet was written using Visual Basic in Microsoft Excel. All the parameters contained in IEEE 738-2012 may be modified in the spreadsheet. The PJM parameters listed in section 11 have been set as default.

The database contains most transmission conductors in service today. The spreadsheet's database has been designed so additional conductors may be easily added. A copy of the spreadsheet is publicly available on the PJM Transmission Owner Guidelines website.

12.1. Description of IEEE 738

The standard presents a method of calculating the current-temperature relationship of bare overhead conductors.

The conductor temperature is a function of:

- Conductor material
- Conductor diameter
- Conductor surface condition
- Ambient weather conditions
- Conductor electrical current

This standard includes mathematical methods for the calculation of conductor temperatures and conductor thermal ratings. Due to a great diversity of weather conditions and operating circumstances for which conductor temperatures and/or thermal ratings must be calculated, the standard does not list actual temperature-current relationships for specific conductors or weather conditions. Each user must make an assessment of which weather data and conductor characteristics are appropriate.

The equations relating electrical current to conductor temperature may be used in either of the following two ways:

- To calculate the conductor temperature when the electrical current is known
- To calculate the current that yields a given maximum allowable conductor temperature

The calculation methods developed in this standard are also valid for the calculation of conductor temperature under fault conditions.

13.Comparison of the PJM OHT Conductor Rating Spreadsheet

A comparison was made between the results of the PJM Ratings spreadsheet, Rate Kit and PLS Cadd using 795 ACSR 26/7 “Drake” conductor. The maximum conductor operating temperature was chosen to be 140 °C and the AC resistance of the conductor was fixed at 0.177Ω/1000 ft @25 °C and 0.139Ω/1000 ft @75 °C for all runs. All other parameters were set to the PJM default values listed in section 9. The results between the PJM spreadsheet and the two programs varied by less than 1%. Figure 12-1 shows the results of the comparison.

Conductor = ACSR 795 KCMIL 26/7 Drake
AC Resistance = RAC@25°C = 0.117 Ω/1000 ft
RAC@75°C = 0.139 Ω/1000 ft
Max Operating Temperature =140°C

PJM RATING SPREADSHEET COMPARISON WITH RATE KIT AND PLS CADD

Aerial Conductor Thermal Rating

Ambient Temp		Daytime Rating									Nighttime Rating									MAX. DELTA
		Normal Amps			Emergency Amps			Load Dump Amps			Normal Amps			Emergency Amps			Load Dump Amps			
(°C)		PJM Sheet	RateKit 5.0	PLS Cadd	PJM Sheet	RateKit 5.0	PLS Cadd	PJM Sheet	RateKit 5.0	PLS Cadd	PJM Sheet	RateKit 5.0	PLS Cadd	PJM Sheet	RateKit 5.0	PLS Cadd	PJM Sheet	RateKit 5.0	PLS Cadd	%
-15	Amps	1418	1417	1415	1718	1718	1715	1856	1842	1840	1475	1475	1473	1766	1766	1763	1907	1893	1891	-
	Delta	-	1	3	-	0	3	-	14	17	-	0	3	-	0	3	-	14	16	-
	%	-	-0.04	-0.18	-	-0.03	-0.19	-	-0.77	-0.90	-	-0.03	-0.18	-	-0.03	-0.18	-	-0.71	-0.84	-0.90
-10	Amps	1392	1392	1390	1693	1693	1690	1827	1813	1811	1451	1451	1449	1742	1741	1739	1877	1865	1862	-
	Delta	-	0	3	-	0	3	-	14	16	-	0	3	-	1	3	-	12	15	-
	%	-	-0.03	-0.18	-	-0.01	-0.18	-	-0.75	-0.87	-	-0.02	-0.18	-	-0.05	-0.18	-	-0.66	-0.80	-0.87
-5	Amps	1367	1366	1364	1667	1667	1664	1796	1784	1782	1427	1426	1424	1717	1716	1714	1848	1836	1834	-
	Delta	-	1	3	-	0	3	-	12	15	-	1	3	-	1	3	-	12	14	-
	%	-	-0.07	-0.19	-	-0.02	-0.19	-	-0.69	-0.82	-	-0.06	-0.20	-	-0.05	-0.16	-	-0.64	-0.76	-0.82
0	Amps	1341	1340	1338	1641	1640	1638	1766	1754	1752	1402	1402	1399	1691	1691	1688	1818	1806	1804	-
	Delta	-	1	3	-	1	3	-	12	14	-	0	3	-	0	3	-	12	13	-
	%	-	-0.07	-0.19	-	-0.05	-0.19	-	-0.66	-0.78	-	0.01	-0.18	-	-0.01	-0.18	-	-0.64	-0.73	-0.78
5	Amps	1314	1314	1312	1614	1613	1611	1734	1723	1721	1377	1376	1374	1665	1664	1662	1787	1777	1774	-
	Delta	-	0	2	-	1	3	-	11	13	-	1	2	-	1	3	-	10	13	-
	%	-	-0.04	-0.19	-	-0.05	-0.19	-	-0.66	-0.76	-	-0.05	-0.18	-	-0.05	-0.18	-	-0.56	-0.70	-0.76
10	Amps	1288	1287	1285	1586	1585	1583	1702	1692	1690	1351	1351	1349	1638	1637	1635	1756	1746	1744	-
	Delta	-	1	2	-	1	3	-	10	12	-	0	2	-	1	3	-	10	12	-
	%	-	-0.04	-0.19	-	-0.06	-0.19	-	-0.62	-0.73	-	0.00	-0.18	-	-0.05	-0.18	-	-0.56	-0.69	-0.73
15	Amps	1260	1260	1257	1557	1557	1555	1670	1660	1659	1325	1324	1322	1610	1610	1607	1724	1715	1713	-
	Delta	-	0	3	-	0	3	-	10	11	-	1	2	-	0	3	-	9	11	-
	%	-	0.00	-0.24	-	-0.03	-0.19	-	-0.59	-0.68	-	-0.06	-0.18	-	-0.02	-0.18	-	-0.52	-0.64	-0.68
20	Amps	1232	1232	1230	1528	1528	1525	1637	1628	1626	1298	1298	1296	1582	1581	1579	1691	1683	1681	-
	Delta	-	0	2	-	0	3	-	9	11	-	0	2	-	1	3	-	8	11	-
	%	-	0.00	-0.19	-	-0.01	-0.19	-	-0.52	-0.67	-	-0.01	-0.18	-	-0.06	-0.18	-	-0.50	-0.64	-0.67
25	Amps	1203	1203	1201	1498	1497	1495	1602	1594	1592	1271	1271	1269	1553	1552	1550	1658	1650	1648	-
	Delta	-	0	2	-	1	3	-	8	10	-	0	2	-	1	3	-	8	10	-
	%	-	-0.02	-0.19	-	-0.06	-0.19	-	-0.53	-0.63	-	0.01	-0.18	-	-0.05	-0.18	-	-0.49	-0.61	-0.63
30	Amps	1174	1173	1172	1467	1466	1464	1568	1560	1558	1243	1243	1240	1523	1522	1520	1624	1617	1615	-
	Delta	-	1	2	-	1	3	-	8	10	-	0	3	-	1	3	-	7	9	-
	%	-	-0.07	-0.19	-	-0.05	-0.19	-	-0.48	-0.61	-	-0.01	-0.25	-	-0.05	-0.18	-	-0.44	-0.55	-0.61
35	Amps	1144	1143	1142	1435	1434	1432	1532	1525	1523	1215	1214	1212	1492	1491	1489	1589	1583	1581	-
	Delta	-	1	2	-	1	3	-	7	9	-	1	3	-	1	3	-	6	8	-
	%	-	-0.06	-0.19	-	-0.05	-0.19	-	-0.43	-0.58	-	-0.05	-0.22	-	-0.06	-0.19	-	-0.40	-0.52	-0.58
40	Amps	1113	1112	1111	1402	1401	1398	1495	1489	1487	1185	1185	1183	1460	1460	1457	1554	1548	1546	-
	Delta	-	1	2	-	1	4	-	6	8	-	0	2	-	0	3	-	6	8	-
	%	-	-0.06	-0.20	-	-0.04	-0.25	-	-0.39	-0.55	-	-0.04	-0.21	-	0.00	-0.20	-	-0.36	-0.48	-0.55
MAXIMUM DELTA %			-0.07	-0.24	-	-0.06	-0.25	-	-0.77	-0.90	-	-0.06	-0.25	-	-0.06	-0.20	-	-0.71	-0.84	**-0.90**

PJM Sheet Ratings calculated per PJM RATING SPREADSHEET v1.20 per IEEE 738™-2006
RateKit 5.0 Ratings calculated RateKIT™v5.0 per IEEE 738™-2002
PLS Cadd Ratings calculated per PLS CADD V10.2 per IEEE 738™-2006

A second comparison of the spreadsheet was performed with the PJM OHT Ratings Spreadsheet and Ratekit using several different conductors and maximum operating temperatures. The deviation between the two methods was found to be less than 1%. Figure 12-2 shows the results of the comparison.

Conductor = *See table*
AC Resistance = *See table*

Max Operating Temperature =see table (Max T °C)

PJM RATING SPREADSHEET RATING COMPARISON WITH RATE KIT- DAYTIME

Aerial Conductor Thermal Rating

NAME	TYPE	SIZE	STRANDING	RAC@ 25°C Ω/1000 ft	RAC@ 75°C Ω/1000 ft	**Ambient Temp** (°C)	**Daytime Rating** **Normal Amps** Max T °C	PJM Sheet	RateKit 5.0	Delta	%	**Emergency Amps** Max T °C	PJM Sheet	RateKit 5.0	Delta	%	**Load Dump Amps** Max T °C	PJM Sheet	RateKit 5.0	Delta	%	Max Delta %
HEN	ACSR	477	30/7	0.03617	0.04337	35	140	806	807	-1	0.12	140	1037	1037	0	0.00	140	1082	1077	5	0.46	0.46
						10		908	908	0	0.00		1147	1147	0	0.00		1204	1197	7	0.58	0.58
DRAKE	ACSR	795	26/7	0.11700	0.13900	35	125	1041	1040	1	0.10	125	1331	1331	0	0.00	125	1427	1419	8	0.56	0.56
						10		1199	1199	0	0.00		1500	1499	1	0.07		1616	1604	12	0.74	0.74
CURLEW	ACSR	1033.5	54/7	0.01723	0.02045	35	140	1364	1363	1	0.07	140	1690	1689	1	0.06	140	1828	1816	12	0.66	0.66
						10		1535	1534	1	0.07		1867	1867	0	0.00		2030	2013	17	0.84	0.84
FALCON	ACSR	1590	54/19	0.01157	0.01366	35	140	1835	1834	1	0.05	140	2222	2222	0	0.00	140	2472	2452	20	0.81	0.81
						10		2063	2062	1	0.05		2455	2454	1	0.04		2740	2714	26	0.95	0.95
BLUEBIRD	ACSR	2156	84/19	0.00903	0.01051	35	140	*2226*	*2226*	0	0.00	140	*2661*	*2660*	1	0.04	140	3000	*2983*	17	0.57	0.57
						10		*2502*	*2501*	1	0.04		*2938*	*2938*	0	0.00		3320	*3291*	29	0.87	0.87
PECOS	ACSS/TW	2156	84/19	0.01098	0.01303	35	250	*2757*	*2756*	1	0.04	250	*3132*	*3131*	1	0.03	250	3356	*3356*	0	0.00	0.04
						10		*2889*	*2888*	1	0.03		*3262*	*3261*	1	0.03		3506	*3474*	32	0.91	0.91
						Max Delta					0.12					0.07					0.95	**0.95**

PJM RATING SPREADSHEET RATING COMPARISON WITH RATE KIT- NIGHT TIME

Aerial Conductor Thermal Rating

NAME	TYPE	SIZE	STRANDING	RAC@ 25°C Ω/1000 ft	RAC@ 75°C Ω/1000 ft	**Ambient Temp** (°C)	**Nighttime Rating** **Normal Amps** Max T °C	PJM Sheet	RateKit 5.0	Delta	%	**Emergency Amps** Max T °C	PJM Sheet	RateKit 5.0	Delta	%	**Load Dump Amps** Max T °C	PJM Sheet	RateKit 5.0	Delta	%	Max Delta %
HEN	ACSR	477	30/7	0.03617	0.04337	35	140	854	854	0	0.00	140	1075	1075	0	0.00	140	1121	1116	5	0.45	0.45
						10		951	951	0	0.00		1181	1181	0	0.00		1240	1233	7	0.56	0.56
DRAKE	ACSR	795	26/7	0.11700	0.13900	35	125	1121	1121	0	0.00	125	1395	1395	0	0.00	125	1491	1483	8	0.54	0.54
						10		1270	1270	0	0.00		1557	1557	0	0.00		1674	1663	11	0.66	0.66
CURLEW	ACSR	1033.5	54/7	0.01723	0.02045	35	140	1450	1450	0	0.00	140	1760	1760	0	0.00	140	1890	1886	4	0.21	0.21
						10		1612	1611	1	0.06		1931	1931	0	0.00		2095	2080	15	0.72	0.72
FALCON	ACSR	1590	54/19	0.01157	0.01366	35	140	1954	1954	0	0.00	140	2322	2322	0	0.00	140	2570	2551	19	0.74	0.74
						10		2170	2169	1	0.05		2545	2545	0	0.00		2831	2807	24	0.85	0.85
BLUEBIRD	ACSR	2156	84/19	0.00903	0.01051	35	140	2374	*2373*	1	0.04	140	2786	*2786*	0	0.00	140	3122	*3102*	20	0.64	0.64
						10		2634	*2634*	0	0.00		3052	*3052*	0	0.00		3432	*3406*	26	0.76	0.76
PECOS	ACSS/TW	2156	84/19	0.01098	0.01303	35	250	2818	*2817*	1	0.04	250	3185	*3184*	1	0.03	250	3411	*3384*	27	0.79	0.79
						10		2947	*2946*	1	0.03		3313	*3313*	0	0.00		3559	*3529*	30	0.84	0.84
						Max Delta					0.06					0.03					0.85	**0.85**

PJM Sheet Ratings calculated per PJM RATING SPREADSHEET v1.20 per IEEE 738™-2006
RateKit 5.0 Ratings calculated RateKIT™v5.0 per IEEE 738™-2002

14. References

T72 189-4 “Effect of Elevated Temperature on the Strength of Aluminum Conductors” by J. R. Harvey

IEEE Paper C72 188-6 “Effect of Elevated Temperature on the Performance of Conductor Accessories” by W. B. Howett and T. E. Simpkins

Southwire “Overhead Conductor Manual,”2007

IEEE Std. 738-2012 “IEEE Standard for Calculating the Current - Temperature Relationship of Bare Overhead Conductors"

IEEE Std. 1283-2013 “IEEE Guide for Determining the Effects of High-Temperature Operation on Conductors, Connectors, and Accessories"

PJM Circuit Rating Review, C&TPS Report to P&E Committee, May 1986

PJM Transmission Owner Guidelines, Section V.A

Appendix 1: Frequency Distribution of Wind and Ambient Temperature Conditions

Table A1-1 – SUMMER

COMPOSITE 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*
0	0.009	0.025	0.042	0.024	0.059	0.070	1.830
5	0.038	0.115	0.195	0.247	0.326	0.427	6.455
10	0.059	0.176	0.299	0.345	0.519	0.634	8.811
15	0.070	0.209	0.355	0.484	0.741	0.955	11.147
20	0.103	0.311	0.528	0.655	1.049	1.401	14.559
25	0.109	0.324	0.550	0.791	1.405	1.743	17.949
30	0.059	0.178	0.302	0.496	0.962	1.381	14.708
35	0.012	0.034	0.058	0.127	0.261	0.389	4.650
Over 35	0.000	0.001	0.001	0.003	0.009	0.010	0.187
	0.459	***1.373***	***2.330***	***3.172***	***5.331***	***7.010***	***80.296***

SUMMER NIGHTS

WIND SPEED-KNOTS

AMBIENT TEMP. °C	*0*	*1*	*2*	*3*	*4*	*5*	*OVER 5*
0	0.031	0.090	0.153	0.114	0.248	0.271	2.998
5	0.125	0.373	0.632	0.659	0.921	1.135	8.495
10	0.174	0.524	0.887	0.987	1.340	1.453	10.003
15	0.257	0.773	1.312	1.174	1.654	2.089	11.975
20	0.351	1.020	1.730	1.582	2.254	2.600	13.952
25	0.236	0.711	1.207	1.671	2.205	2.582	12.846
30	0.037	0.112	0.188	0.342	0.426	0.516	2.490
35	0.000	0.001	0.002	0.006	0.013	0.011	0.064
Over 35	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	1.211	***3.604***	***6.111***	***6.535***	***9.061***	***10.657***	***62.823***

Note: Data is taken from page A-18, of 1973 PJM report, "Determination of Thermal Ratings for Bare Overhead Conductors".

Table A1-2 – WINTER

COMPOSITE 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*
0	0.105	0.321	0.541	0.751	1.315	1.649	22.146
5	0.233	0.695	1.184	1.633	2.380	2.912	31.418
10	0.118	0.354	0.600	0.875	1.079	1.351	16.749
15	0.046	0.134	0.230	0.282	0.344	0.433	7.302
20	0.007	0.023	0.039	0.062	0.062	0.082	2.164
25	0.000	0.000	0.000	0.003	0.000	0.003	0.348
30	0.000	0.000	0.000	0.000	0.000	0.000	0.007
35	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~~
	0.509	***1.527***	***2.594***	***3.606***	***5.180***	***6.430***	***80.134***

WINTER NIGHTS

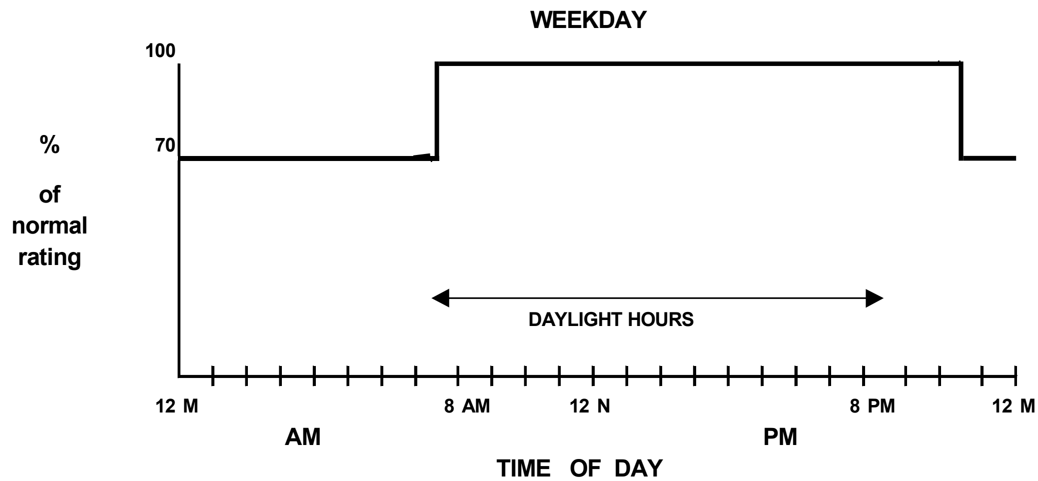
WIND SPEED-KNOTS

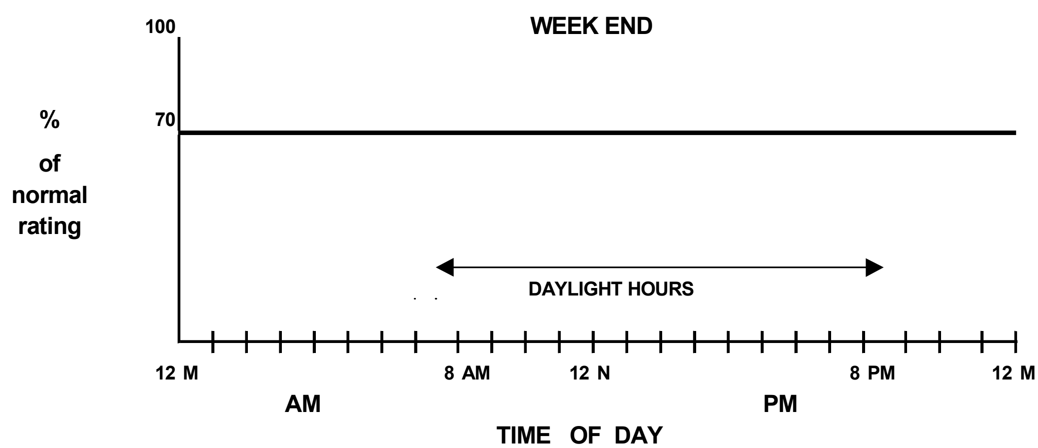
AMBIENT TEMP. °C	*0*	*1*	*2*	*3*	*4*	*5*	*OVER 5*
0	0.287	0.856	1.453	1.581	2.709	3.038	27.265
5	0.450	1.345	2.282	2.778	3.286	3.592	28.548
10	0.136	0.411	0.791	0.709	0.884	1.073	10.873
15	0.023	0.078	0.132	0.151	0.213	0.190	3.953
20	0.004	0.008	0.016	0.004	0.012	0.012	0.918
25	0.000	0.000	0.000	0.000	0.000	0.000	0.008
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	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~~
	0.900	***2.698***	***4.674***	***5.223***	***7.104***	***7.905***	***71.565***

~~Note:~~ Data is taken from page A-19, of 1973 PJM report, "Determination of Thermal Ratings for Bare Overhead Conductors".

Figure A1-3

PJM LOAD CYCLE
(SUMMER AND WINTER)





Appendix 2: Example of Loss of Strength Calculations

Example of Loss of Strength Calculation for 1590 kcmil 45/7 ACSR (Lapwing)

The following Temperatures and Durations were obtained from the weather model computer program developed for the 1973 PJM conductor report

Temperature (°C)	Duration (Hours)
100	402
105	284
110	225
115	132
120	67
125	14
130	1
135	1

From the Paper "Effect of Elevated Temperature Operation on the Strength of Aluminum Conductors" (reference 13.1) the following equations and variables for calculating loss of strength in ACSR conductors are:

$$\text{RS} = \text{RS EC} * \left(\frac{\text{STR EC}}{\text{STR T}}\right) + 100 * \left(\frac{\text{STR ST}}{\text{STR T}}\right) * 1.09$$

$$\text{RS EC} = \left(-0.24 * \text{T} + 134\right) * \text{t}^{-(0.001 * \text{T} - 0.095) * \frac{0.1}{\text{d}}}$$

If $\left(-0.24 * \text{T} + 134\right) > 100$ Use 100

Where:

RS = Remaining strength as a percentage of initial strength.

RS EC = Remaining strength as a percentage of initial strength of the EC strands.

T = Temperature (°C)

t = Elapsed time (hours)

D = Strand diameter (inches)

STR EC = Calculated initial strength of EC strands (lb)

STR ST = Calculated initial strength of the steel core (lb)

STR T = Calculated initial strength of the conductor (lb)

Step 1 Calculate Initial Strength of the Conductor and Aluminum and Steel Components

From: ASTM B232 "Standard Specification for Concentric-Lay Stranded Aluminum Conductors, Coated-Steel Reinforced (ACSR)"

Aluminum

45 strands @ 0.1880" dia. ea., Area of One Strand = 0.02776 in2 , Rating Factor = 91%
Average Tensile Strength (ASTM B230) = 24.0 ksi

Steel

7 strands @ 0.1253" dia. Ea. Area of One Strand = 0.01233 in2 Rating Factor = 96%
Strength at 1% Elongation (ASTM B498) = 180.0 ksi

Total Conductor

Aluminum: (STR EC) $$45 * 0.02776\ \text{in}^2 * 24.0\,\text{ksi} * \left(\frac{1000\,\text{lb}}{\text{kip}}\right) * 0.91 = 27{,}285\,\text{lb}$$

Steel Core: (STR ST) $$7 * 0.01233\,in^2 * 180\,ksi * \left(\frac{1000\,lb}{kip}\right) * 0.96 = 14{,}915\,lb$$

Conductor: (STR T) $$27{,}285\,\text{lb} + 14{,}915\,\text{lb} = \underline{\underline{42{,}200\,\text{lb}}}$$

Step 2 Determine Remaining Strength (RS) of Aluminum Strands

Using the equation for RS EC and inputting various temperatures and durations into an Excel spreadsheet, curves (% Remaining Strength vs. Hours) for each temperature can be developed. Then using these curves, the remaining strength of the aluminum strands can be determined.

402 hrs at 100°C results in	**RS = 98%**	**is equivalent to 20 hrs at 105°C**
284 + 20 hrs at 105°C results in	RS = 97%	is equivalent to 47 hrs at 110°C
225 + 47 hrs at 110°C results in	RS = 96%	is equivalent to73 hrs at 115°C
132 + 73 hrs at 115°C results in	RS = 94%	is equivalent to 74 hrs at 120°C
67 + 74 hrs at 120°C results in	RS = 94%	is equivalent to 61 hrs at 125°C
14 + 61 hrs at 125°C results in	RS = 93%	is equivalent to 39 hrs at 130°C
1 + 39 hrs at 130°C results in	RS = 93%	is equivalent to 26 hrs at 135°C
1 + 26 hrs at 135°C results in	RS = 93%	

Step 3 Determine The Remaining Strength of the Conductor

$$\text{RS} = \text{RS EC} * \left(\frac{\text{STR EC}}{\text{STR T}}\right) + 100 * \left(\frac{\text{STR ST}}{\text{STR T}}\right) * 1.09$$

$$\text{RS} = 93 * \left(\frac{27{,}285\,\text{lb}}{42{,}200\,\text{lb}}\right) + 100 * \left(\frac{14{,}915\,\text{lb}}{42{,}200\,\text{lb}}\right) * 1.09 = \underline{\underline{98.65\%}}$$

Step 4 Determine Loss of Strength of the Conductor

$$\text{Loss of Strength} = 100 - \text{RS}$$

$$\text{Loss of Strength} = 100 - 98.65 = \underline{\underline{1.35\%}}$$

Appendix 3: Sample Ratings Reports

Appendix 4: User Guide and Sensitivity Analysis – "PJM Conductor Rating Spreadsheet"

This appendix is provided as a separate, stand-alone file available from the PJM Transmission Owners Guideline website.