2017 PLS-CADD Advanced Training and User Group

IEEE 738-2012
Radial Conductor Temperature
Impact on Ratings

by

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Introduction

- My objective
  - Show the relative impact of radial temperature on several common conductors
- The engineer (transmission owner) has three choices:
  1. Use PLSCADD or their in-house program to calculate the correct rating using the correct surface temperature.
  2. Use rating adjustment based on the number of aluminum layers.
  3. Ignore the effects of radial temperature and assume conductor temp is homogeneous.

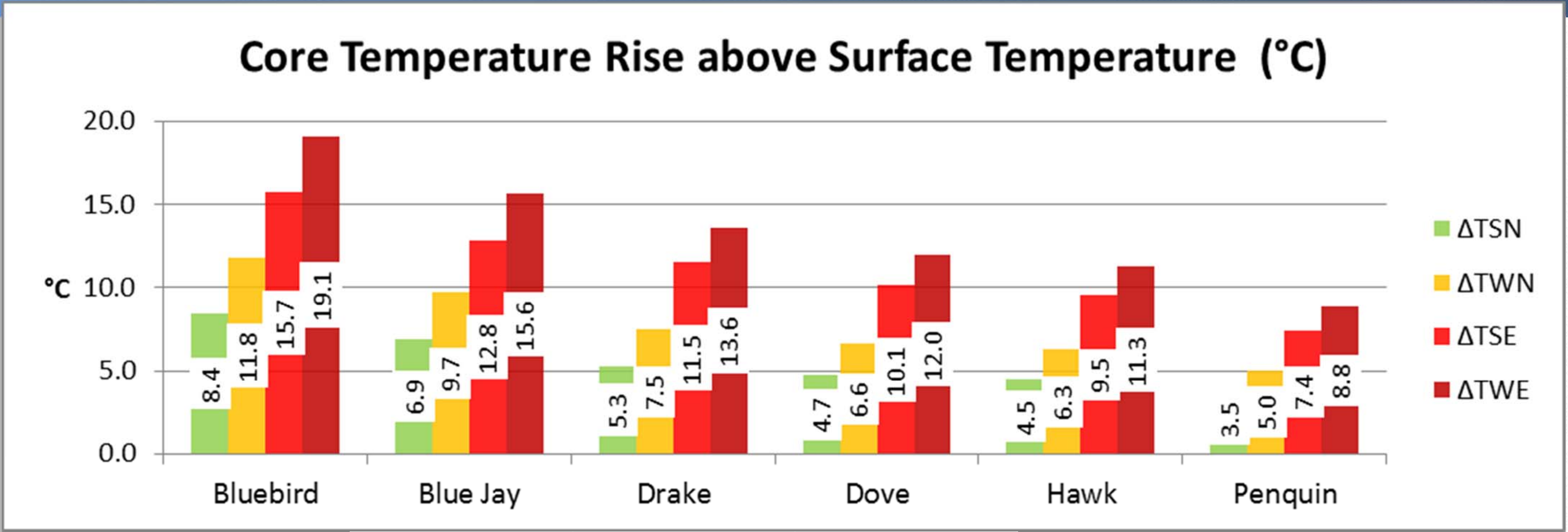
Background (USA)

- NERC FAC-008
  - Transmission Utilities must
    - Have published ratings
    - Operate to those ratings
  - Rating Methodology based (on at least one)
    - Equipment Manufacturer's
    - One or more Industry Standards (IEEE, CIGRE, etc.)
    - Practice verified by Testing, Performance, Engineering analysis

Slide 1: Thermal Dynamic FACT

- **Conductor Core is hotter than the surface.**
  - Greater sag based on warmer steel core
  - Compute impact on rating
    - Sample calculation for ACSR only
    - Assumes rated temperature is above the knee-point.
  - Increased annealing of ACSR is relatively insignificant.
    - Most of the aluminum is in the outer layer(s)
    - Steel does not anneal at these operating temperatures

Slide 2: Thermal Gradient



	Ambient	MOT*
ΔTS-Normal	90°F Summer	93°C (200°F)
ΔTW-Normal	32°F Winter	93°C (200°F)
ΔTS -Emergency	90°F Summer	150°C (300°F)
ΔTW-Emergency	32°F Winter	150°C (300°F)

* MOT = Conductor Max Operating Temperature

Slide 3: PLSCADD Conductor Sag/Tension

- PLSCADD plots sag based on the temperature of the metal strands supporting the conductor.
  - For ACSR at elevated temperatures,
    - Steel core supports the conductor
    - Sag is correct for temperature of the steel
    - Max temperature is correct for steel core

So the surface is Cooler

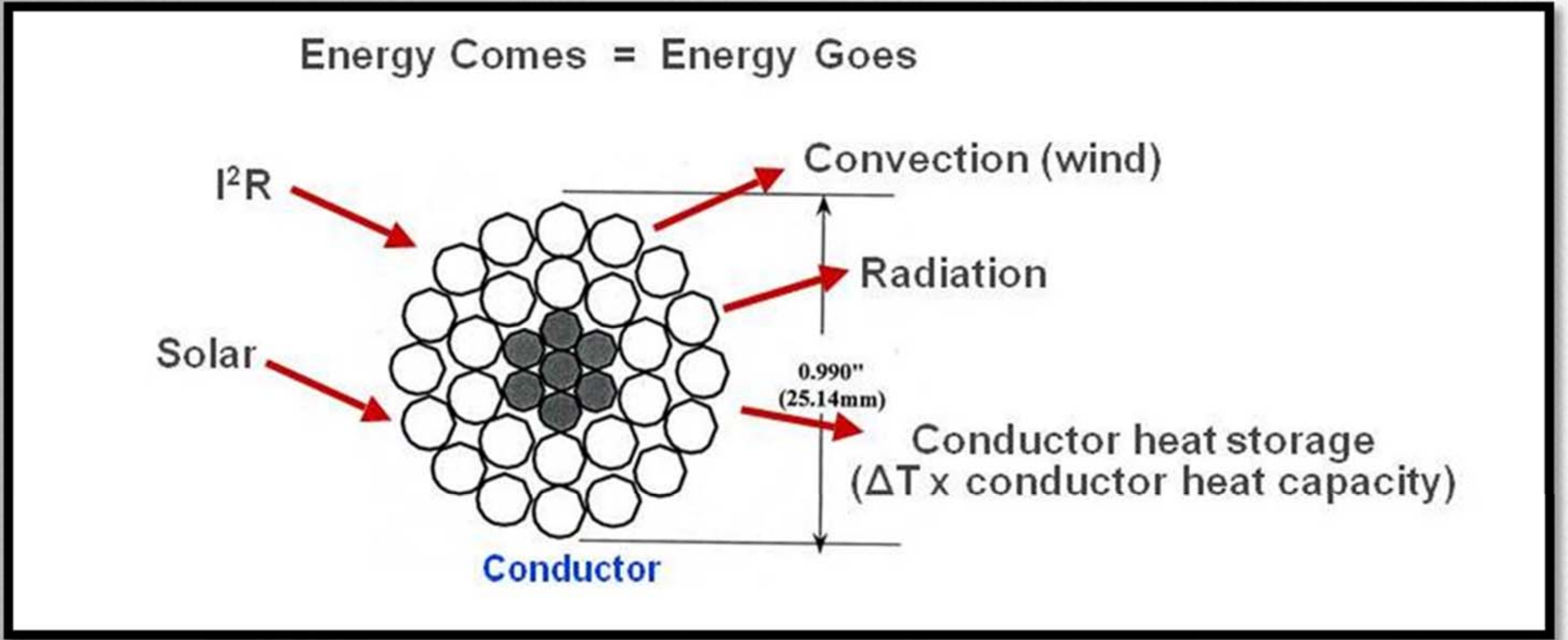
- *Ratings are based on "Surface Temperature"*

Slide 4: IEEE-738 Rating Calculations

- Heat balance computation at the surface

$$I^2R + Q_s = Q_R + G_C$$

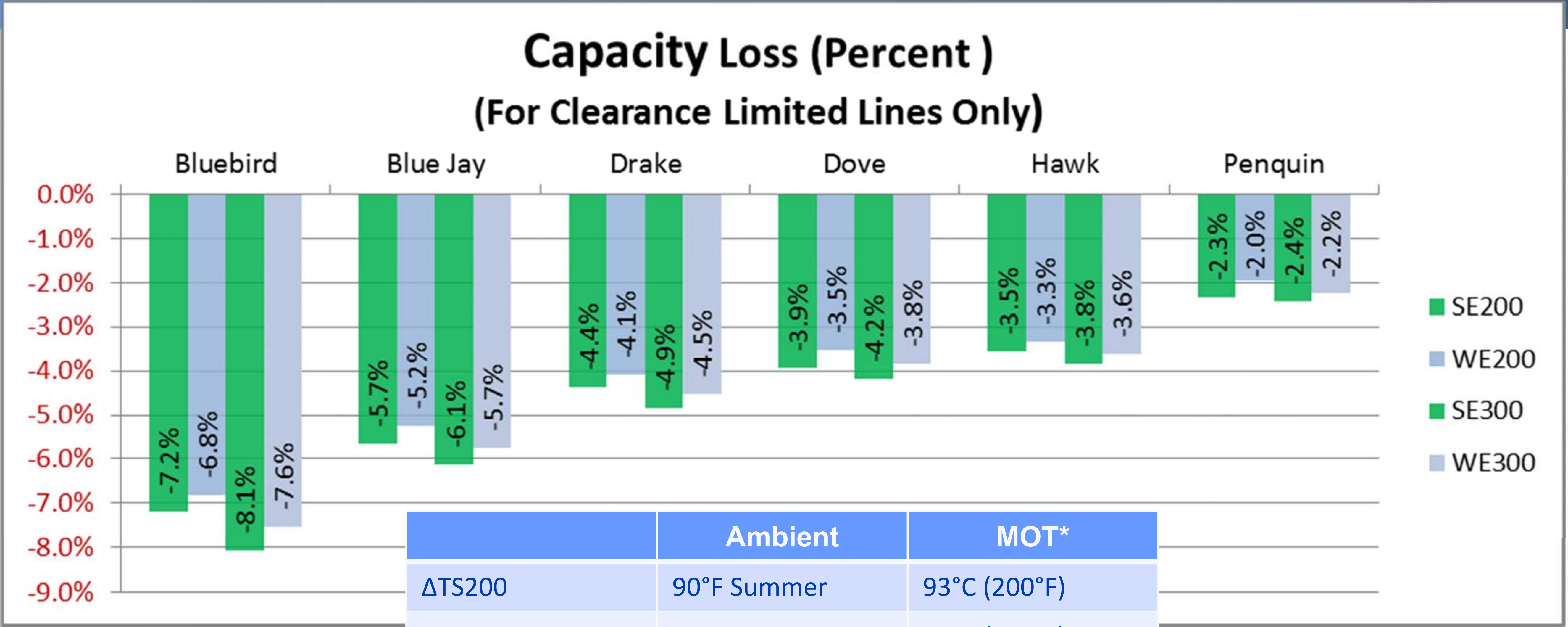
I^2R Resistive heating (the only internal factor)
Qs Solar heat input striking the surface
Q_R Radiation heat loss off the surface
Q_C Conductive to the surrounding



Slide 5: Ratings Options *Considering Thermal Gradient*

1. Get Surface Temperature from PLSCADD
   - Use surface temperature → Rating
     - IEEE-738
     - CIGRE 207
2. Use a Factor to Adjust Ratings
   - Percent decrease in rating
     - Varies primarily by number of aluminum layers, not wire size
     - Relatively constant regardless of max operating temperature (MOT)
     - Approximation appears acceptable because adjustment is small

Slide 6: Typical Ratings Adjustment Factors



	Ambient	MOT*
ΔTS200	90°F Summer	93°C (200°F)
ΔTW200	32°F Winter	93°C (200°F)
ΔTS300	90°F Summer	150°C (300°F)
ΔTW300	32°F Winter	150°C (300°F)

* MOT = Conductor Max Operating Temperature

Conclusion:
Can We Ignore Impact Radial Conductor Temperature?

For lines limited by conductor annealing:

- Maybe, Is the additional annealing significant?
  - Most of the aluminum is in the outer layer(s) at/near surface temperature
  - Internal temperature rise is small—Minor increased annealing—Minimal affect on strength
  - Steel does not anneal at these low temperatures

For lines limited by clearance:

- No? Or might it depends on conductor size? MOT?
  - Greater impact on larger conductors with **more layers of aluminum.**

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"Effects of High-Temperature Operation on Conductors, Connectors, and Accessories"

Ticket to Ignore Thermal Gradient
Except for Operation of Conductors >150°C

IEEE 1238-2012

4.4 High-temperature effects on sags and tensions

4.4.2 Aluminum Compression:

If conductors are operated above the “off load temperature,” the use of sag-tension programs which account for the additional sag due to aluminum compression should be employed.

4.4.2 Conductor Thermal Gradient:

- Most sag-tension modeling tools continue to assume a homogenous radial conductor temperature profile.
  - If the conductor is operating above knee point, sag is based on core temperatures.
- Above 150°C, there could be potential impacts on sag-tension due to the conductor core being substantially hotter than the conductor surface.
  - Above 150°C, the core may be substantially (as much as 25°C) hotter than the surface. (Based on limited research above 150°C)
  - Impacts would be less significant at lower temperatures.

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ACTION

- Are you using PLSCADD option *"IEEE-738-2012"* ?
- Should you?
  - Nothing is precise. How conservative are you?
    - Are your records current?
      - Recent as-built survey? LiDAR?
      - Clearance buffer doesn't really count.
    - How conservative are your assumptions underlying your Rating Methodology?
      - Ambient conditions
      - Maximum operating temperature of conductor, splices.
      - Operating practice

Summary

- Radial temperature gradient is real
  - Significant at high temperature—above knee point.
  - Impact on ratings may be expressed as a percentage of rating
  - Relative impact varies with different conductors (size, type…)
- The engineer (transmission owner) has three choices:
  1. Use PLSCADD or their in-house program to calculate the correct rating using the correct surface temperature.
  2. Use a rating adjustment factor based on the number of aluminum layers.
  3. Ignore the effects of radial temperature and assume conductor temp is homogeneous.

IEEE-738-2012 Excerpts

$$T_{core} - T_s = \frac{I^2 \cdot R\left(T_{avg}\right)}{2\pi \cdot k_{th}} \cdot \left[\frac{1}{2} - \frac{D_{core}^2}{D_o^2 - D_{core}^2} \cdot \left(\ln \frac{D_o}{D_{core}}\right)\right]$$

- K_{th} range = 4 to 0.5
- For ACSR with tension in aluminum strands, K_{th} ≈ 2 W/m-°C
- For ACSR w/o tension in aluminum strands, K_{th} ≈ 1 W/m-°C

IEEE-738-2012 Excerpts

- Radial temperature difference depends on:
  a) Conductor strand shape (round or trapezoidal if under tension).
  b) Magnitude of the electrical current in aluminum layers.
  c) Electrical resistance, which increases with temperature.
  d) The number of layers of aluminum wires.
  e) The condition of aged conductor (i.e., oxidation and bird-caging).
  f) The contact area and pressure between aluminum layers.

IEEE-738-2012 Excerpts

- Low current density
  - < 1/2 amp/kcmil → radial temperature difference may be neglected.
- Higher current density, especially with 3-4 aluminum layers
  - radial temperature differences of 10 °C to 25 °C have been measured in laboratory tests
- Testing has been primarily with ACSR.
  - ACSS may have lower K_{th} values
- Should consider Radial Temperature Difference if
  - Gradient is found to exceed 10 °C
- May ignore for short duration loads on ACSR, e.g.
  - Fault current (< 60 sec); Transient loads (5 to 30 min)