Dynamic Rating of Overhead Lines

IEEE Tutorial
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IEEE

Summary

- Static line ratings are based on worst-case estimates of weather conditions and are usually system-wide.
- Dynamic line ratings are based on actual weather conditions along specific lines, and use the same heat balance equations as static (IEEE 738).
- If implemented correctly, dynamic ratings should not reduce line reliability and should increase capacity.
- There are a wide range of line monitors that work well to measure real-time wind along the line and serve as the basis for dynamic ratings.
- Integration into system operations can be challenging. There must be a compelling reason to justify the complexity.

Topics for Tutorial

- **Quick Quiz Question**
- **The thermal heat balance calculation (relating current to conductor temperature)**
- **Conductor Temperature Limits**
- **Thermal line ratings – Static and Dynamic**
- **What monitors exist & what do they measure?**
- **Integration into Operations**

QQ - If the temperature of the overhead line conductor is measured in multiple spans in real-time, that's all the system operator needs to know– T/F?

- False - The system operator wants a rating in amps or MVA not conductor temperature or sag. Dynamic or real-time line ratings are predictions, valid for 15 min or 4 hours or a day ahead. If the power flow is less than or equal to this rating, then the conductor temperature will not exceed the maximum line temperature. Ratings are calculated not measured.

Topics for Tutorial

- **Quick Quiz Question**
- **The thermal heat balance calculation (relating current to conductor temperature).**

PICTORIAL DIAGRAM OF CONDUCTOR HEAT BALANCE [1]

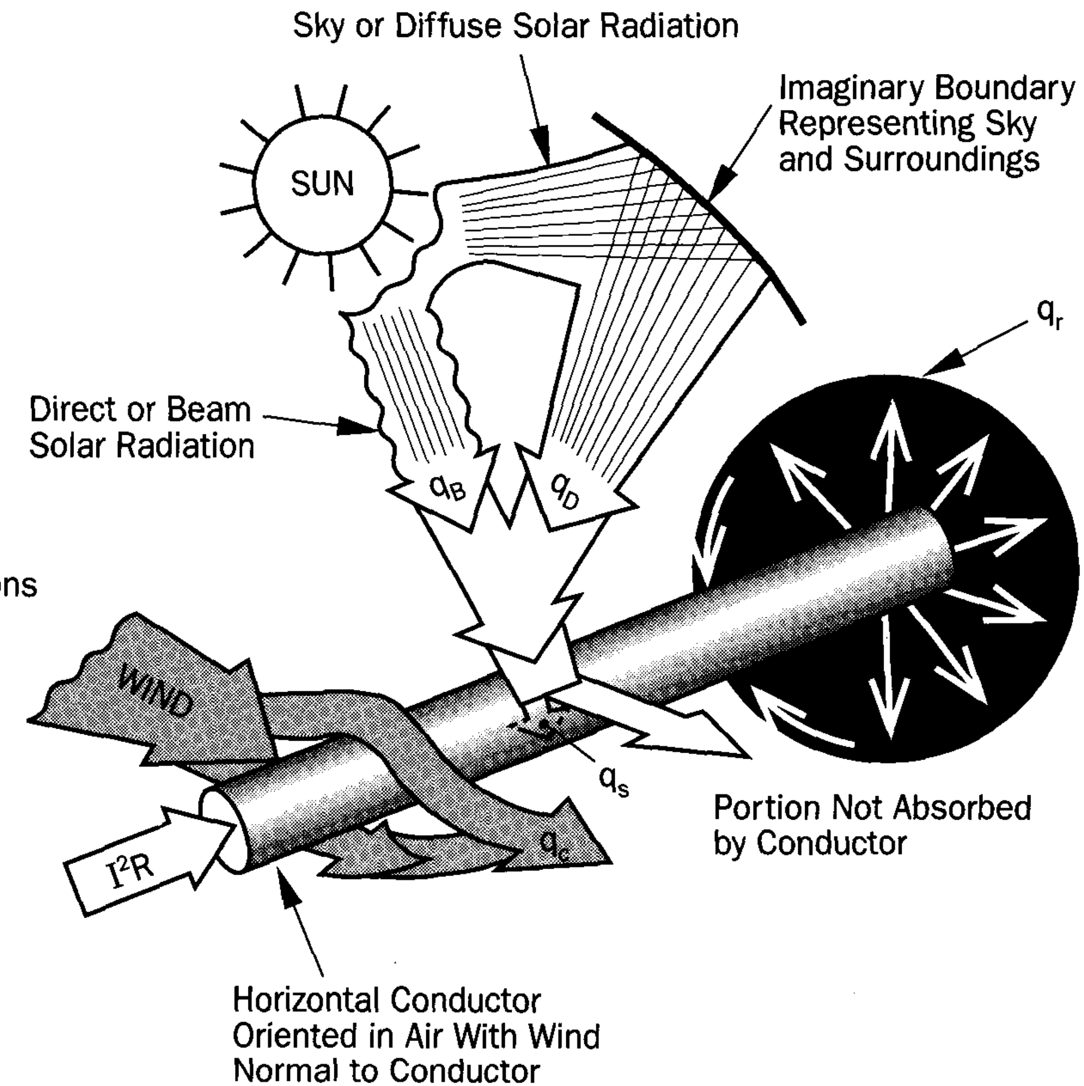
Under Steady State Conditions

$$\Sigma \text{ Heat In} = \Sigma \text{ Heat Out}$$

$$I^2R + q_s = q_c + q_r$$

From Which

$$I = \left(\frac{q_c + q_r - q_s}{R} \right)^{.5}$$



Heat Balance Equation

$$I^2R + Q_S = mC\frac{dT}{dt} + Q_R + Q_W$$

Solve for T as a function of I (and t)

Determine I for a given T

Where does the heat come from? Air Temp 40C, 2 fps wind

Current amps	I^2R Losses w/ft	Solar Heat w/ft	Cond Temp ^oC
0	0	9 max	48 (8C rise)
300	2.5	9 max	52 (12C rise)
1000	28	9 max	100 (60C rise)

Where does the heat go?
Air Temp 40C, 1000 amps

Wind Speed ft/sec	Forced Convection w/ft	Radiation w/ft	Cond Temp ^{o}C
0	19 (natural convection)	19	120 (80C rise)
2	23	13	100 (60C rise)
4	26	9	85 (45C rise)

Forced Convection Heat Loss

$$Q_c = \left[1.01 + .371 * (\frac{D * \rho * V}{\upsilon})^{.52} \right] * (k_f * (T_c - T_a))$$

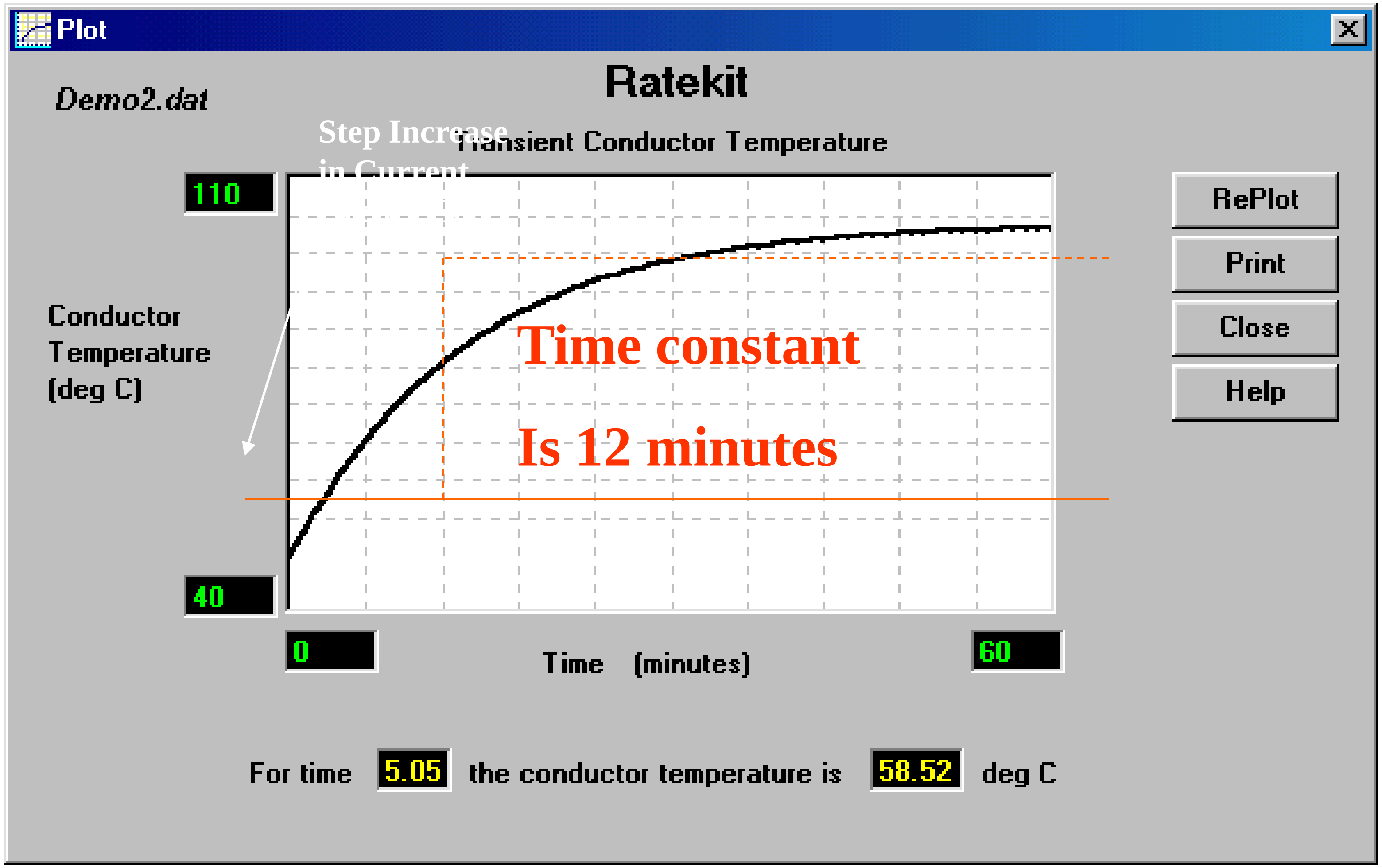
- Formula:
  - D is the conductor diameter
  - ρ is the density of the air
  - V is the wind speed
  - μ is the viscosity of air
  - k_f is the thermal conductivity of air
  - T_c and T_a are the temperatures of the conductor and air.

Radiation Heat Loss

$$Q_r = 0.138 * D * \varepsilon * \left[\left(\frac{T_c + 273}{100} \right)^4 - \left(\frac{T_a + 273}{100} \right)^4 \right]$$

- At low temperatures, the energy radiated is small and is in long wavelengths
- At high temperatures the energy radiated is high and is in shorter wave- lengths.
- The rate of radiation increase is quite rapid and is proportional to the 4^{th} power of the Absolute Temperature.

Typical Thermal Time Constant



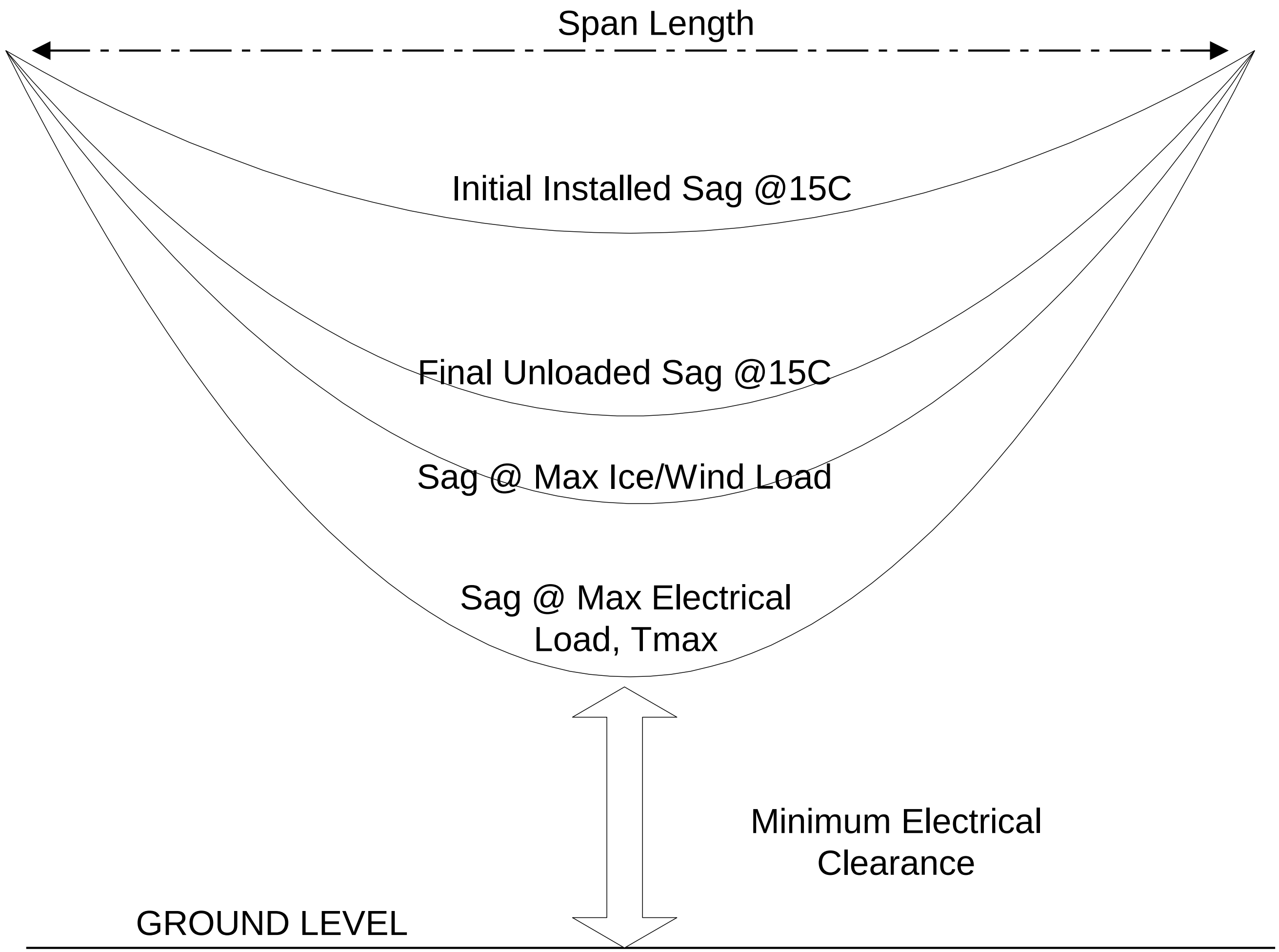
Topics for Tutorial

- **Quick Quiz Question**
- **The thermal heat balance calculation (relating current to conductor temperature)**
- **Conductor Temperature Limits**

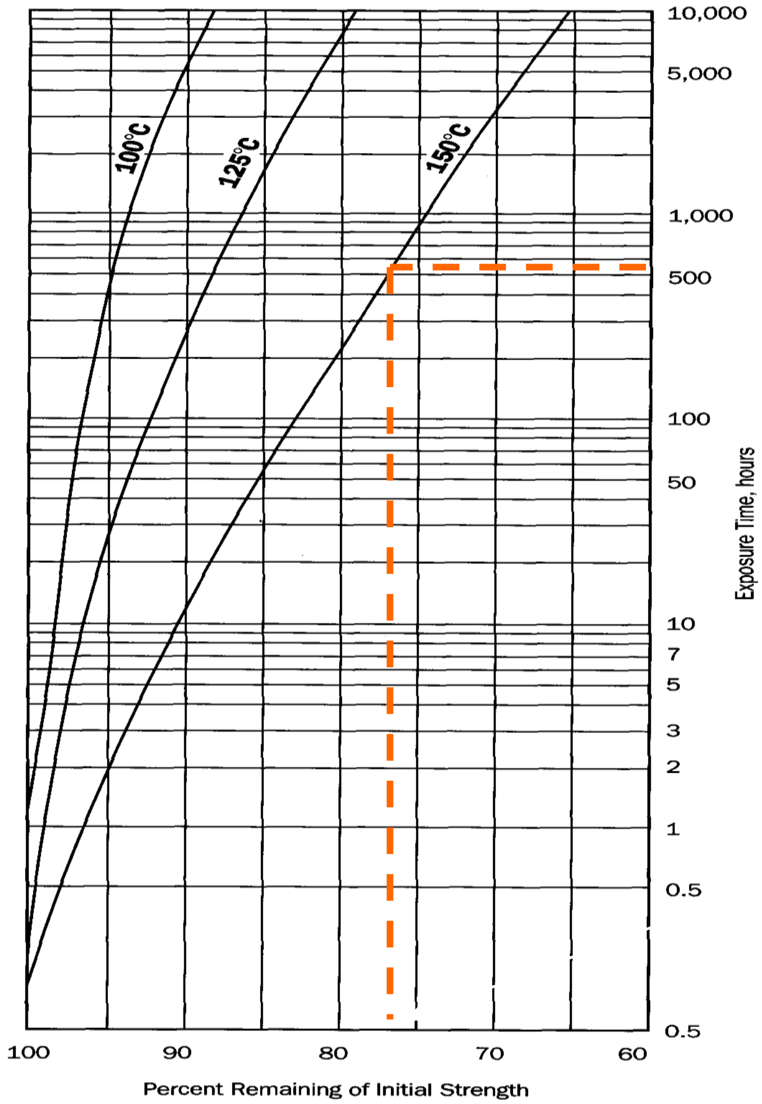
Conductor Temperature Limits

- For normal or continuous ratings, existing lines with ACSR are typically limited to a continuous temperature between 75C and 100C.
- For short time emergency ratings, existing lines with ACSR are typically limited to a maximum temperature of 100C to 180C.
- Without a steel core, temperature limits are at least 10C to 20C lower.
- HTLS conductors are typically limited to 150C to 180C continuous and 180C to 240C emergency depending on the materials in the conductor.

Sag Increase with Temperature and Time



ANNEALING OF INDIVIDUAL ALUMINUM STRANDS



Time-temperature relationship for loss-of-strength for 1350-H19 aluminum strands. Tensile tests made at room temperature after exposure to indicated temperature.

Topics for Tutorial

- **Quick Quiz**
- **The thermal heat balance calculation (relating current to conductor temperature)**
- **Conductor Temperature Limits**
- **Thermal line ratings – Static and Dynamic**

What is a Dynamic Thermal Line Rating?

- It is the maximum allowable ***MVA or ampere*** value, calculated based upon actual rather than worst-case weather conditions. If the line load is kept below its rating, the line will meet or exceed its 40 yr design life and minimum clearances will be maintained to ground, buildings, and other conductors.

Calculating Dynamic Ratings with IEEE 738

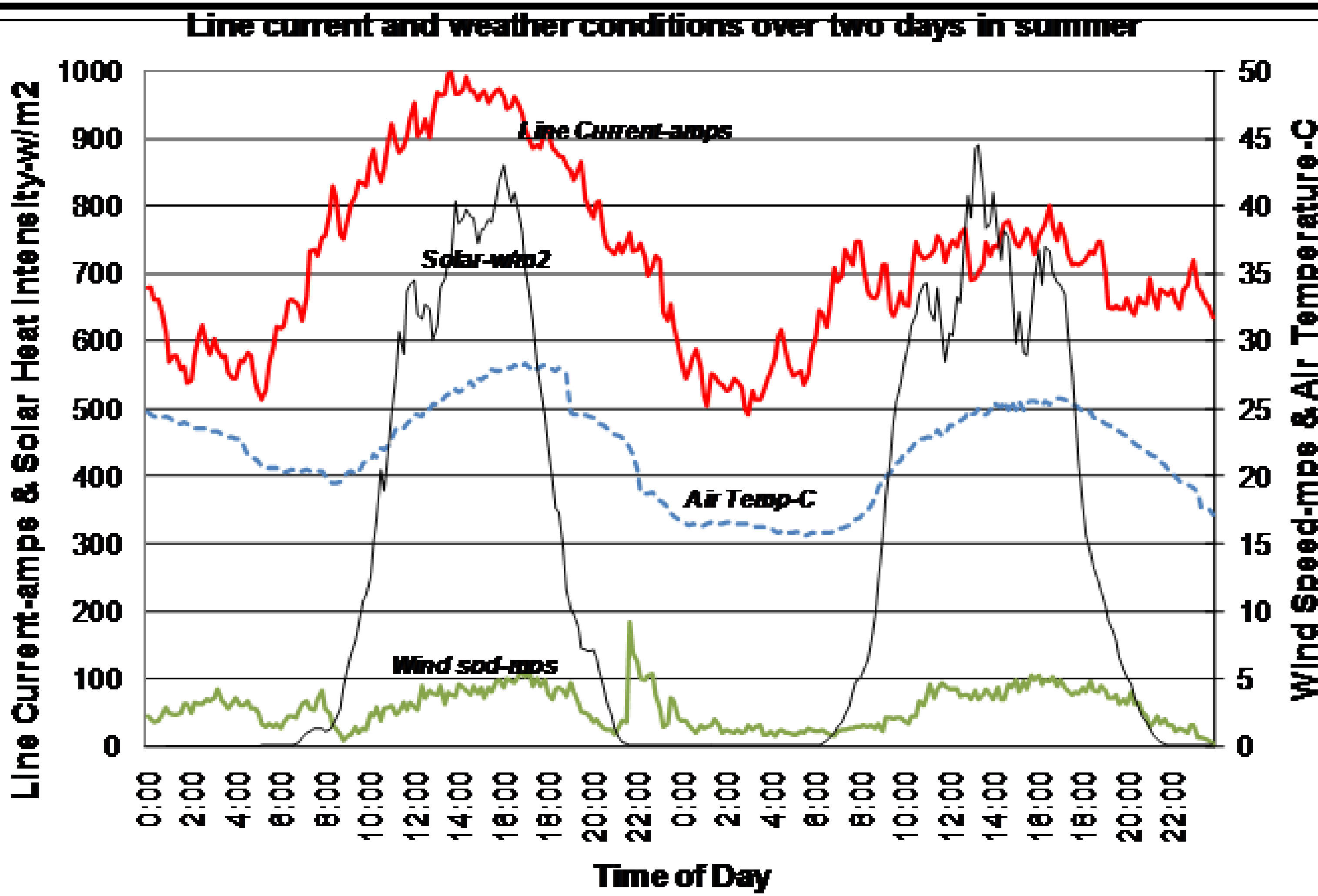
- The simplest form of dynamic thermal rating is seasonal ratings.
- For example, in NYISO, the normal continuous Summer Rating of lines is calculated for an air temperature of 35C while the Winter Rating is calculated for an air temperature of 10C. Both assume a wind of 3 fps and full sun.
- For 795 kcmil Drake ACSR, at 95C, the Summer rating is 1100 and Winter is 1330 amps.
- The adjustment of rating is about 0.8% per deg C.

Another very common Dynamic Rating method is Ambient-Adjusted Ratings

- Recalculate line ratings daily or even hourly according to the predicted air temp for the rating period (4-hr, day). Easy to integrate into operations.
- For example, if the Summer Line Rating is 1100a (worst-case air temp 35C), the “next-day” rating is adjusted to 1200a if the predicted max air temp is 25C throughout the region that the line traverses.
- In error if the prediction of air temp is incorrect, if wind speed depends on air temperature, if air temp along line exceeds 25C, if wind speed assumption is not conservative.

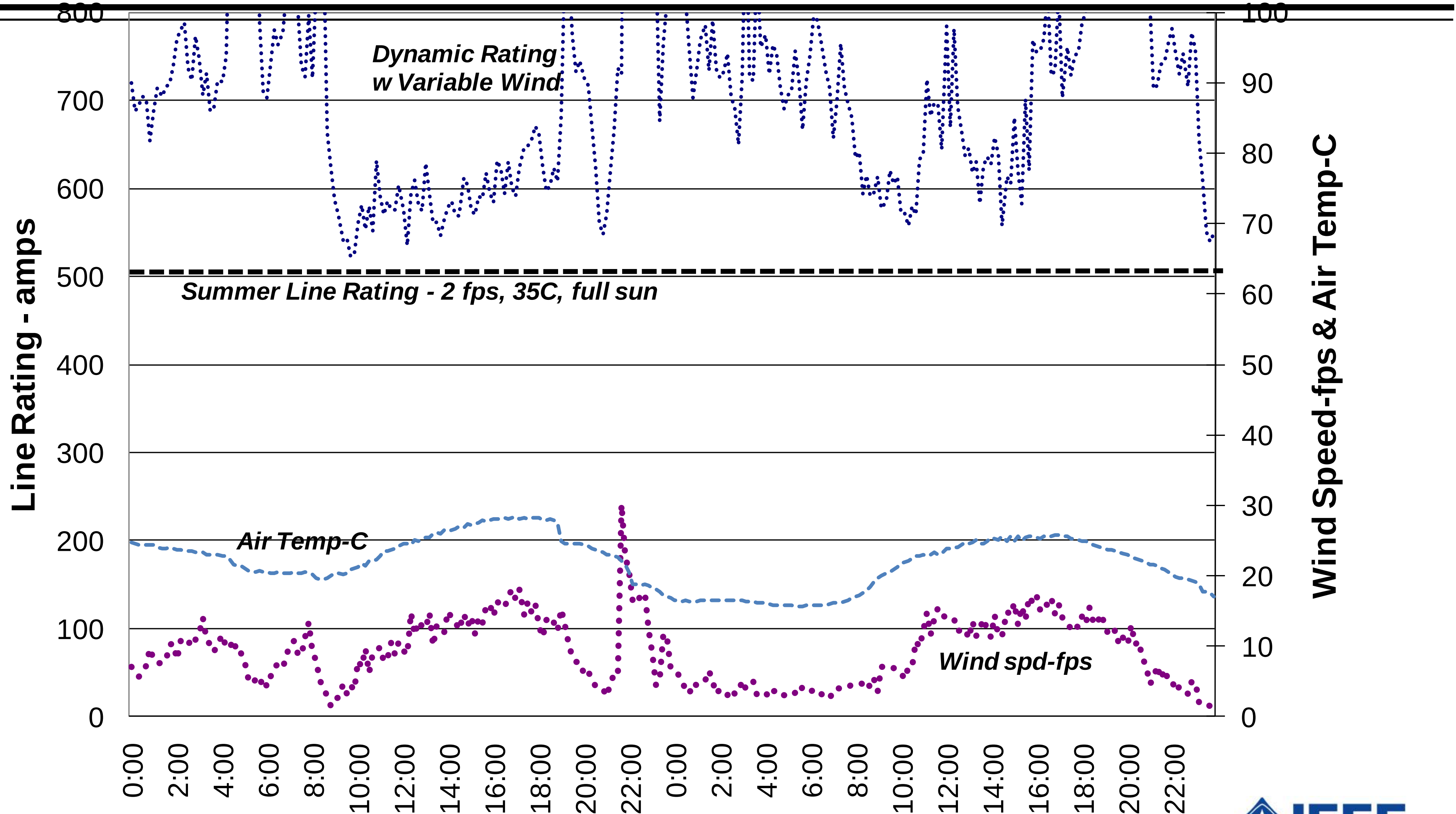
All Dynamic Rating Methods

- Are calculated using a heat balance program like IEEE 738.
- Require real-time weather data:
  - Air temperature (at least)
  - Solar heating
  - Wind speed and direction



Line current and weather conditions over two days in summer
Line Current-amps & Solar Heat Intensity-w/m2
Wind Speed-mps & Air Temperature-C
1000
900
800
700
600
500
400
300
200
100
0
50
45
40
35
30
25
20
15
10
5
0
Line Current-amps
Solar-w/m2
Air Temp-C
Wind spd-mps
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time of Day

Comparison of dynamic ratings with static line ratings for Oriole ACSR @75C over 2 summer days



Dynamic Rating Observations

- Air temperature varies little along an overhead line and is quite predictable (even a day ahead).
- Solar heating is similar.
- Wind speed and relative direction can vary sharply from span to span and must be measured in the right-of-way to be accurate.
- Line monitors (sag, tension, or cond. Temp.) or low-stall anemometers in the ROW are essential.

Overhead Line Monitors

- **Anemometers yield wind speed and direction in a single span.**
- **Cond. Temp. monitors can use the line as a single-span hot wire anemometer if current is known.**
- **Sag-tension monitors require conversion of sag-tension to cond. temp. and then to wind speed but applies to sag-section not single span.**

2D & 3D Anemometers

Thermal Rate Non-Contact Line Simulation Monitor

Dynamic Rating from Anemometer data -

Line current [amps]	Solar Heating [w/m2]	Air Temp [C]	Cond. Temp. [C]	Perp. Wind speed [fps]	
400	Noon	35	53.6	2	
400	Noon	35	49.1	4	
400	Noon	35	44.9	8	
400	Noon	25	43.8	2	
400	Noon	25	39.1	4	
400	Noon	25	34.9	8	

Overhead Line Monitors

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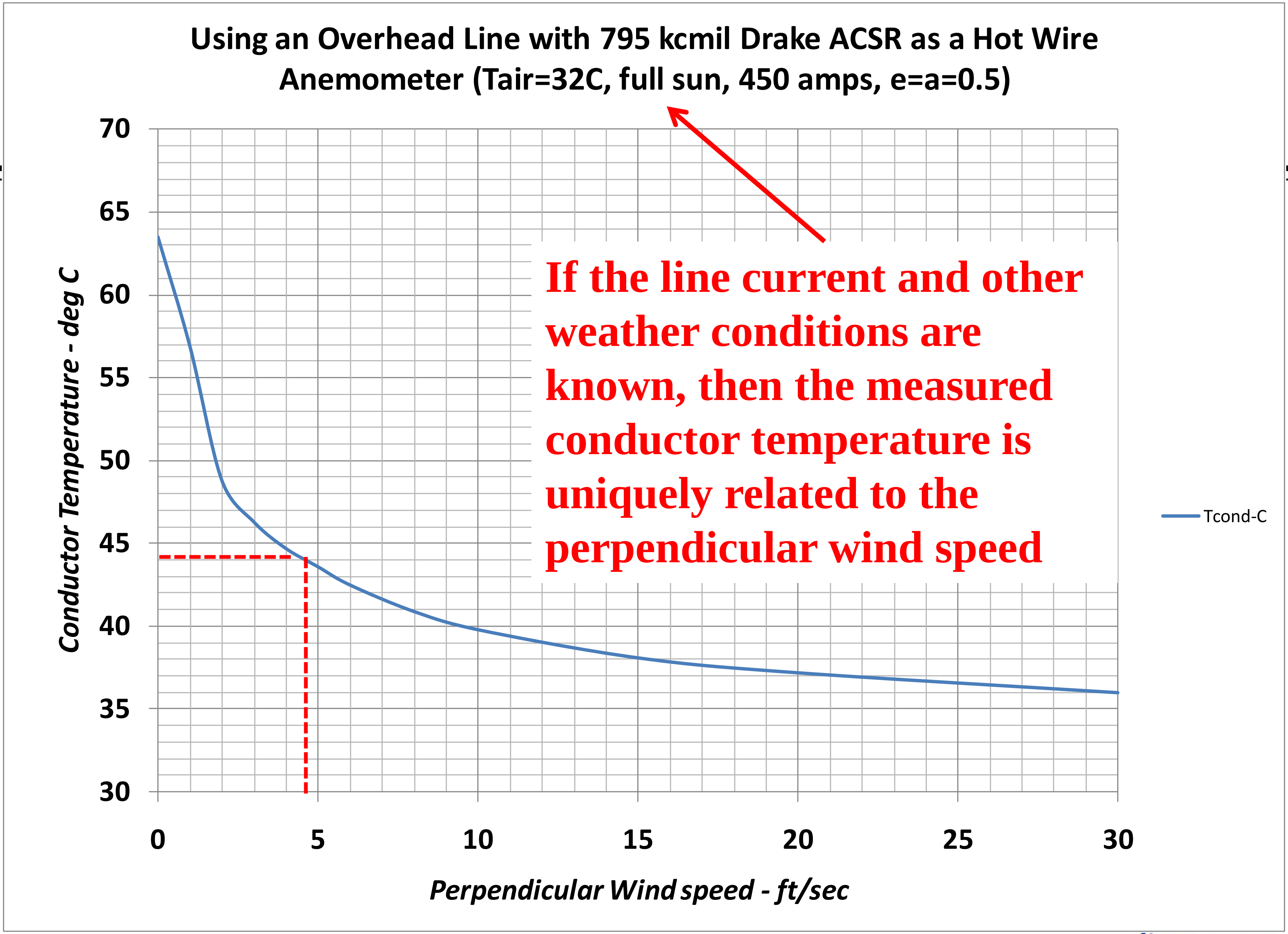
- Cond. Temp. monitors can use the line as a single-span hot wire anemometer if current is known.
- Sag-tension monitors require conversion of sag-tension to cond. temp. and then to wind speed but applies to sag-section not single span.

Power Donut Temperature and Current Monitor


Use of the transmission line itself as an anemometer

- Lines need to be “hot” (current at least 0.5 to 1 amp/mm2) to work accurately as an anemometer.
- Other weather data is required to determine the effective perpendicular wind speed.
- These observations are true whether conductor temperature, line tension, span sag, conductor vibration or sag clearance is monitored.



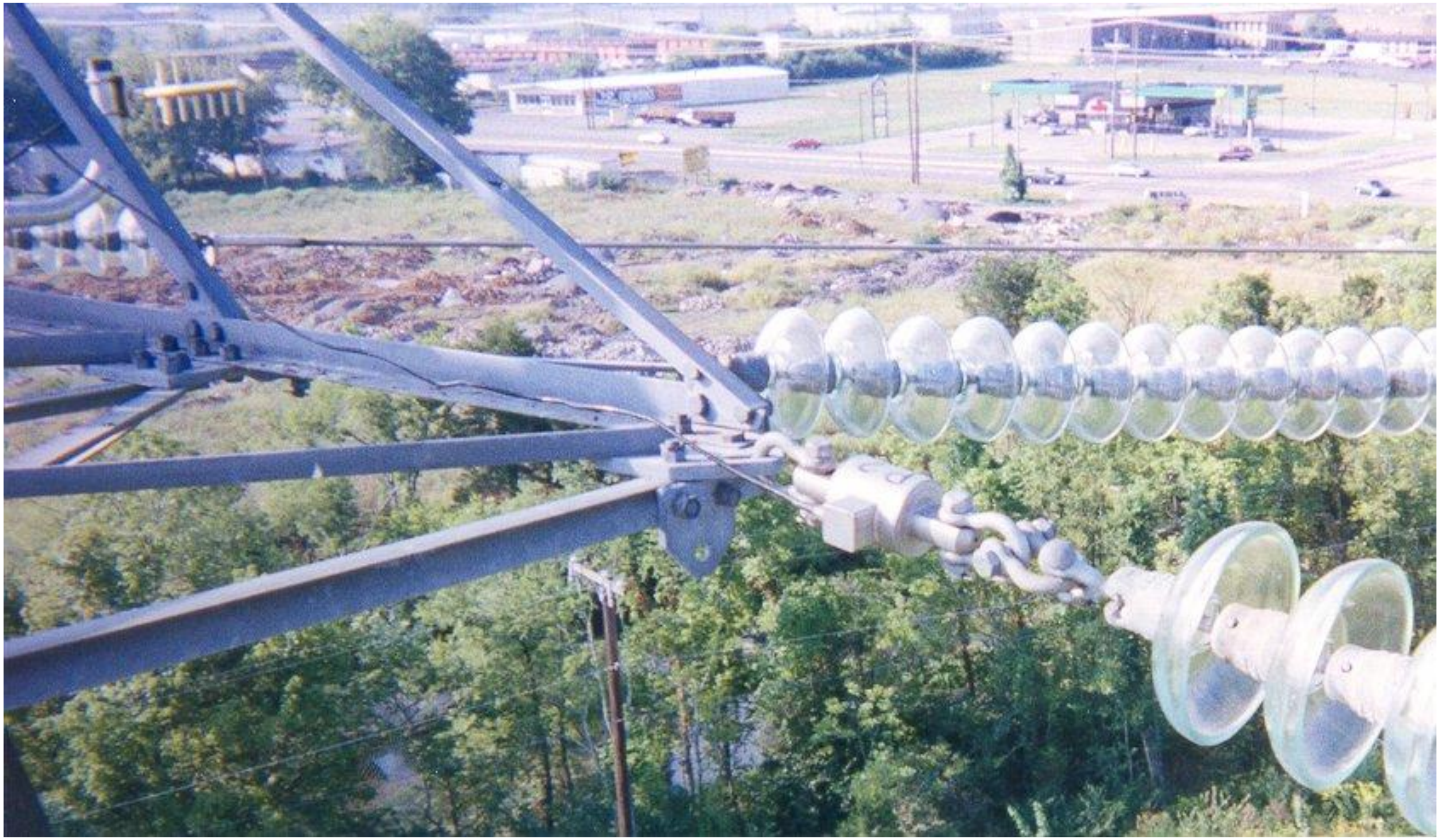
Using an Overhead Line with 795 kcmil Drake ACSR as a Hot Wire Anemometer (Tair=32C, full sun, 450 amps, e=a=0.5)
If the line current and other weather conditions are known, then the measured conductor temperature is uniquely related to the perpendicular wind speed
Conductor Temperature - deg C
70
65
60
55
50
45
40
35
30
0
5
10
15
20
25
30
Perpendicular Wind speed - ft/sec
Tcond-C

Overhead Line Monitors

- **Anemometers yield wind speed and direction in a single span.**
- **Cond. Temp. monitors can use the line as a single-span hot wire anemometer if current is known.**
- **Sag-tension monitors require conversion of sag-tension to cond. temp. and then to effective perp. wind speed for whole sag-section.**

Real time rating systems

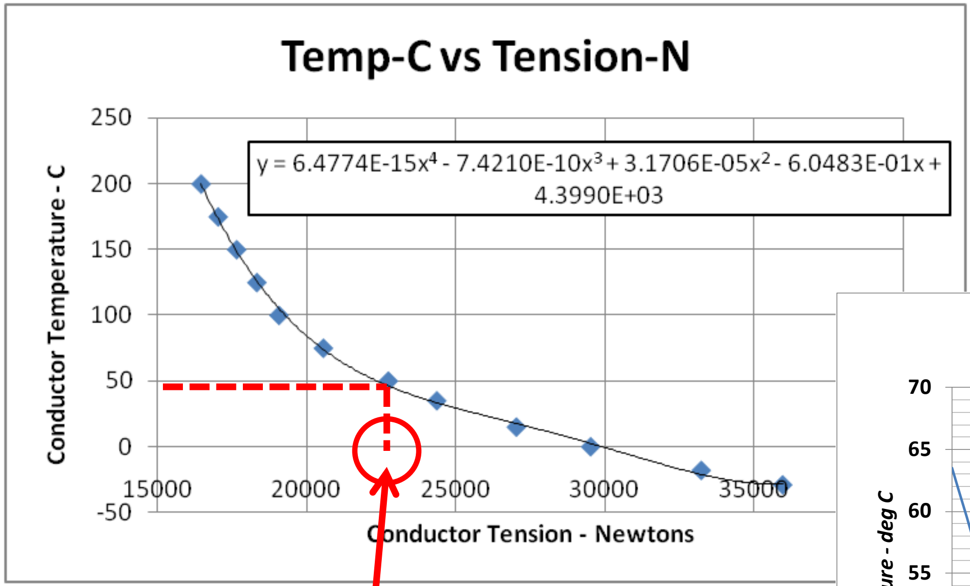
Load cells



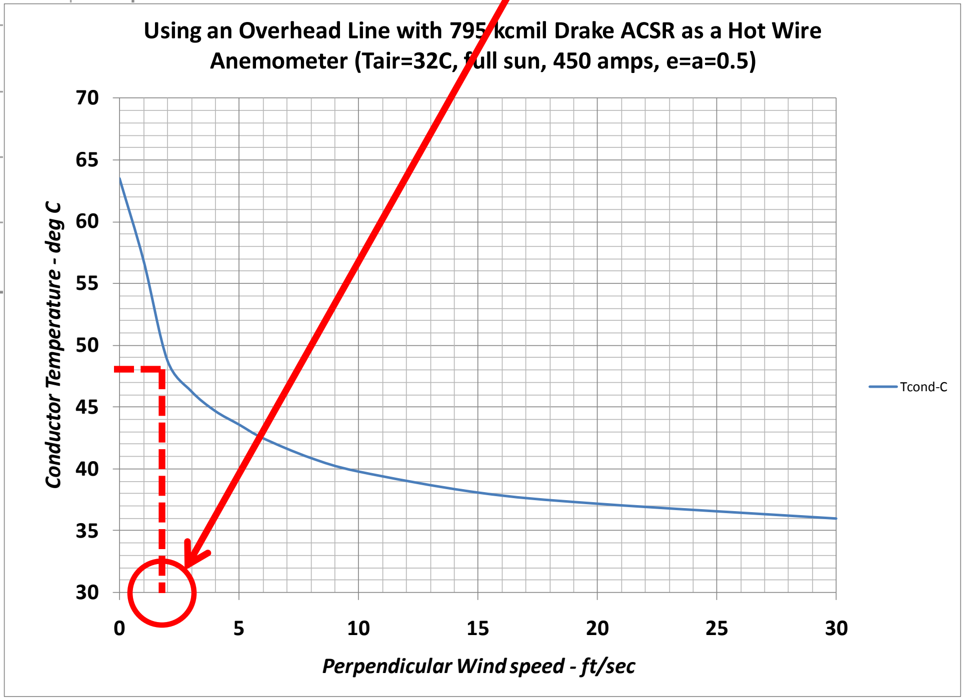
Net Radiation Sensor

Magnetic Sensor under 500kV Line

Converting Line Monitor Data into Effective Perp. Wind speed



2 – An average cond. Temp of 48C corresponds to an average perp. Wind speed of 2 ft/sec.



1 - A line tension of 23 kN corresponds to an average cond. temp of 48C.

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Integration into Operations

- For dynamic ratings to work, system operations must find the idea compelling and the increased ratings useful.
- Displays of dynamic ratings must be integrated into the existing operator displays so they are available when needed but ignorable when not.
- Interfacing dynamic ratings with RAS programs requires proven reliability but is a promising way to use this data.
- Security issues are very difficult in many applications.
- Each installation may be intended to solve a different problem. It is unlikely that monitor-based ratings will apply system-wide

Conclusions

- Static line ratings are based on worst-case estimates of weather conditions and are usually system-wide.
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