Day-Ahead Dynamic Thermal Line Rating using Numerical Weather Prediction

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Outline

1. Introduction of Dynamic Line Rating
2. Problem
3. Proposed solution
4. Results

Dynamic Thermal Line Rating (DLTR)

Line rating

- The limit for the maximal current in the conductor
- Set by the operator
- Why? To keep the line safe
    - Thermal rating -> safe from overheating
    - Other limits exists (stability, voltage quality)

Thermal model of a transmission line

- Electrical current, sunlight increase the temperature
- Radiative, Air temperature, Wind speed decrease temperature

Dynamic Thermal Line Rating (DTLR)

Static Thermal Line Rating (SLR)

- Does not change very often
- Worst case environmental conditions assumed for safety
    - 40°C, 0.6 m/s, full sunlight

Dynamic Thermal Line Rating (DTLR or DLR)

- Rating changes with real ambient conditions
- Realtime: sensors to estimate the rating

Theoretically, Realtime DTLR can fully utilize the entire capacity of the OTH

Problem

Realtimeness

- Electricity markets
- Powerflow calculations
- Power generation cannot respond in real-time
- **Support by the management systems of the operator**
  - Main motivation
  - Expansion of wind power generation in southern Alberta
  - EMS does not support real-time update of line rating

Solution

Daily DLR

Line rating updated once a day based on day-ahead predictions

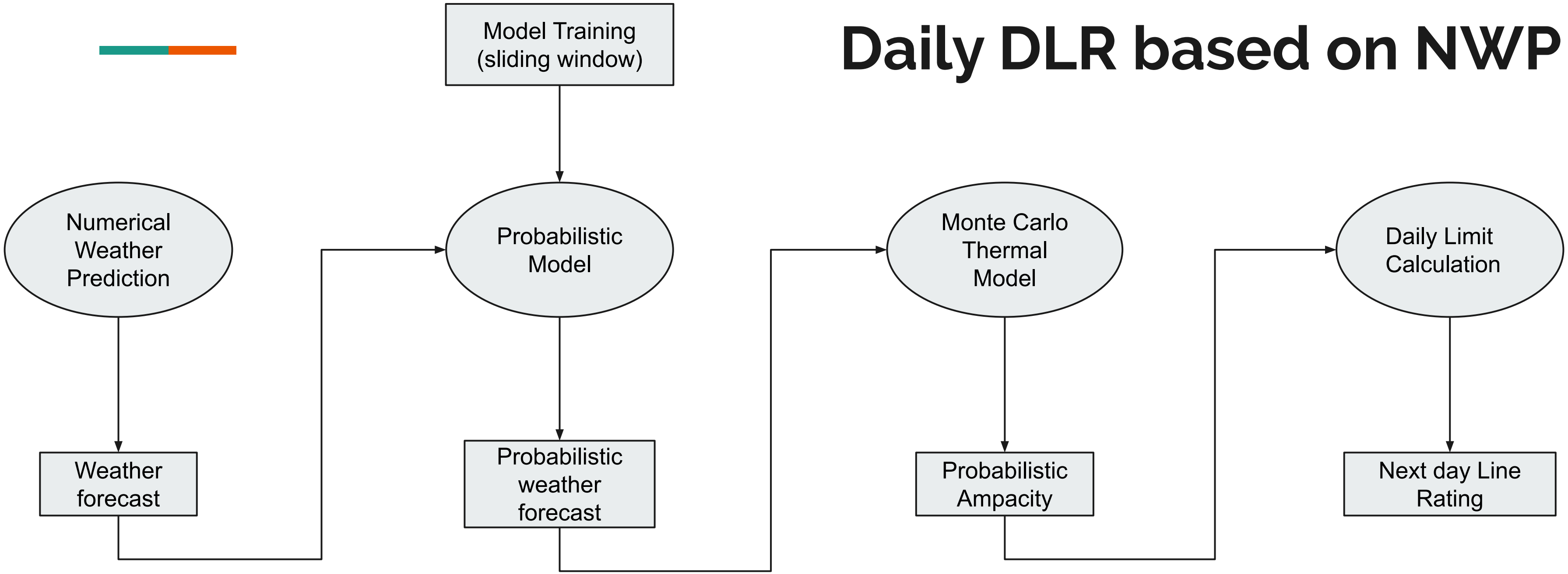
Advantages:

- EMS allows changes to the line rating once a day
- No need for line rating sensors
  - Indirect calculation of DLR from weather prediction

Disadvantages:

- Does not fully utilize the Real Time DLR
- Sourcing of weather forecasts
- Maintenance of forecasting models and software

Daily DLR based on NWP



Probabilistic model

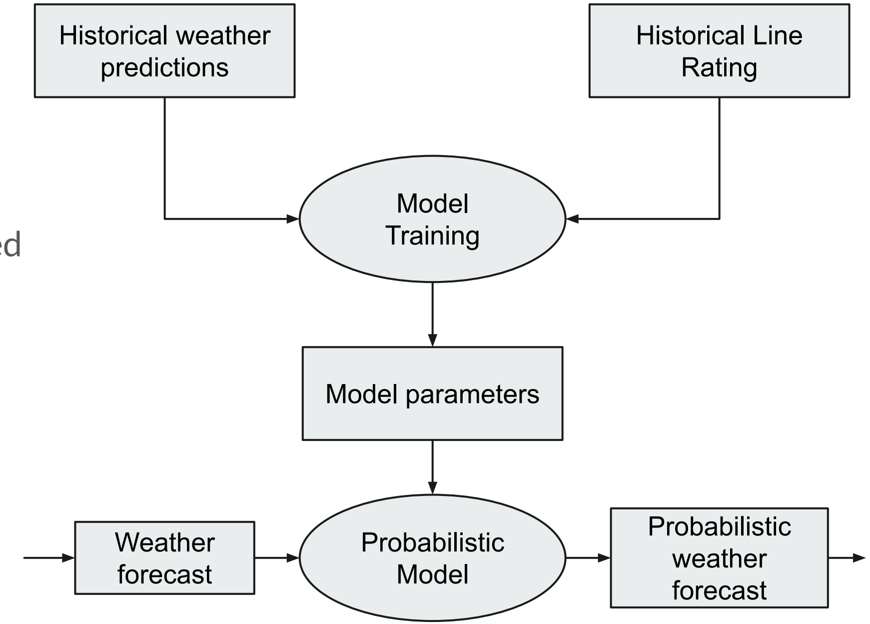
- NWP provides imperfect deterministic predictions
- To guarantee safety, uncertainty has to be quantified
- Parameters updated daily on a training window
- Maximum Likelihood optimization

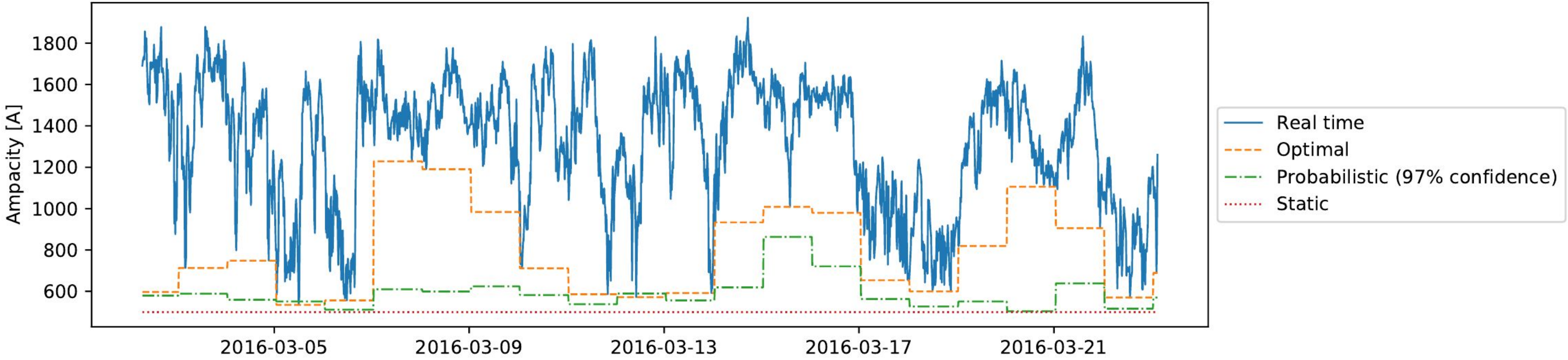
Example: Wind Speed model:

$$\hat{v}(t) \sim N_{trunc}(\mu, \sigma)$$

$$\mu = a_0 + a_1 \hat{v}_{NWP}$$

$$\sigma = b_0 + b_1 \hat{v}_{NWP} + b_2 t$$





Ampacity [A]
1800
1600
1400
1200
1000
800
600
2016-03-05
2016-03-09
2016-03-13
2016-03-17
2016-03-21
Real time
Optimal
Probabilistic (97% confidence)
Static

Results

Dataset

- 1 year of NWP in 2016
  - Daily forecasts
  - WRF meteorological model
- Sensor data
  - 2016
  - 4 weather stations located alongside a short OTH in southern Alberta
  - 3 minutes sampling interval

Evaluation

- Simulation of the presented use-case
- Daily predict the ampacity for the next day

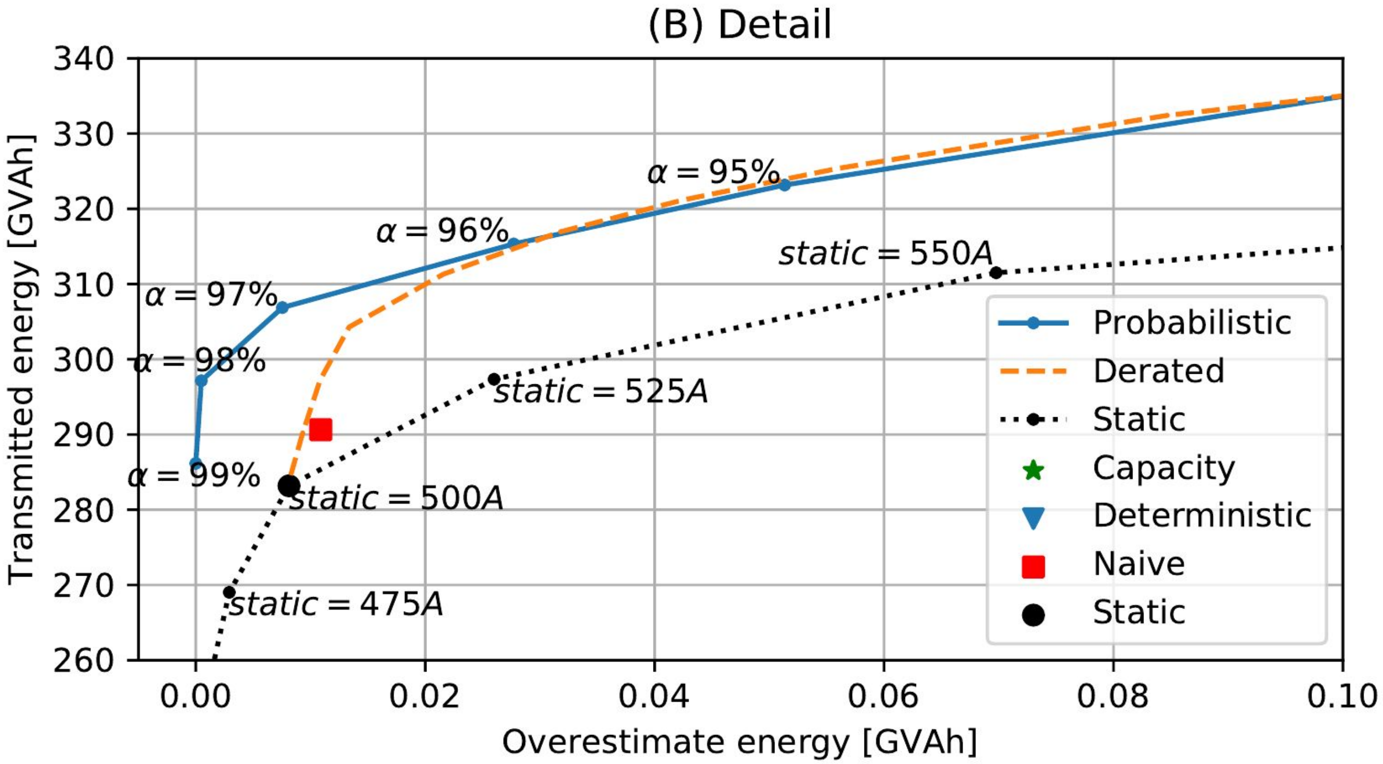
Transmitted energy: $$E = V \cdot \sum_{n=1}^{N} \hat{A}(n) \cdot dt,$$

Energy overestimate: $$E_o = V \cdot \sum_{n=1}^{N} \max(\hat{A}(n) - A(n), 0) \cdot dt$$

Transmitted energy over 1 year

Increase over SLR

	E [GVAh]	$1 - E/E_{static}$ [%]	E_o [MVAh]	T_o [hour]	
Real-time capacity	984.2	131.7	0.0	0.00	Realtime
Daily Capacity, $\hat{A}_{perfect}$	591.5	39.3	0.0	0.00	Perfect forecast
Naive algorithm	425.9	0.3	10.7	3.75	
Static $475A$	403.5	-5.0	4.6	2.00	
Static $500A$	**424.8**	**0.0**	**17.6**	**5.50**	SLR
Static $525A$	446.0	5.0	51.1	13.75	
Derated $\alpha = 0.01$	426.8	0.5	17.8	5.50	
Derated $\alpha = 0.05$	434.9	2.4	18.6	5.50	
Derated $\alpha = 0.10$	445.1	4.8	19.8	6.00	
Derated $\alpha = 0.15$	455.2	7.2	23.6	8.50	
Derated $\alpha = 0.20$	465.4	9.6	33.5	11.25	
Derated $\alpha = 0.24$	473.5	11.5	45.9	13.00	
Probabilistic $q = 99\%$	425.0	0.1	0.3	0.75	
Probabilistic $q = 98\%$	442.5	4.2	7.3	1.75	
Probabilistic $q = 97\%$	**457.2**	**7.6**	**17.6**	**3.50**	Proposed
Probabilistic $q = 96\%$	469.9	10.6	37.7	7.75	
Probabilistic $q = 95\%$	481.3	13.3	68.1	12.75	
Deterministic NWP	627.8	47.8	4249.8	248.25	



(B) Detail
Transmitted energy [GVAh]
Overestimate energy [GVAh]
340
330
320
310
300
290
280
270
260
0.00
0.02
0.04
0.06
0.08
0.10
α = 95%
α = 96%
α = 97%
α = 98%
α = 99%
static = 550A
static = 525A
static = 500A
static = 475A
Probabilistic
Derated
Static
Capacity
Deterministic
Naive
Static

Conclusion

- Forecasting allows us to overcome the problematic real-time nature of DLR.
  - Realtime DLR increase by 132%, but cannot be used.
- Daily DLR could have achieved up to 39% increase in transmitted energy on the studied line in 2016.
  - Further increase would require to decrease the forecasting interval
- The presented method achieved 7.8% increase while maintaining the same risk as current SLR.
  - Future research direction: Improve the forecasting method so that more of the daily DLR potential can be utilized.

Thank you!

Questions?