CIGRE-US National Committee

2023 Next Generation Network Paper Competition

Navigating Uncertainties in Dynamic Line Rating Estimation

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Why Dynamic Line Ratings?

Increased Capacity

***100% growth** in grid capacity required by 2035*

Interconnection Backlog

1,400+ GW of interconnection projects stuck in the queue

Forest Fires

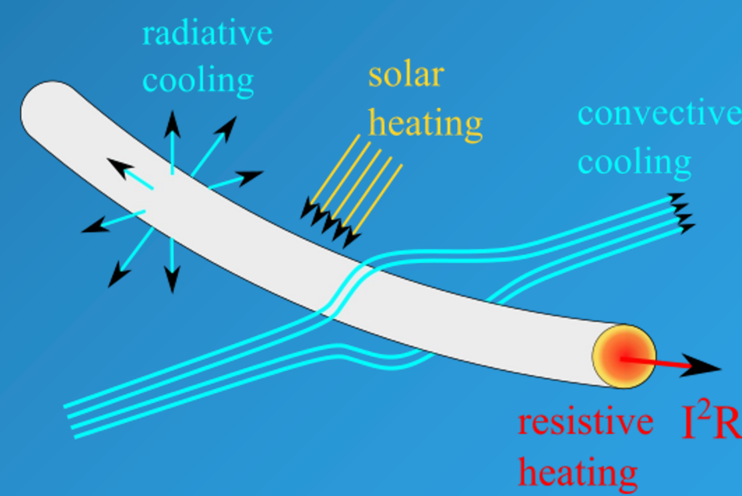
Exceeding clearance limits can ignite vegetation

Blackouts / Brownouts

***$90B+** in economic losses from Texas' 2021 storm*

What are Line Ratings?

Functional Dependencies	
Resistive Heating $q_R(T_c) > 0$	**Radiative Cooling** $q_r(T_a, T_c, \varepsilon_c) < 0$
Solar Heating $q_s(Q_s, \alpha_c) > 0$	**Convective Cooling** $q_c(T_a, T_c, v_a, \theta_a) < 0$
T_c - *Conductor Temperature* α_c - *Conductor Absorptivity* ε_c - *Conductor Emissivity*	Q_s - *Solar Irradiance* T_a - *Air Temperature* v_a - *Air Speed* θ_a - *Air Direction*



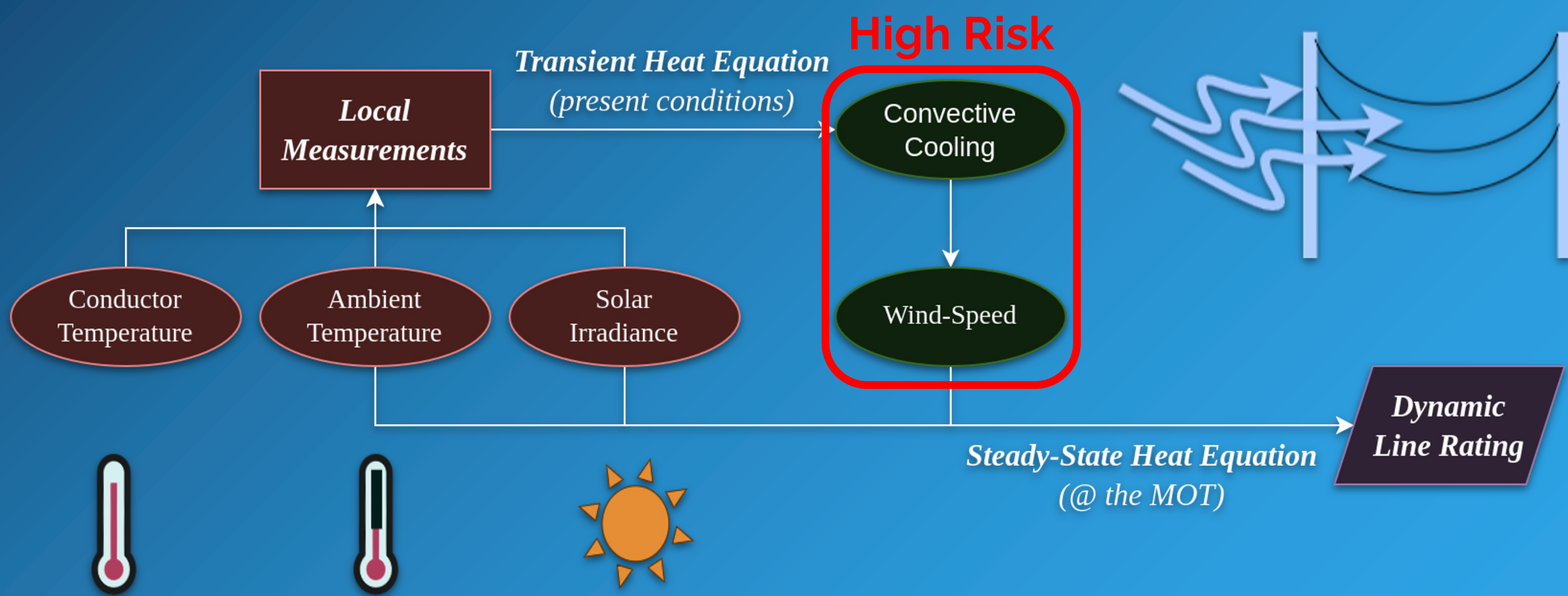
$$mc\frac{dT_c}{dt} = I^2R + q_r + q_s + q_c$$

Heating / Cooling

Rate of Change of T_c

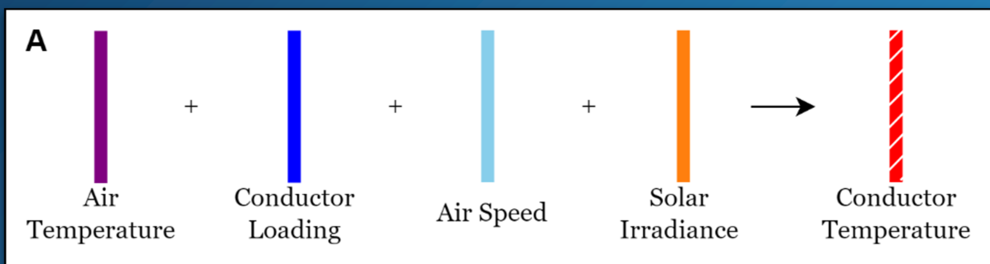
What are Dynamic Line Ratings?

498 Guide for Application of Direct Real-Time Monitoring Systems

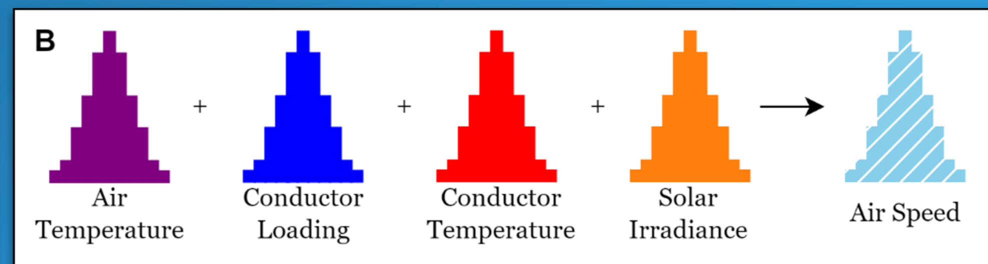


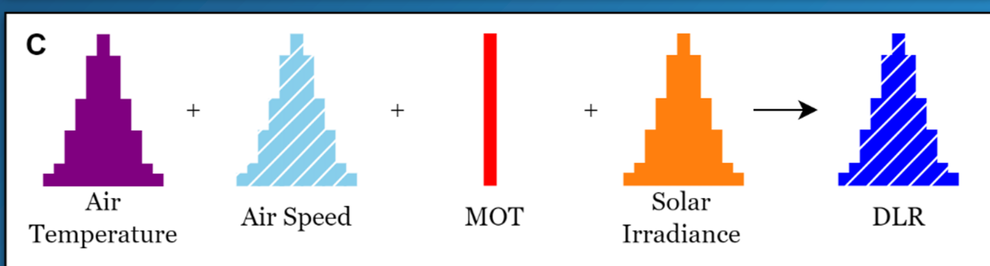
Uncertainty Propagation

Simulate the “true” conditions

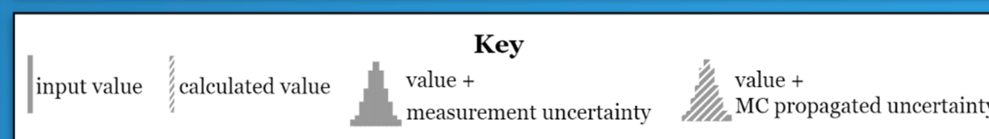


Add measurement error





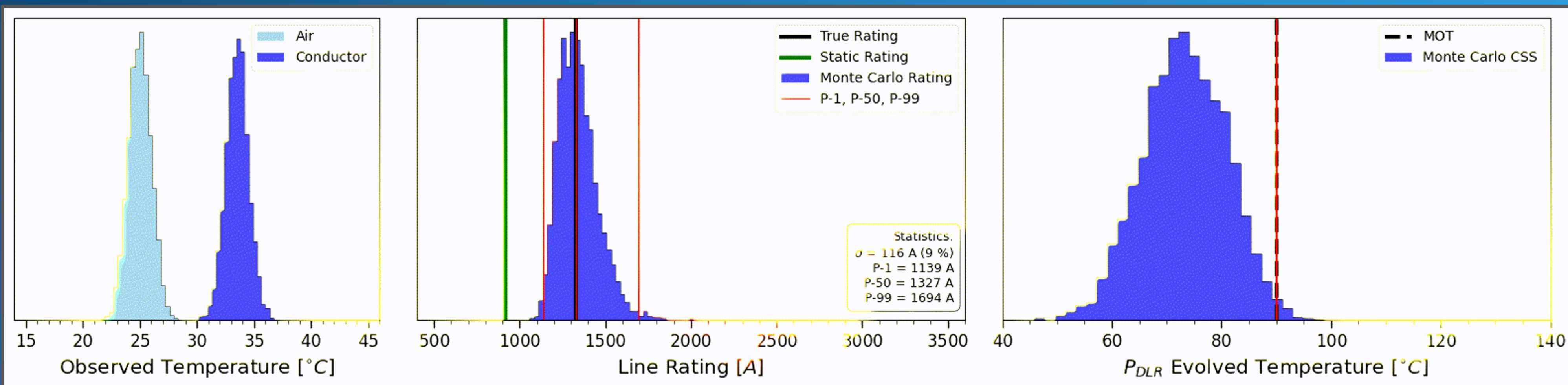
Calculate all possible DLR



A Distribution of all possible DLRs observed.

Uncertainty Propagation

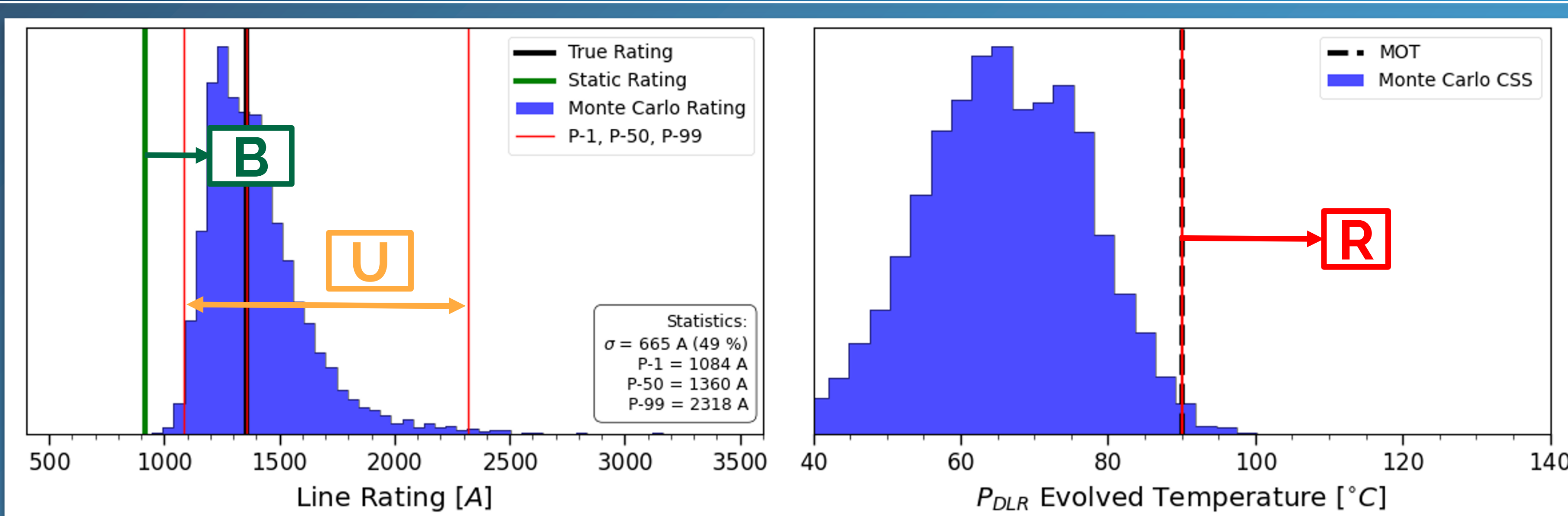
➢ High-temperature rise leads to low DLR uncertainty, and well behaved evolved conductor temperatures.



➢ Low-temperature rise explodes the DLR uncertainty, and results in unpredictable evolved conductor temperatures.

Defining the Metrics

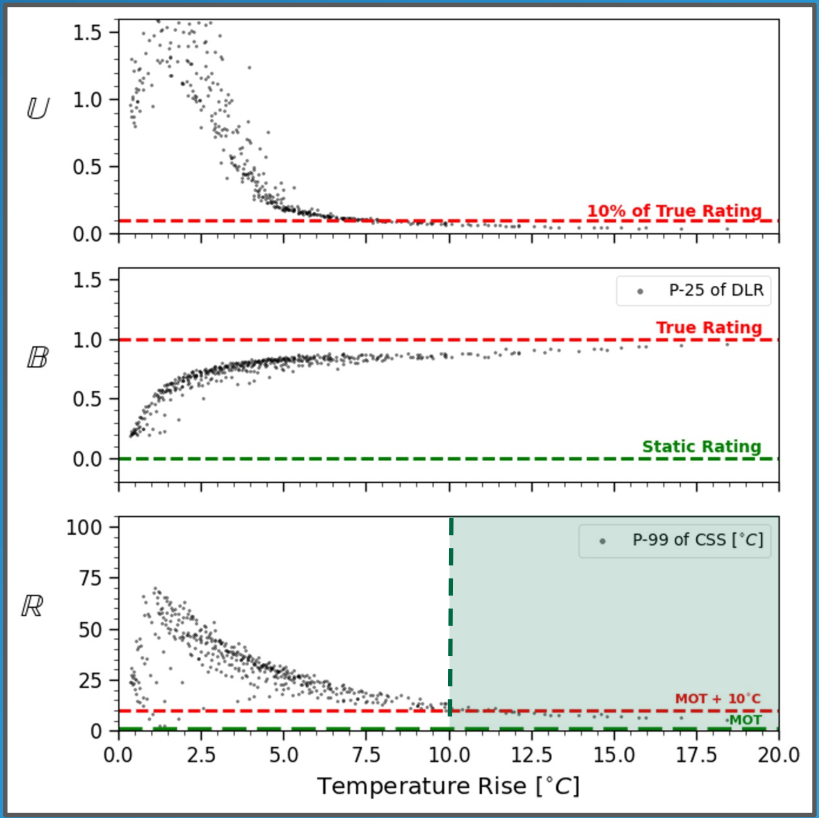
Uncertainty, Benefit, & Risk



$$\mathbb{U} = \frac{\sigma_{DLR}}{DLR} \qquad \mathbb{B} = \frac{P_{DLR} - SLR}{DLR - SLR} \qquad \mathbb{R} = P_{CSS} - MOT$$

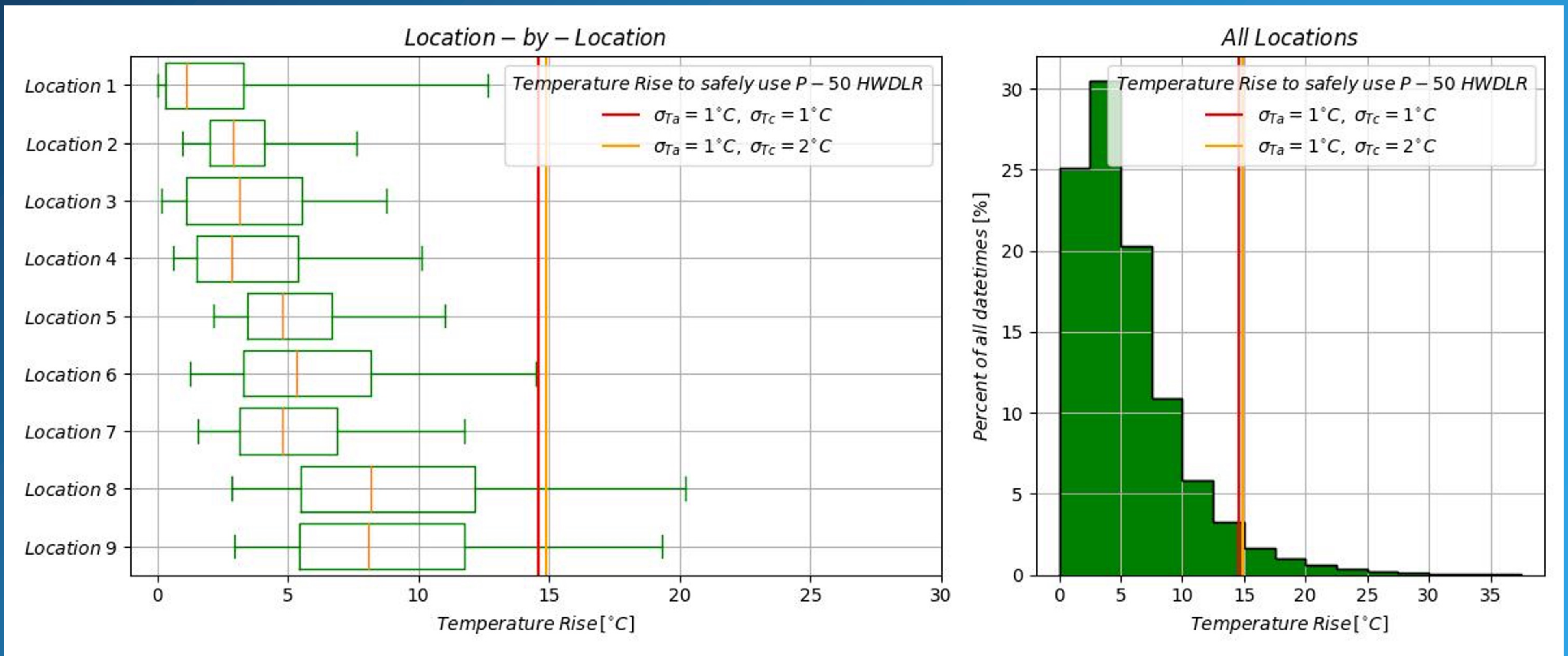
Uncertainty, Benefit, & Risk

- ➢ The **Uncertainty** in DLR increases as the temperature rise decreases.
- ➢ The **Benefit** of the DLR decreases as the temperature rise decreases.
- ➢ The **Risk** of the DLR increases as the temperature rise decreases.



Sampe: 9 Sites

Statistics from the Field



Sample: 9 Sites

Statistics from the Field

	σ_{Ta} = 0.5 °C σ_{Tc} = 1.0 °C	σ_{Ta} = 1.0 °C σ_{Tc} = 1.0 °C	σ_{Ta} = 1.0 °C σ_{Tc} = 2.0 °C
P_{DLR} - 50	4.4 %	4.4 %	4.4 %
P_{DLR} - 25	13.2 %	10.2 %	4.6 %
P_{DLR} - 10	29.0 %	27.9 %	11.3 %
P_{DLR} - 01	100 %	100 %	100 %

Percentage of time the DLR p-value is a ***safe*** choice:

$P_{CSS}\text{-}99 < MOT + 10^oC$

Thank You

"Any measurement that you make, without any knowledge of the uncertainty, is meaningless."

- ***Walter Lewin***

Appendices

Outline

I. Dynamic Line Ratings

- ➢ How are Line Ratings defined?
- ➢ The Hot-Wire DLR Approach [CIGRE TB-498]

II. Uncertainty Propagation

- ➢ Monte Carlo Simulations
- ➢ Measurement Error → DLR Uncertainty

III. Uncertainty, Benefit, & Risk

- ➢ UBR as Insightful Metrics
- ➢ The Impact of Temperature Rise
- ➢ How frequently is the HW-DLR safe?

Dynamic Line Ratings

The Transient Heat Equation:

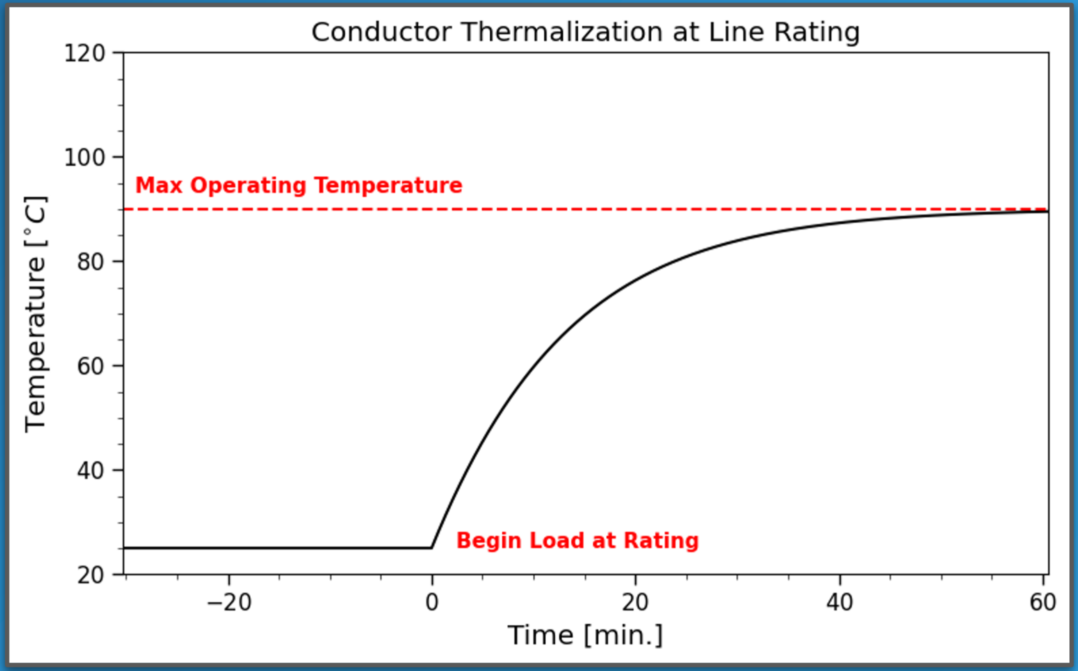
$$mc\frac{dT_c}{dt} = I^2R + q_r + q_s + q_c$$

Heating / Cooling

Rate of Change of T_c

The Steady-State Heat Equation:

$$0 = I^2R + q_r + q_s + q_c$$



Uncertainty Propagation

- Many parameters impact the calculation of DLR.
- Uncertainty in these inputs, propagate to the DLR uncertainty.
- The calculations each term can be found in ***IEEE-738 2012***.

$$mc\frac{dT_c}{dt} = q_R + q_s + q_r + q_c$$

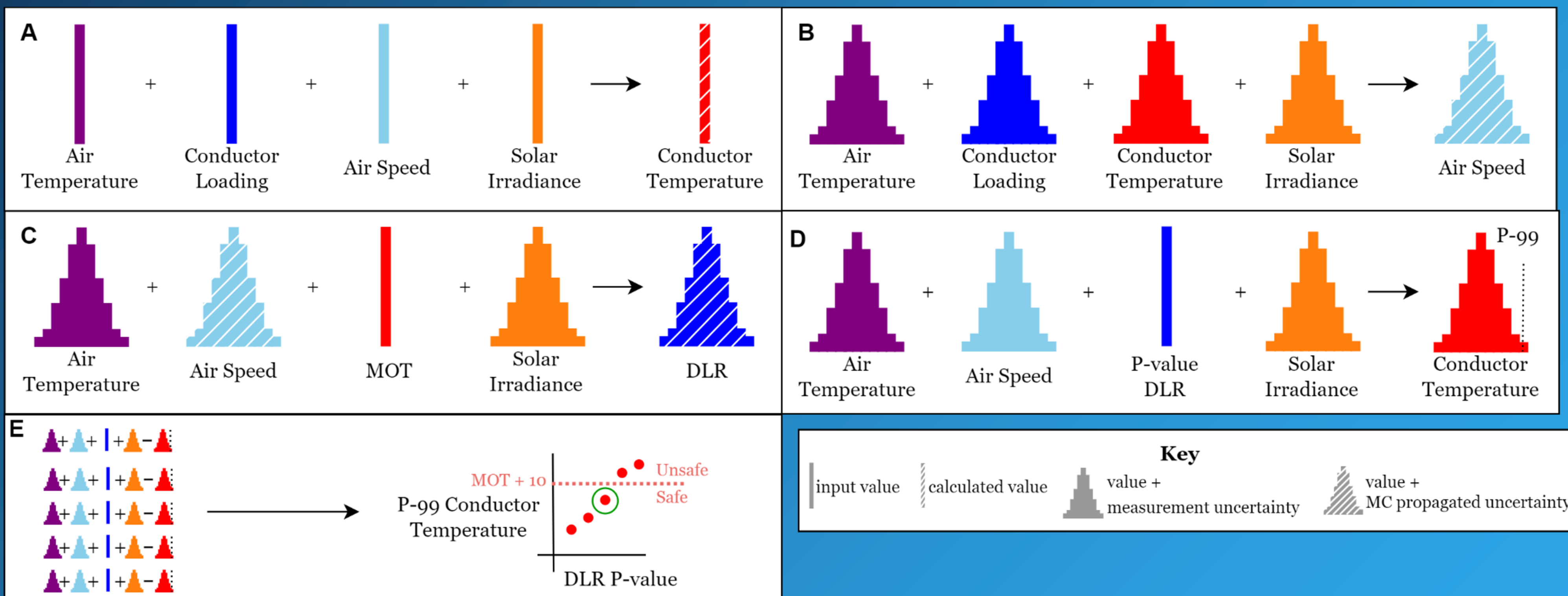
Heat Density Term [J / m]	Dependencies
Resistive Heating $q_R(T_c) > 0$	T_c - *Conductor Temperature*
Solar Heating $q_s(Q_s, \alpha_c) > 0$	Q_s - *Solar Irradiance* α_c - *Conductor Absorptivity*
Radiative Cooling $q_r(T_a, T_c, \varepsilon_c) < 0$	T_a - *Air Temperature* T_c - *Conductor Temperature* ε_c - *Conductor Emissivity*
Convective Cooling $q_c(T_a, T_c, v_a, \theta_a) < 0$	T_a - *Air Temperature* T_c - *Conductor Temperature* v_a - *Air Speed* θ_a - *Air Direction*

Uncertainty Propagation

Parameter	Value	Uncertainty (σ)
Air Speed	1.5 m/s (0.61 m/s)	——
Air Temperature	25.0 °C (40.0 °C)	1.0 °C
Cond. Name / Type	Drake / ACSR	——
Cond. Absorptivity / Emissivity	0.8 / 0.8	0.02 / 0.02
Cond. Loading	200 A	5.0 A
Cond. Temperature	——	1.0 °C
Solar Irradiance (Noon)	1027 W/m^2 (1025 W/m^2)	50 W / m^2

Table 1: All of the results involved in this work, unless otherwise stated, were derived from the assumed conditions and measurement uncertainties tabulated here. The parenthetical values are the conditions used to generate the static line rating.

Uncertainty, Benefit, & Risk



➢ Choose a P_{DLR} value, rerun the Monte Carlo to determine if the P_{CSS}-99 exceeds the MOT + 10 °C.

Defining the Metrics

Uncertainty, Benefit, & Risk

Uncertainty

> *What is the confidence in the derived DLR relative to the "true" DLR?*

$$\mathbb{U} = \frac{\sigma_{DLR}}{DLR}$$

Benefit

> *How much capacity does the choice in DLR p-value add to the SLR relative to the "true" DLR?*

$$\mathbb{B} = \frac{P_{DLR} - SLR}{DLR - SLR}$$

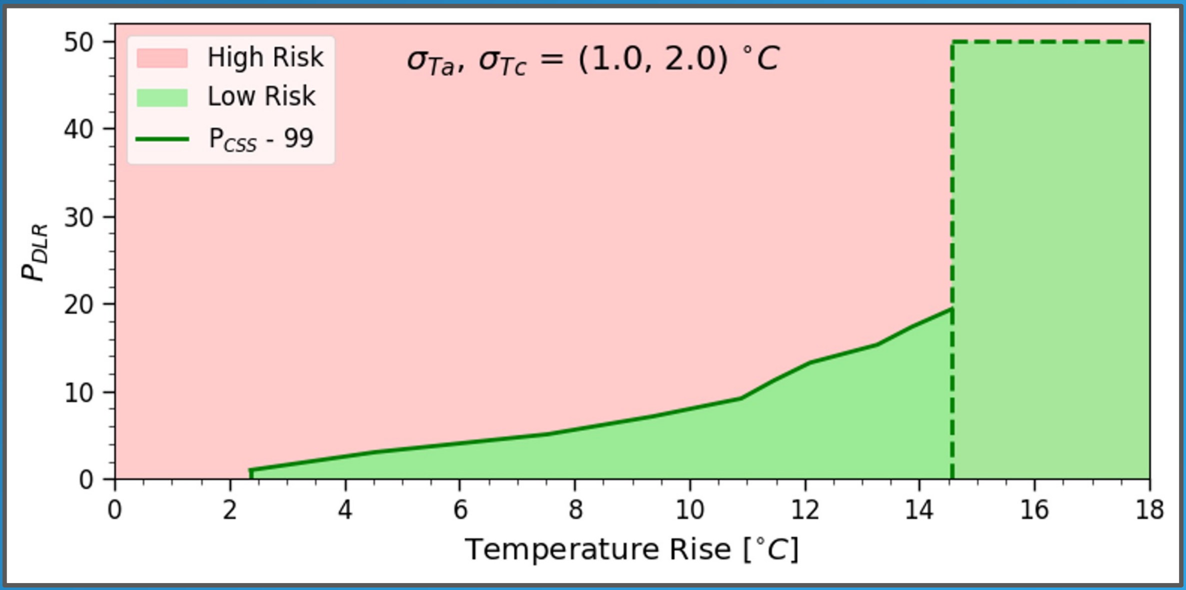
Risk

> *How much above MOT could the line temperature reach using this DLR?*

$$\mathbb{R} = P_{CSS} - MOT$$

Uncertainty, Benefit, & Risk

- Reiterate the process on the previous slide:
  - Choose a new DLR p-value
  - Find the temperature rise for which *P_{CSS}-99 < MOT + 10ºC*
- The threshold for safe P_{DLR} is shown as a function of temperature rise; the green region indicates safe P_{DLR} .
- As the uncertainty in ambient and conductor temperatures increases, the safe P_{DLR} region gets smaller.



Sample: 9 Sites

Frequency of High Risk Scenarios

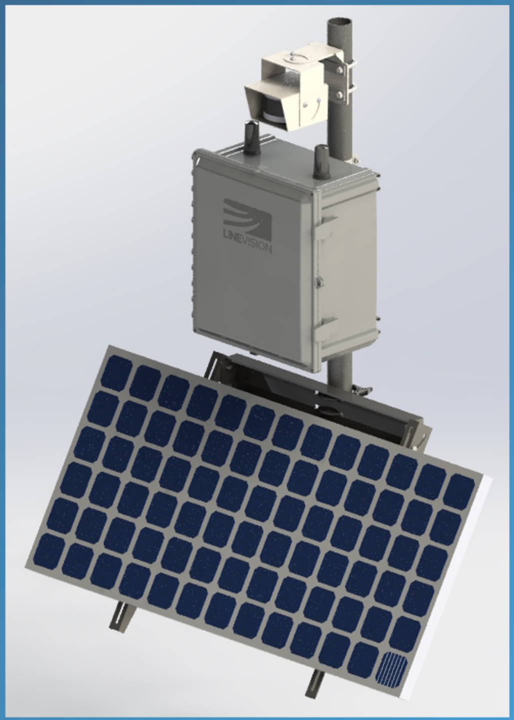
Range of conditions for the 9 locations studied. Loading values are on a per sub-conductor basis.

Variable	Range Included within Study
Latitude	$34.5 - 53.5\ ^{\circ}$
Cond. Type	ACSS, ACSR, ACAR, various sizes
Cond. Absorptivity / Emissivity	$0.5 - 0.9$
Average / Maximum Loading	$34 - 557\ A$ / $366 - 1,388\ A$
Time Period Observed	$122 - 348\ days$

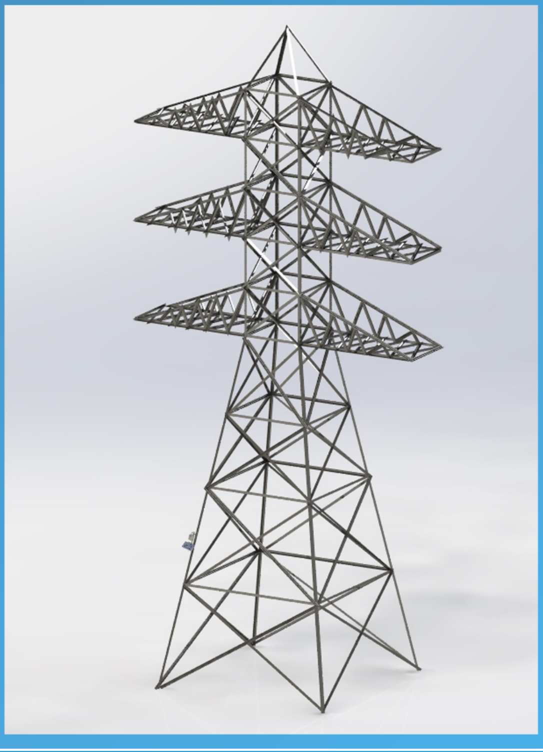
Data Collection

OHL Monitoring

LiDAR Data Collection



Installed on Tower



LINEVISION

Accelerating the **Net Zero Grid**

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