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AEP Station Bus and Conductor Ampacity Calculation Methodologies

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SUMMARY

This paper discusses the methodology for AEP station bus and conductor ampacity calculations. IEEE 605 [1] and IEEE 738 [2] formulas are used for rigid and strain bus/conductors, respectively. The assumptions incorporated in the calculations can vary based on the station location, life expectancy of station equipment, and power system operating conditions. As a result, the assumptions fluctuate based on station location and can vary for utilities with larger footprints such as AEP. The assumptions should be applied conservatively to avoid jeopardizing the system's reliability and economic impact should be considered to make the best use of the selected equipment. The most critical assumptions--including ambient temperature, wind speed and direction, absorptivity and emissivity, and maximum conductor operating temperature--are discussed in this paper. A comparison between AEP's assumptions and PJM's is also provided to illustrate how AEP compares with the rest of the utility industry.

KEYWORDS

Station Bus & Conductor, Ampacity, Applications

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INTRODUCTION

Given a specified set of parameters, including an ambient air temperature and a maximum permissible bus operating temperature, the determination of a bus ampacity rating is reduced to a fairly straightforward heat transfer problem. Unfortunately, the problem is complicated by the large number of variables that affect this calculation, particularly when the geographic range and environmental diversity of the AEP system is considered. To make matters worse, the utility industry has never established a rigid set of criteria for determining bus ampacity ratings.

Station Bus Applications

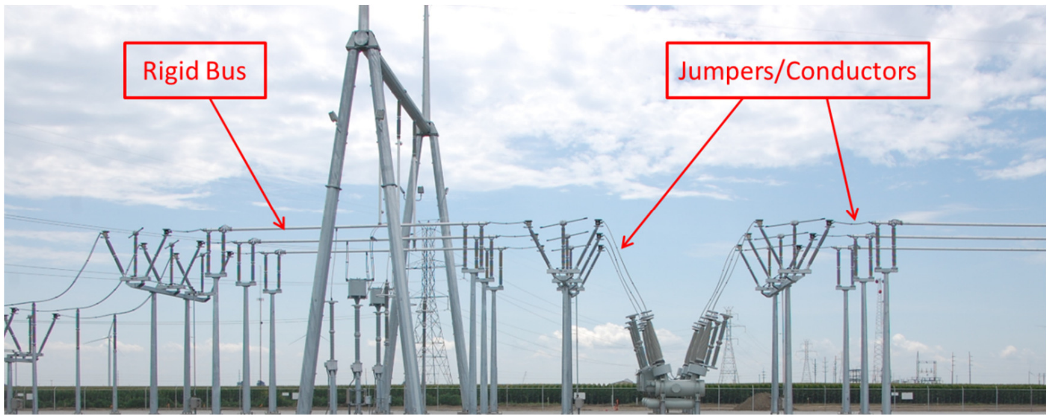

Fig.1. Station bus layout

As shown in Fig. 1, there are two main categories of station bus and conductors, rigid bus and strain jumpers. Rigid bus and strain jumpers connect series and shunt substation equipment, such as disconnect switches, circuit breakers, power transformers, shunt capacitor banks, shunt reactors, and measuring devices). Rigid bus can be made from a variety of shapes and materials based on various applications. Aluminum round tubular bus is most popular for long bus runs, while the rectangular/angle aluminum or copper bars are mostly used in shorter lengths in order to connect two jumpers. Strain jumpers and conductors are widely used in three situations: 1) connecting rigid bus to the station equipment; 2) connecting between two rigid bus; and 3) transitioning from transmission line conductors down to station equipment. The jumpers/conductors applied in a station typically consist of a few types of common overhead conductors, such as ACSR, AAC, and ACSS. Rigid bus design is better for long spans between two support structures due to their reduced clearance and sag issues, while jumpers are more flexible and generally easier to install, better for contraction and expansion, and reduce bus stress on equipment connections.

Ampacity Calculation Methods

Calculation of substation bus conductors should use the methods presented in IEEE 605 for rigid bus, and the calculation methods of IEEE 738 for strain bus/jumpers.

The heat gains of the energized station bus/conductors are primarily the Ohmic losses, which are a function of current magnitude flowing through conductor and conductor's resistance. In addition, three types of heat transfer also play a significant role in the ampacity calculations for bus conductors. They are convective losses, radiation losses, and solar absorption.

A bus conductor loses heat through natural and forced convection. Natural convection is a result of the temperature difference between the surface of the bus conductor and the surrounding ambient air. The greater the temperature difference, the greater the heat loss through natural convection. Natural convective heat loss is also a function of the orientation of the conductor's surface, the width of the conductor's surface, and the conductor's surface area.

Forced convective heat loss is a function of the wind blowing over the surface of the bus conductor. It is affected by the wind speed, the length of the wind flow path over the conductor, the conductor's surface area, and the temperature difference between the bus conductor surface and the ambient air.

A conductor loses heat through the emission of radiated energy to the conductor's surroundings. Factors that affect radiation heat losses are the temperature difference between the conductor and surrounding bodies, the surface area of the conductor, the emissivity of the conductor, and the absorptivity of the surrounding environment.

The conductor heat gains and losses are illustrated in Fig. 2. Note that all of the aforementioned parameters can be calculated with equations in IEEE 605 or 738, which are included in multiple spreadsheets developed by AEP. The details of those equations are not included in this paper.

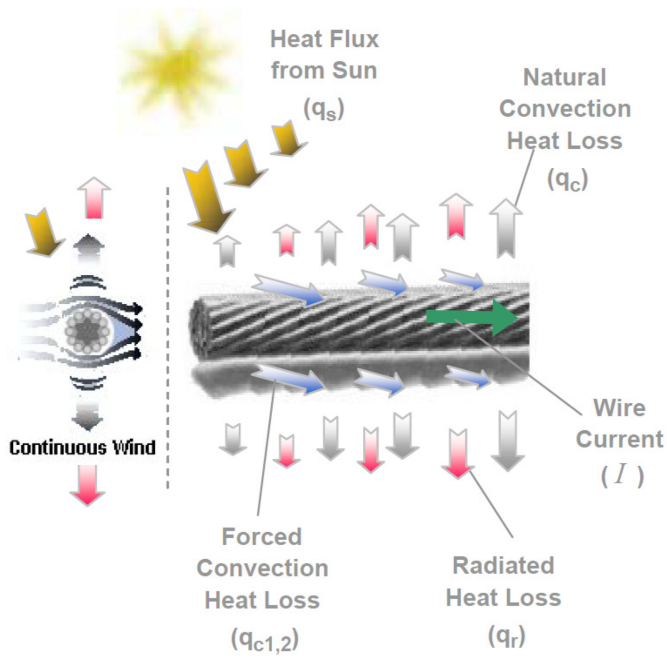

Fig. 2. Conductor heat gains and losses

AMPACITY CALCULATION ASSUMPTIONS

Ambient Temperature

The ambient temperature is a part of the calculation of conductor temperature for determination of the ampacity. The conductor temperature is the temperature rise due to heat generation from current flow (I^2R) and heat gain through solar absorption, added to the ambient temperature.

The following are the three major considerations in selecting the design basis ambient temperature:

- Cumulative material strength degradation due to elevated temperature
- Cycling temperature effects on bus conductors
- Temperature effects in apparatus connected to the bus conductors

Since material degradation is a cumulative effect, the appropriate ambient temperature statistic is the daily average high temperature.

As a result, AEP used the public weather data from the National Climatic Data Center (NCDC) to generate a 30-year average of daily maximum temperatures for selected stations throughout the AEP footprint as summarized in Table I. Note that the AEP east and west footprint is shown in the Fig. 3.

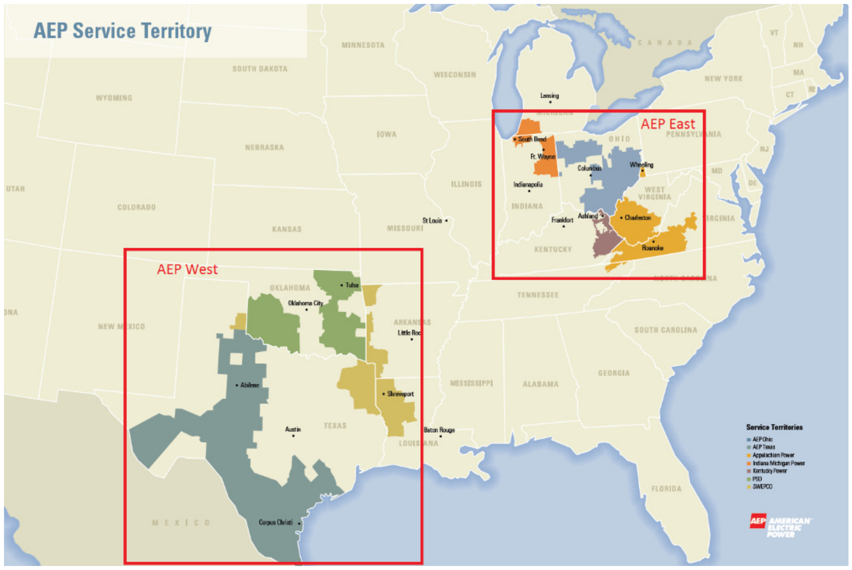

Fig. 3. AEP service territory map

Table I. Ambient Temperature Data

Location	AEP East		AEP West	
Season	Summer (June, July, Aug.)	Winter (Dec., Jan., Feb.)	Summer (June, July, Aug.)	Winter (Dec., Jan., Feb.)
Maximum Average Daily Temperature	27.8 to 30 °C	5 to 9 °C	34.5 to 36.1 °C	16 to 21 °C

In general, calculated conductor ampacity changes about 1% for each degree C change in the ambient. If a different maximum ambient temperature is used in different areas of AEP West, the difference in calculated ampacity would be approximately 4%. This variation is well within the tolerance of data and engineering methods used to calculate conductor ampacity.

For AEP East, applying the temperature variations to different regions would result in calculated ampacity that is in a range of approximately 3%.

The temperatures given above reflect the maximum average daily temperature. In summer, the peak electrical load usually occurs at the same time as the maximum daily temperature. The maximum daily temperature is approximately 5°C higher than the maximum average daily temperature. Therefore, the maximum summer ambient temperature should be 40°C for AEP West and 35°C for AEP East. In winter, the peak electric loads would occur during the lowest ambient temperatures. AEP recommends using the values currently used by AEP to rate their transmission line ampacity. These values are 2°C for AEP East and 20°C for AEP West.

Finally, the conductor normal and emergency ratings are assumed to be static at 100% of that value. In reality, load profiles vary throughout the day and it would be odd to have a conductor held continuously at the peak load current. Thus, the ratings that are applied to all conductors represent the worst case installation (strain), worst case ambient temperature, and worst case loading, which are unlikely to occur simultaneously.

Wind Velocity

Wind speed and direction are major considerations in establishing the design bases for overhead transmission lines. IEEE 605 includes wind speed in the heat balance equations for forced convective heat transfer.

Numerous publications over the decades have used 2 feet per second (approximately 1.5 miles per hour) as an example in presenting ampacity of conductors. The early editions of the Electrical Transmission and Distribution Reference Book [3] included a value of 2 feet per second, as an example, when published in the 1940's, 50's, and 60's. In addition, PJM, SPP, and a number of other utilities are also using 2 feet per second as their wind velocity assumptions for their ampacity calculations. Note that the ampacity of overhead transmission line conductors can be calculated by assuming higher wind speed, because they have higher elevations from the ground compared with those inside a station.

Absorptivity and Emissivity

Due to the difficulty in identifying all of the heat absorbing surfaces inside and outside the substation and quantifying the absorptivity of those surfaces, it is usual to assume that the absorptivity of the surrounding environment equals the conductor emissivity.

Emissivity for aluminum and copper ranges from 0.2 for new conductor to 0.95 for bus painted black. Aluminum, after extended outdoor exposure, will have an emissivity of 0.3 to 0.5. Copper, after extended outdoor exposure, will have an emissivity of 0.7 to 0.85. AEP uses 0.5 for aluminum and 0.8 for copper to develop the ampacity tables.

Maximum Conductor Operating Temperature

AEP has developed a methodology to define Emergency Maximum Operating Temperature (EMOT) in terms of loss of strength. AEP limits the loss of strength for ACSR, AAC, AAAC, and ACAR to 10% over a 50 year period. The calculations are based on 1,000 hours operating at the EMOT with the remainder of the 50-years (437,300 hours) operating at a Normal Maximum Operating Temperature (NMOT). AEP determined that 1,000 hours over 50 years (approximately one day a year) was a sufficient amount of time for emergency operations over the life of the station.

Note that the NMOT of 95°C and 85°C are selected for aluminum and copper conductors, respectively, since the conductors will operate at their corresponding temperatures indefinitely without any loss of strength [4].

The below equations [5] can be used to estimate the loss of strength under cumulative time and temperature exposures to determine the EMOT values:

AAC (1350-H19)	AAAC (6201-T81)	ACAR	ACSR
$RS = (-0.24T + 134)t^{-(.001T-0.095)*\frac{0.1}{d}}$ $if\ (-.24T + 134) > 100,\ use\ 100$	$RS = (-0.52T + 176)t^{-(.0012T-0.118)*\frac{1}{d}}$ $if\ (-.52T + 176) > 100,\ use\ 100$	$RS = RS_{1350} * \frac{A_{1350}}{A_{Total}} + RS_{6201} * \frac{A_{6201}}{A_{Total}}$	$RS = RS_{1350} * \frac{Str_{1350}}{Str_{Total}} + 100 * \frac{Str_{St}}{Str_{Total}} * 1.09$

Where

RS = Remaining Strength as a percentage of initial strength
T = Temperature, °C
t = Elapsed time, hours
d = Strand diameter, inches
A_{1350} = Area of 1350 strands
A_{6201} = Area of 6201 strands
A_{Total} = Total area, $A_{1350} + A_{6201}$
Str_{1350} = Calculated initial strength rating of 1350 strands
Str_{St} = Calculated initial strength rating of steel strands
Str_{Total} = Calculated intial strength of the conductor, $Str_{1350} + Str_{St}$

The predictor equations were generated from a statistical analysis of over 100 Alcoa laboratory tests [5]. The cumulative effect of loss of strength can be predicted using the models for multiple time and temperature exposures. Rather than having a unique EMOT for every conductor in the system, AEP assigns EMOTs for each stranding group. The smallest wire size within the stranding group controls the temperature since it is the most susceptible to loss of strength. AEP methodology of calculating EMOTs is incorporated in a spreadsheet tool such as the one in Fig. 4.

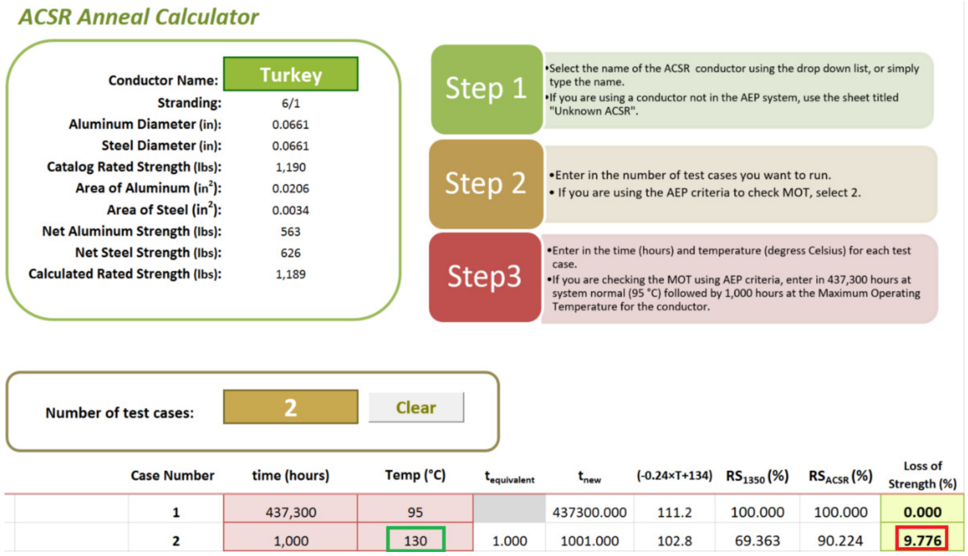

Fig. 4. No. 6 Turkey (6/1) using AEP's EMOT criteria

The example in Fig. 4 shows the loss of strength of the No. 6 Turkey ACSR conductor (which is the smallest ACSR conductor in AEP system) using AEP EMOT criteria. When the operating temperature of 95°C is applied on this conductor for 437,300 hours, there is no loss of strength on aluminum wires. However, if the operating temperature of 130°C is applied on this conductor for 1,000 hours which are accumulated to the previous operating hours, the remaining strength on aluminum wires is decreased significantly to less than 70%, which results in the overall ACSR conductor to have about 10% loss of strength after combining the strengths from both the aluminum and steel components. As a result, 130°C is selected as the AEP station ACSR conductor EMOT rating as shown in Table II, which is a summary table for AEP station bus/conductor NMOT and EMOT ratings.

Table II. Normal/Emergency Maximum Operating Temperature

Conductor	Normal Maximum Operating Conditions	Emergency Maximum Operating Conditions
Stranded aluminum conductor (SAC or AAC)	95°C	115°C
Aluminum pipe, angle, or rectangular bar	95°C	115°C
Stranded copper conductor	85°C	115°C
Copper pipe or rectangular bar	85°C	115°C
Aluminum conductor, steel reinforced (ACSR)	95°C	130°C
Aluminum conductor, alloy reinforced (ACAR)	95°C	125°C
Aluminum conductor, steel-supported (ACSS)*	250°C	250°C

In general, the ratings are considered to be conservative as they represent worst case scenarios inside a substation applied to all conductors. Most conductors inside a station are not held in strain (short spans) and would not be subject to the same concerns of loss of strength and sag when operating above the maximum temperature.

DISCUSSION OF CONSERVATIVE RATING VERSUS OTHERS

AEP has benchmarked our methodology with several other utilities and found our base assumptions are in line with those of other utilities and in some areas more conservative. The PJM rating methodology [6] is used for this example.

The AEP methodology uses 0.5 for emissivity/absorptivity for aluminum conductors while the PJM guide (and most other users) use values between 0.7 and 0.9. The higher emissivity/absorptivity will result in higher ampacity for a given maximum operating temperature. Other users were in line with a wind speed of 2 feet per second; however, AEP assumed a wind direction 60 degrees from the bus axis. The PJM guide and others assume a wind direction of 90 degrees from bus axis. The higher angle increases cooling efficiency and would also increase the ampacity for a given maximum operating temperature.

The PJM normal and emergency maximum operating temperature values are shown in Table II along with the corresponding AEP values. The values are similar to AEP, however a few differences can be found. For example, aluminum conductor (AAC) maximum operating temperatures are 95°C Normal/115°C Emergency for AEP. In the PJM methodology, aluminum conductor maximum operating temperature is 105°C Normal/130°C Emergency. The PJM methodology does not distinguish between different types of aluminum conductors, such as ACSR, while the AEP methodology does consider different conductor constructions.

Table II. Normal/Emergency Maximum Operating Temperature

Conductor	**NMOT**		**EMOT**	
	PJM	**AEP**	**PJM**	**AEP**
Stranded aluminum conductor (SAC or AAC)	105°C	95°C	130°C	115°C
Aluminum pipe, angle, or rectangular bar	90°C	95°C	115°C	115°C
Stranded copper conductor	75°C	85°C	95°C	115°C
Copper pipe or rectangular bar	90°C	85°C	115°C	115°C
Aluminum conductor, steel reinforced (ACSR)	105°C	95°C	130°C	130°C
Aluminum conductor, alloy reinforced (ACAR)	105°C	95°C	130°C	125°C
Aluminum conductor, steel-supported (ACSS)*	N/A	250°C	N/A	250°C

CONCLUSIONS

This paper describes AEP's methodology of calculating station bus/conductor ampacity ratings. IEEE 605 and IEEE 738 equations are used to calculate the conductor heat gains and losses impacted by current magnitude, ambient temperature, wind speed and direction, sun and conductor positions, conductor absorptivity and emissivity, and the maximum operation temperature. The aforementioned assumptions from AEP perspectives are mainly discussed in this paper. In addition, a benchmark with PJM guidelines is also provided.

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