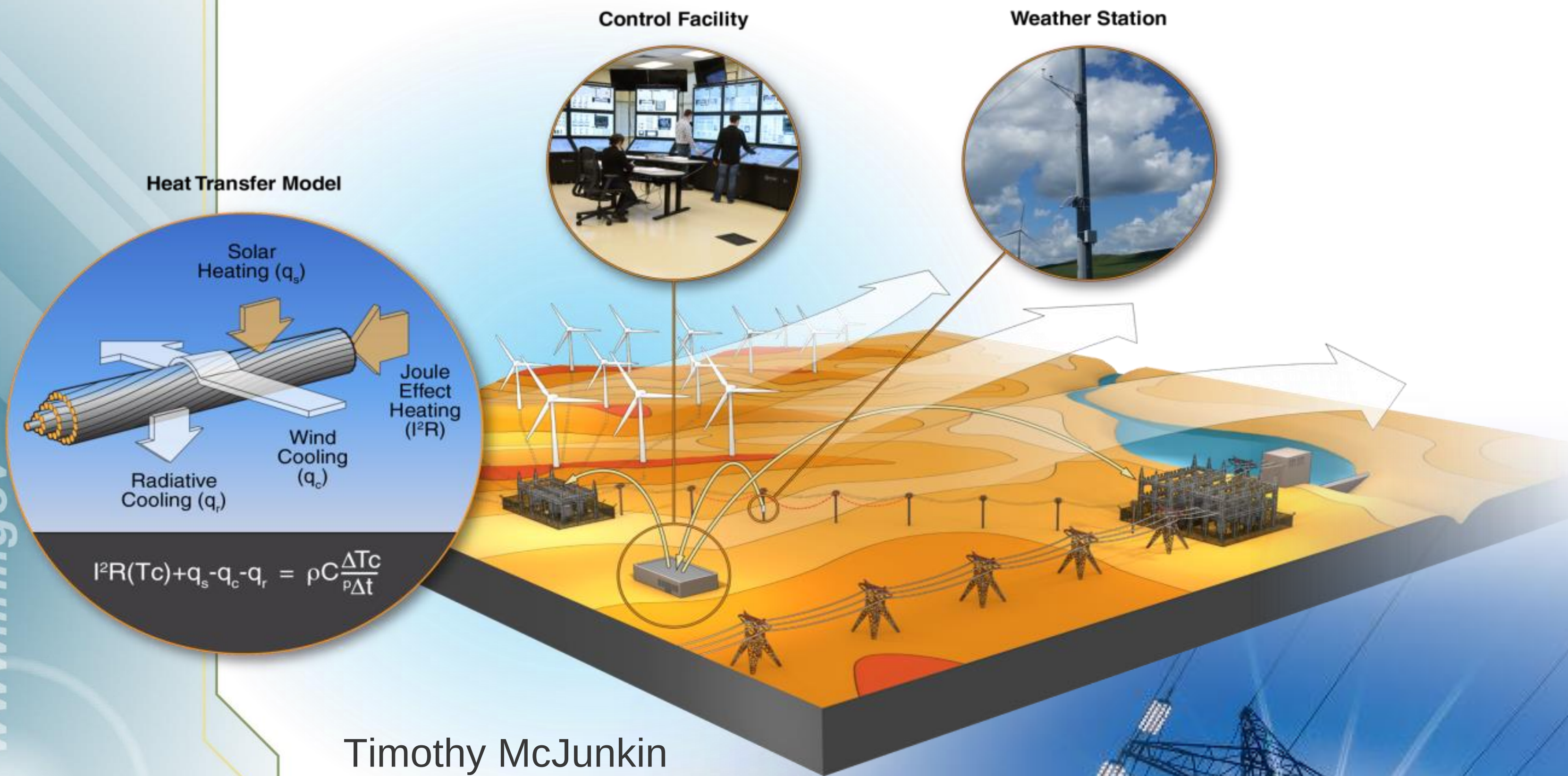
INL/MIS-16-37713 Rev3

UVIG Forecasting Workshop

Importance of Forecasting to Dynamic Line Rating of Transmission Lines



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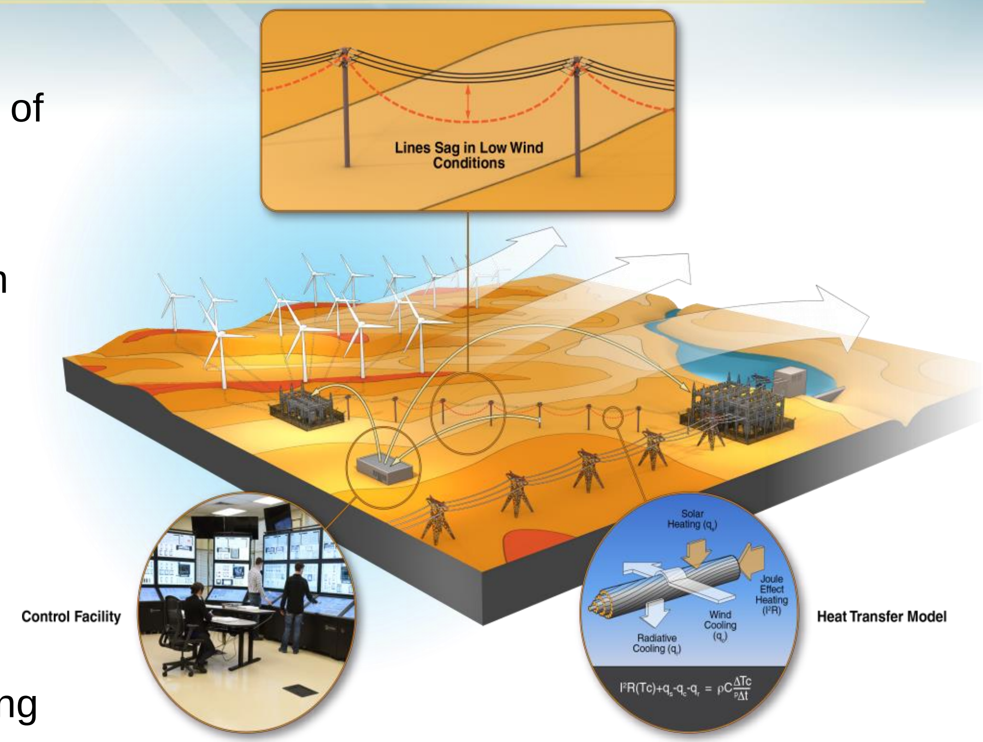
State of the Industry

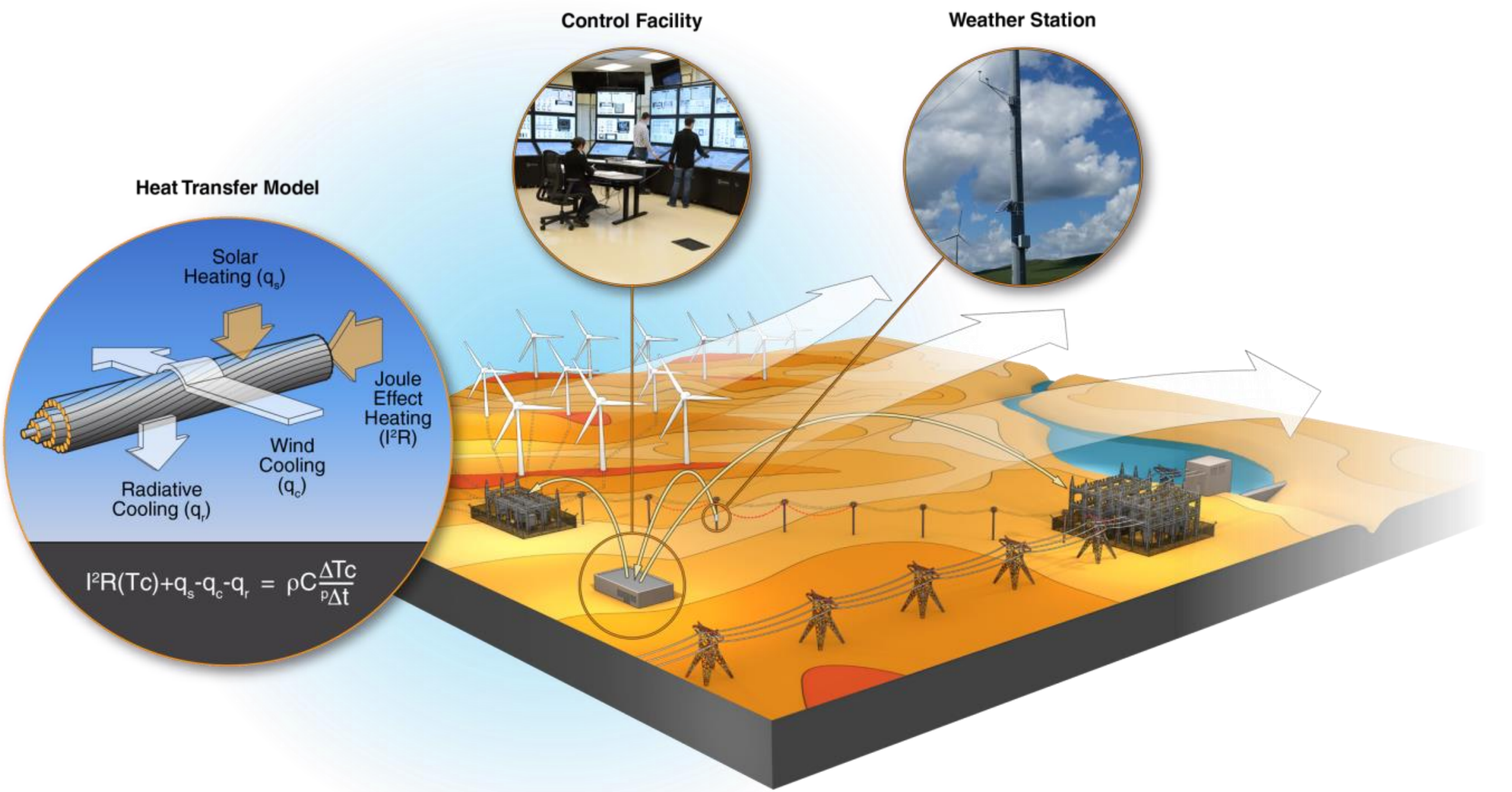
- The US produces 4.1 trillion Kilowatt-hours of electricity per year
- Distributed by 500 Power Companies
- 160,000 Miles of High Voltage transmission lines in the U.S. known as ”the grid.”
- Challenge is getting it to cities, factories, military bases in the right amounts when needed
- Power utilities operate transmission lines based on **static ratings**, which set a conservative limit on the amount of current the lines can safely carry without overheating



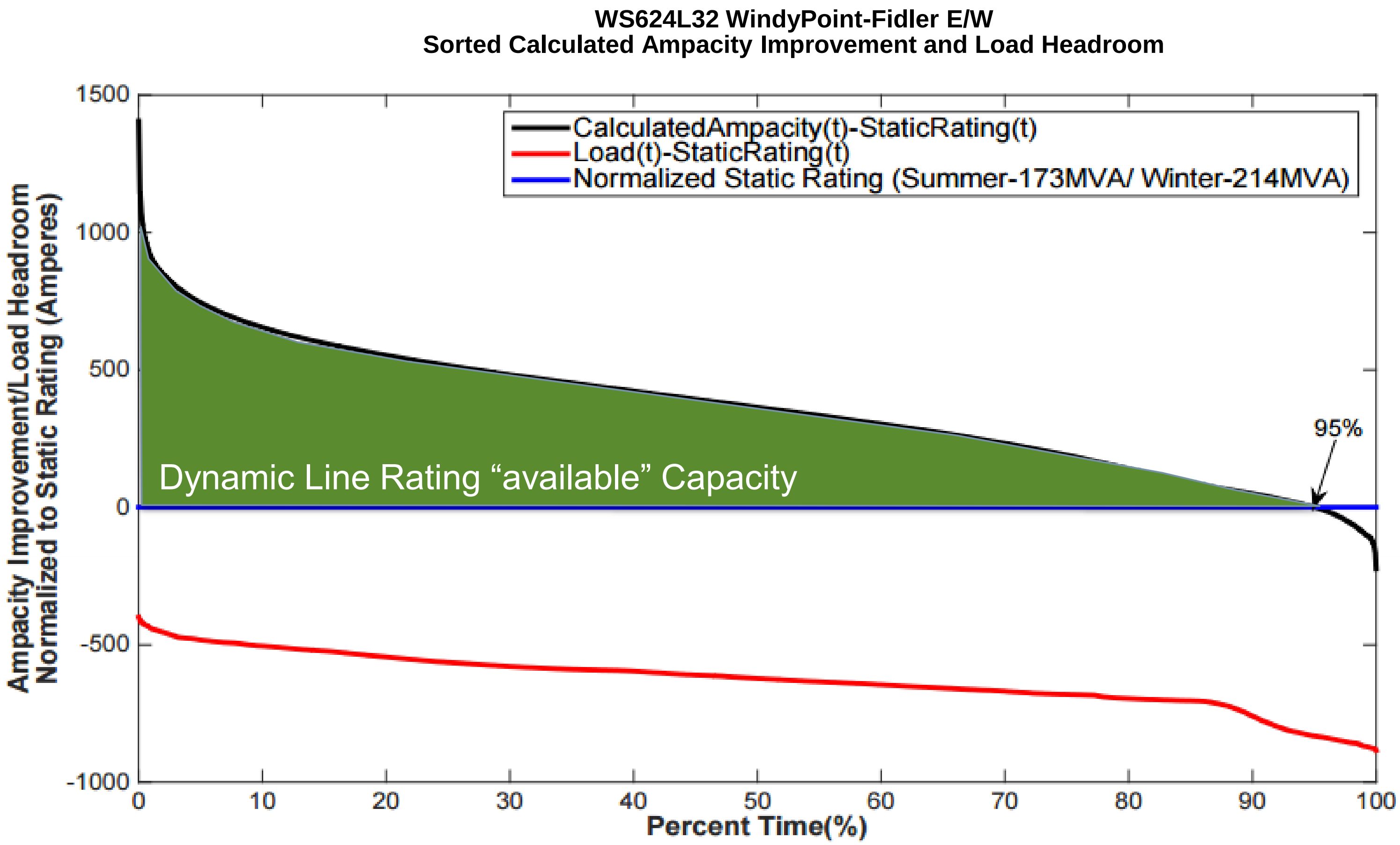
- **Without accurately measuring the environmental conditions and their effects, lines can be critically underutilized.**
- **Without conservative and accurate forecasts of capacity utilities can NOT plan and effectively use the capacity.**

Weather Based DLR Approach

Computational Fluid Dynamics Informed Weather Based Dynamic Line Rating



Available Capacity Improvement with DLR… but



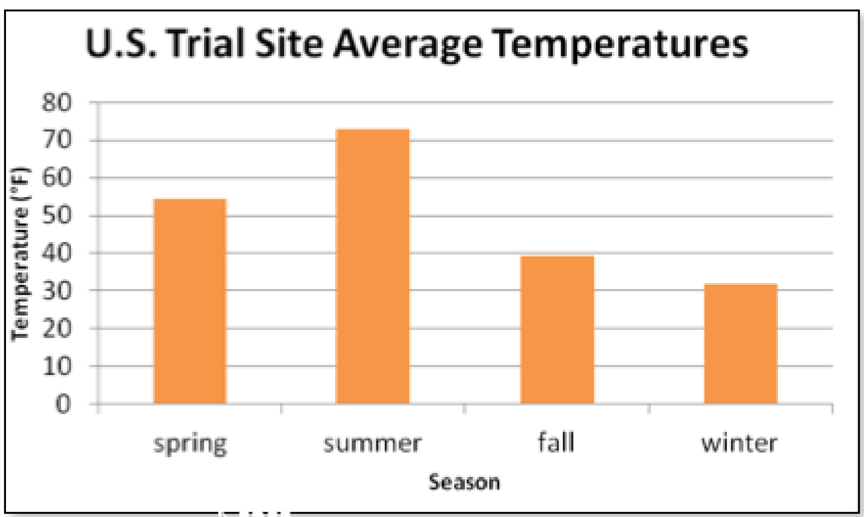
…how can it be made usable
DLR Forecasting Decision Guidance

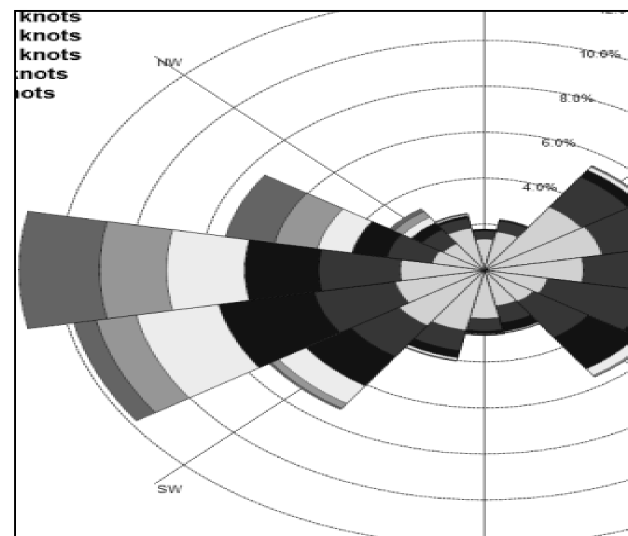
Time scales

1. Instantaneous
2. Short-term: Thermal Inertia
3. Short-term look ahead
4. Daily Peak Loading, Generation Dispatch
5. Maintenance, Power Marketing
6. Maintenance, Marketing, Construction
7. Construction, Refurbishment, Voltage Upgrades

1 2 3 4 5 6 7 Time

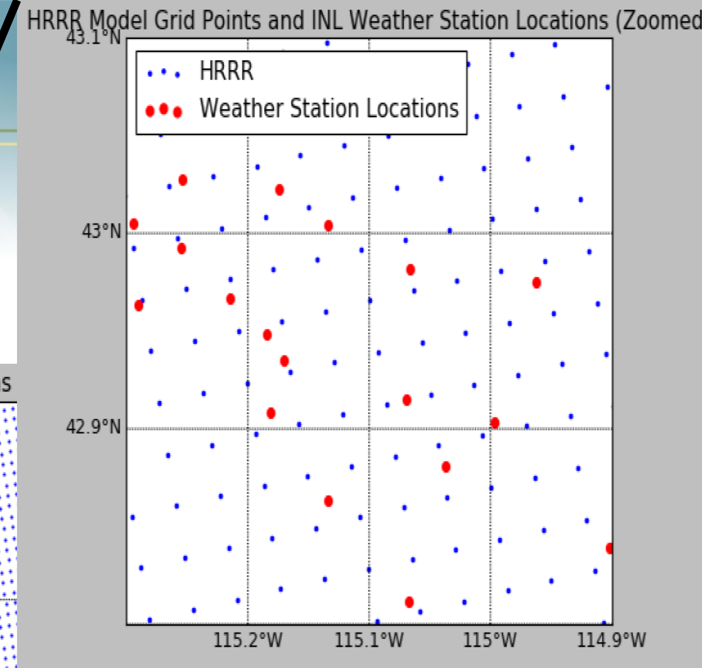
1: t
2: $15\,\text{min} \le t \le 60\,\text{min}$
3: $60\,\text{min} \le t \le 4hr$
4: $4hr \le t \le 24hr$
5: $24hr \le t \le 48hr$
6: $3days \le t \le 7days$
7: $t \ge months$

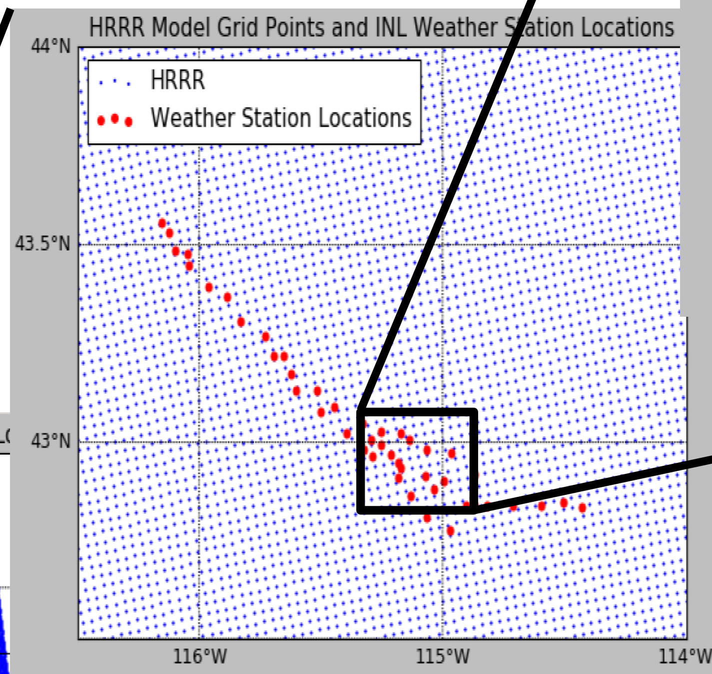


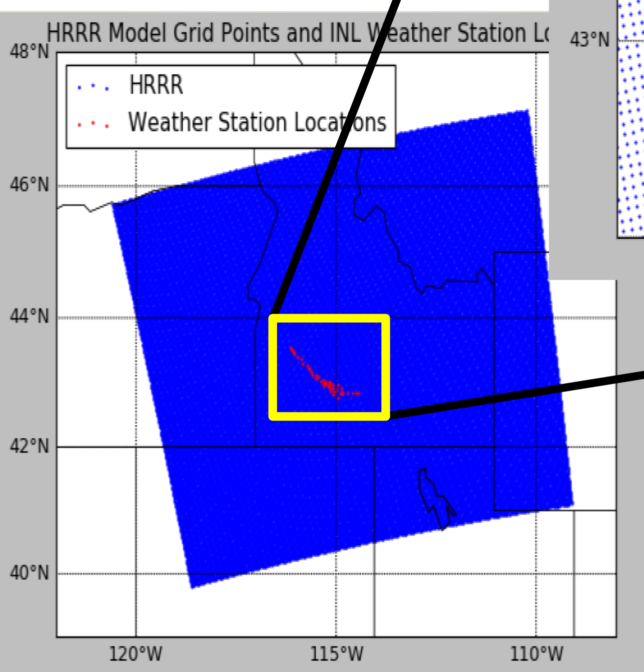


NOAA HRRR Grid and INL Collaboration Early Results

High-Resolution Rapid Refresh (HRRR)

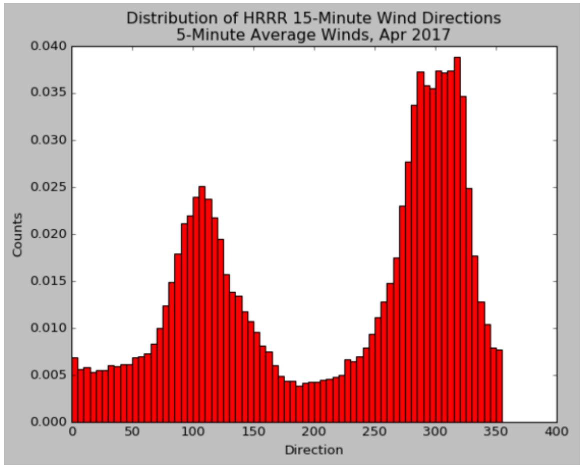


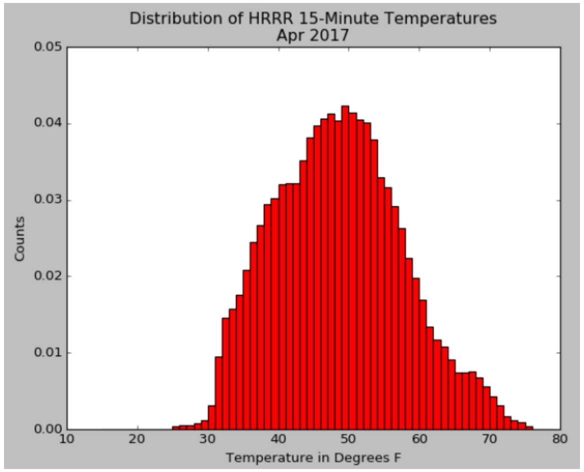


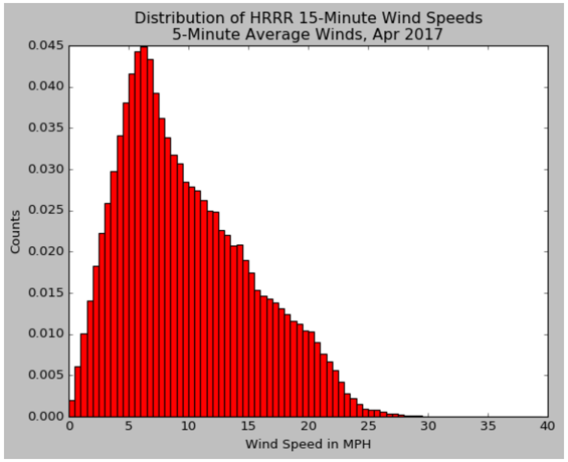


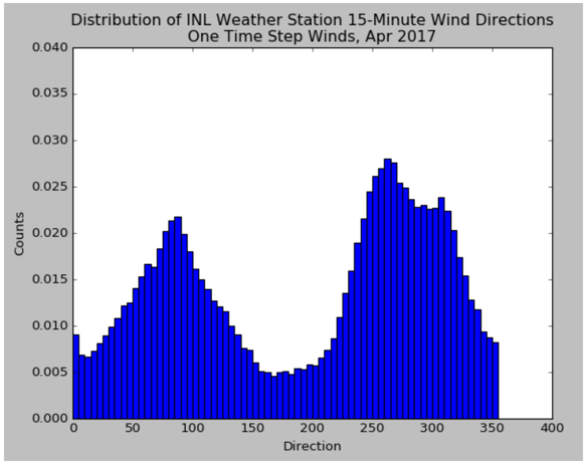
- HRRR output is available on a 3 km grid
  - Temperature
  - Wind speed and direction
  - Insolation

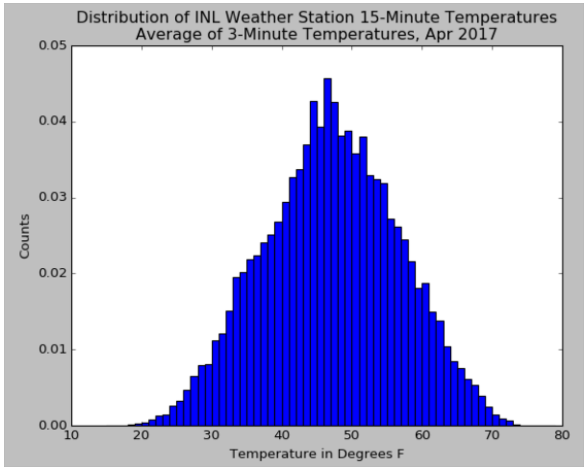
NOAA HRRR Grid and INL Collaboration Early Results

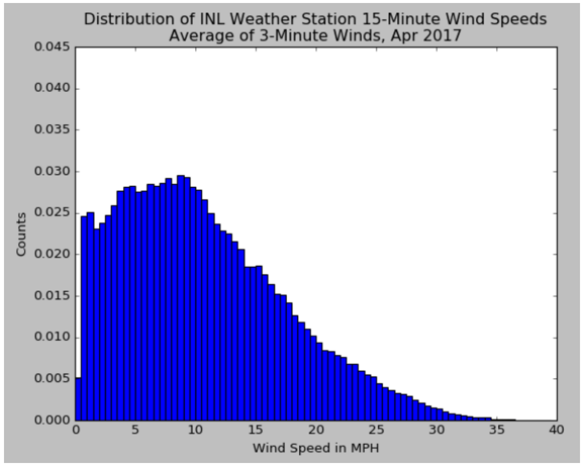












Importance of Forecasting Needs for Dynamic Line Rating

- Concurrent Cooling with Wind Generation is the easy part – still need forecast for possibility .
- Development of the "True" Dynamic Line Rating requires Forecasting.
- Uncertainty of forecasts must be understood such that we miss on the conservative side of any tolerance but advance the rating.
- Accuracy from a DLR application perspective means forecasts are project accurate measure of line capacity or line temperature given the thermal time constant--individual errors in wind speed forecast minute to minute isn’t the most important aspect)
- Different expectations/needs in different time frames.
- <60 minutes out—accuracy with high confidence to assess emergency (contingency of a line outage) or opportunistic (take advantage of a market condition.
- Hourly out through 24 hours out – conservatively assess the capacity similar to load and generation markets/planning requires relatively lower accuracy but good assessment of what the conservative end of the forecast
- Beyond 24 hours – less temporal fidelity expected more – need more experience with forecast data applied to the application to understand the limits → Collaboration with NOAA

Idaho National Laboratory

WIND INTEGRATION R&D

Concurrent Cooling, Dynamic Line Rating

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Back up Slides

Operational and Strategic Implementation of Dynamic Line Rating for Optimized Wind Energy Generation Integration

“A “Cool” Way to (1) Increase the Utilization of Existing Transmission and Distribution Infrastructure - DLR, and (2) the Optimization of New Infrastructure Developments – P&R Toolkit”

Affordable and effective implementation of real-time weather and forecast based dynamic line rating of overhead transmission lines by mitigating transmission congestion and optimizing the use of electricity infrastructure for the integration of wind energy to enhance the nation’s energy portfolio.

The Challenge:

Provide science based methodologies and solutions that are readily adopted and usable by a conservative, regulated industry

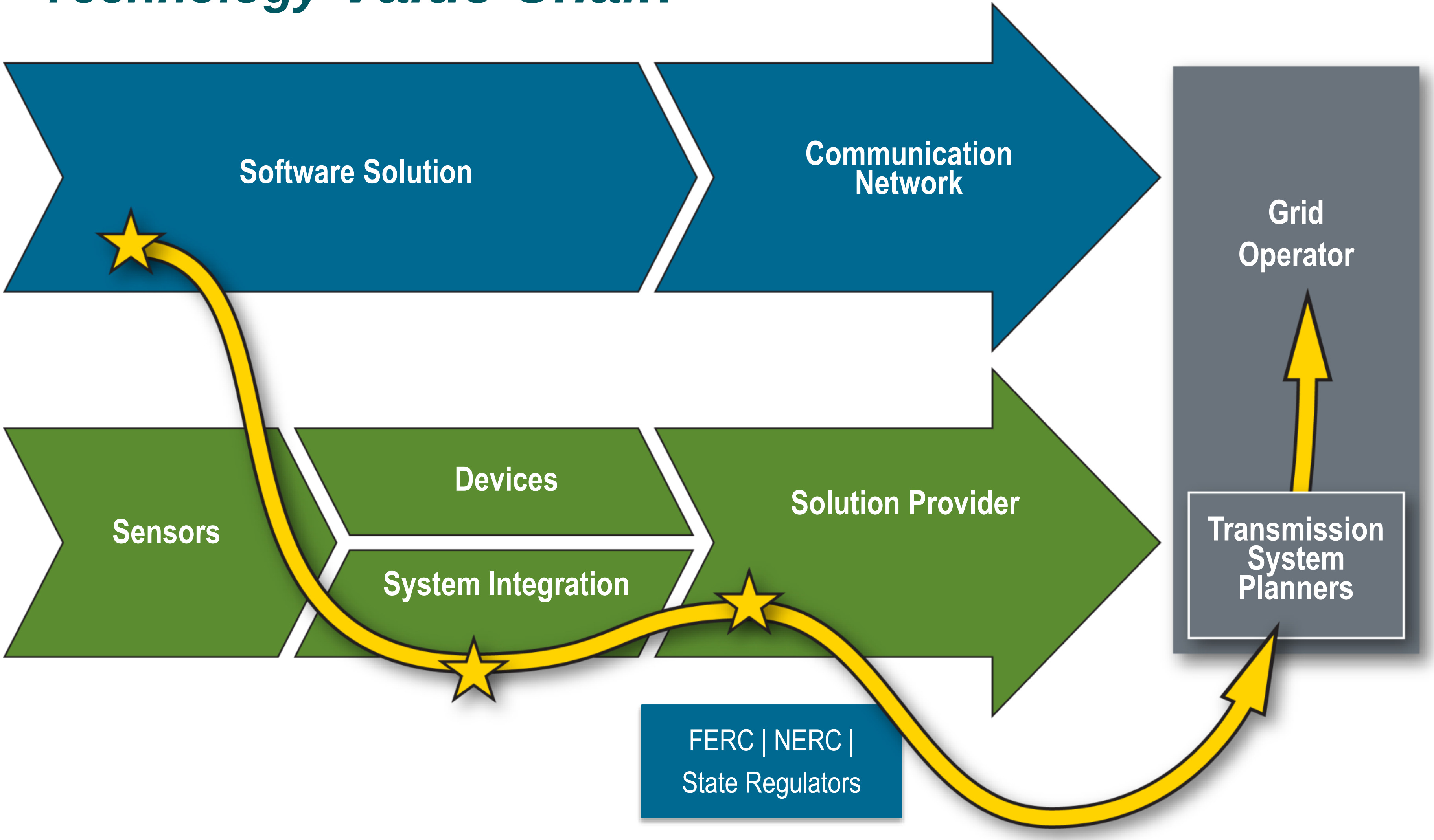
Requirements:

Provide industry with a low cost, robust solution set, and enabling human operators to make informed decisions and take appropriate actions without being overwhelmed with data

Helping Operators Implement Dynamic Line Rating

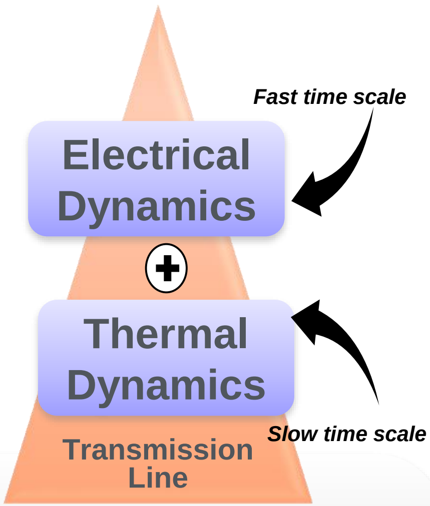
Defining and Conveying transmission line current and temperature limits

Technology Value Chain



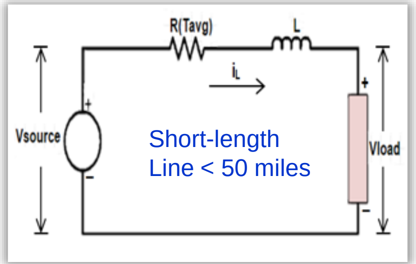
Time Scales in Transmission Lines

Time Scale Concept



- IEEE Std. 738 does not address the slow and fast inherent dynamics
- Perturbations in a transmission line are not taken into account
- Computationally challenging system!

Time Domain Modeling



electrical dynamics

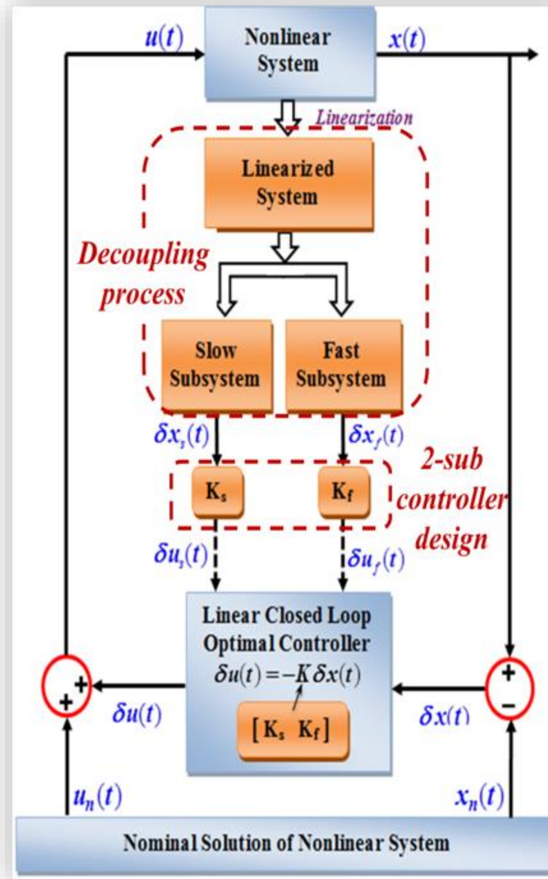
$$\frac{di_L(t)}{dt} = -i(t)\frac{R(T_{avg})}{L} - i(t)\frac{R_{load}}{L} + \frac{v_{source}}{L},$$

thermal dynamics

$$\frac{dT_{avg}(t)}{dt} = \frac{1}{mC_p}\left[R(T_{avg}(t))i_L^2(t) + q_s - q_c - q_r\right]$$

- Instantaneous calculations of Line Current and Line Temperature
- Real-time calculations – Decision Making → SCADA/EMS
- Import MATLAB® model library into GLASS
- Controller Design - Mitigating system perturbations

Controller Design



Example: Flow Gate use of TDLR with Human Factors Engaged

- Oklahoma Gas and Electric use of line ratings—currently static
- Track N-1 Contingency Line current versus ratings
  - Simple Table of Lines and the percent of rating under N-1 line amperage
  - Color coding on alarm setting
  - Would prefer no additional fields

Flowgate Values

1	Line 1	86.017%	13	Line 13	86.017%
2	Line 2	86.017%	14	Line 14	86.017%
3	Line 3	86.017%	15	Line 15	86.017%
4	Line 4	86.017%	16	Line 16	86.017%
5	Line 5	86.017%	17	Line 17	86.017%
6	Line 6	86.017%	18	Line 18	86.017%
7	Line 7	86.017%	19	Line 19	98.024%
8	Line 8	86.017%	20	Line 20	86.017%
9	Line 9	86.017%	21	Line 21	86.017%
10	Line 10	86.017%	22	Line 22	86.017%
11	Line 11	86.017%	23	Line 23	86.017%
12	Line 12	86.017%	24	Line 24	86.017%

- Propose possible designs:
  - Engage with HF interviews
  - Highest value if added information is not “just more” information to process immediately but something that may even give more time to evaluate – Human Performance Principle
  - Time to maximum conductor temp under contingency condition is one concept in consideration
  - Next step provide alternatives including our biases preferred candidate and perform an evaluation with operators/stakeholders

Partners and Collaborators

Boise State University – Boise, ID
- Graphical processing units CFD research (GIN3D)
- Masters student, DLR standard development

Durham University – Durham, UK
- Collaborator & methodology validation/comparison
- Joint publications

Idaho Power Company – Boise, ID
- Test area (~500 line miles)
- Equipment funding and installation
- Engineering support

Idaho State University – Pocatello, ID
- Graduate intern (1.5 years) – full-time position hire
- 2010 to 2012 Senior Design Projects (8 students)
- 2013 to 2015 PhD Candidate - Dissertation

Montana Tech – Butte, MT
- Undergraduate student intern (4 years)
- Graduate student intern (2 years)

Genscape (Promethean Devices) – Boston, MA
- Field validation subcontract (3 months)

University of Idaho – Moscow, ID
- PhD student intern supporting multiple publications
- Undergraduate student intern (3 years)

WindSim AS – Tonsberg, Norway
- Computational fluid dynamics (CFD) software collaborator and development partner

AESO – Alberta, Canada

AltaLink – Alberta, Canada

Nexans, The Valley Group – USA

Southwire Company – Carrollton, GA

Lindsey Manufacturing – Azuza, CA

StormGeo – Houston, TX

TechFlow – San Diego, CA

OSIsoft – San Leandro, CA

Bonneville Power Administration – Portland, OR

Southwest Power Pool – Little Rock, AR

Stantec – Portland, OR

Interactions w/ Industry & Academia – 10+ Non-Disclosure Agreements, **1** SPP Agreement Executed, **1** CRADA Project Executed, **1** CRADA Project Initiated, Over **$1M** invested by industry/academia partners over a 3-year period.