Options for Increased Line Thermal Ratings

DOE – INL DTCR

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Talk Summary

- Definition of Line Thermal Ratings?
- Power flow Constraints amd Line thermal Ratings
- Static vs Dynamic Methods of Uprating
- Relevant IEEE/CIGRE Activities
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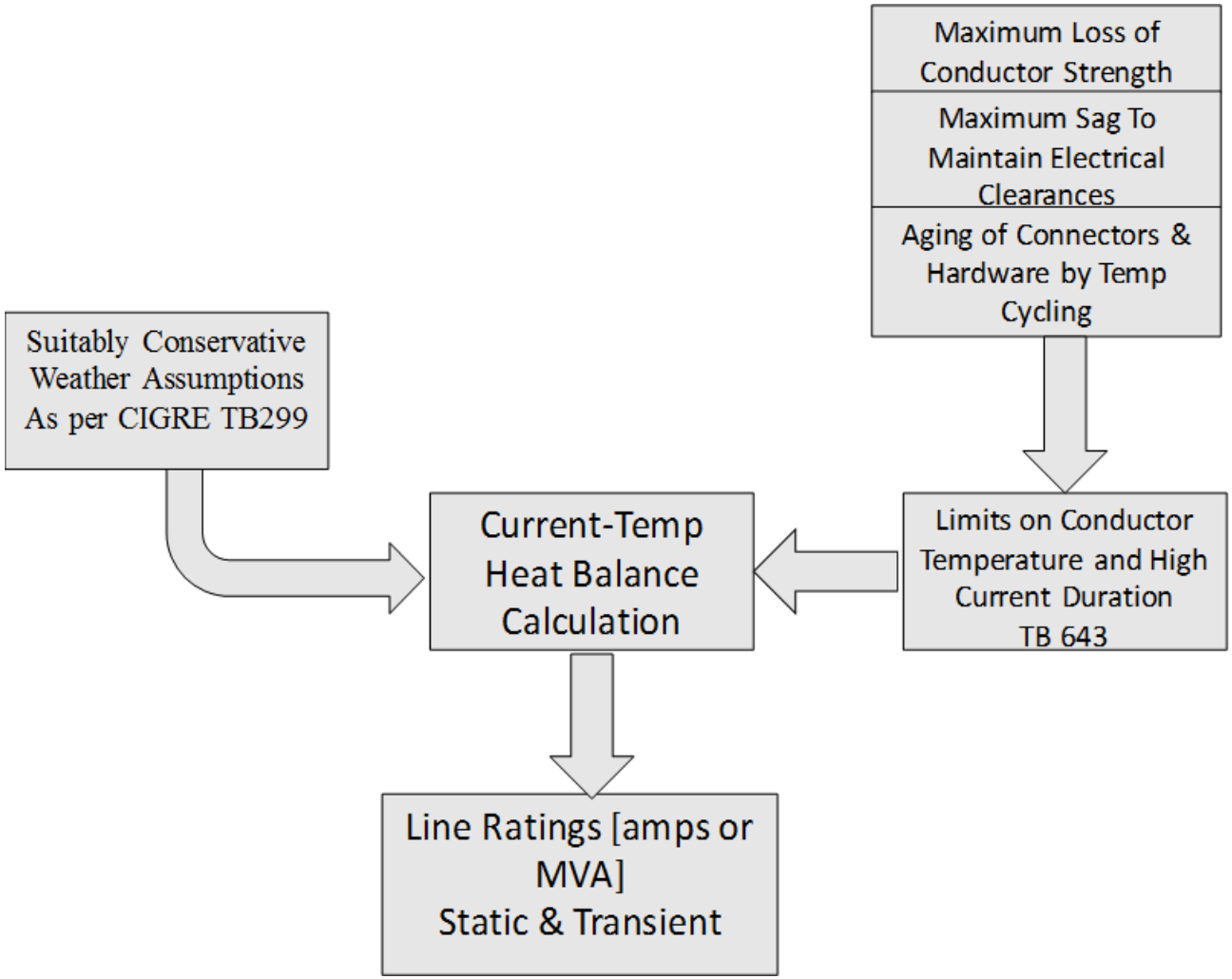
What is a line thermal rating?

- It is the maximum line current, for which the resulting line conductor temperature does not exceed a specified maximum conductor temperature for suitably conservative weather conditions. The maximum conductor temperature is calculated to limit cumulative damage to the conductor system and to assure minimum electrical clearances are maintained.

How are Line Ratings Calculated?



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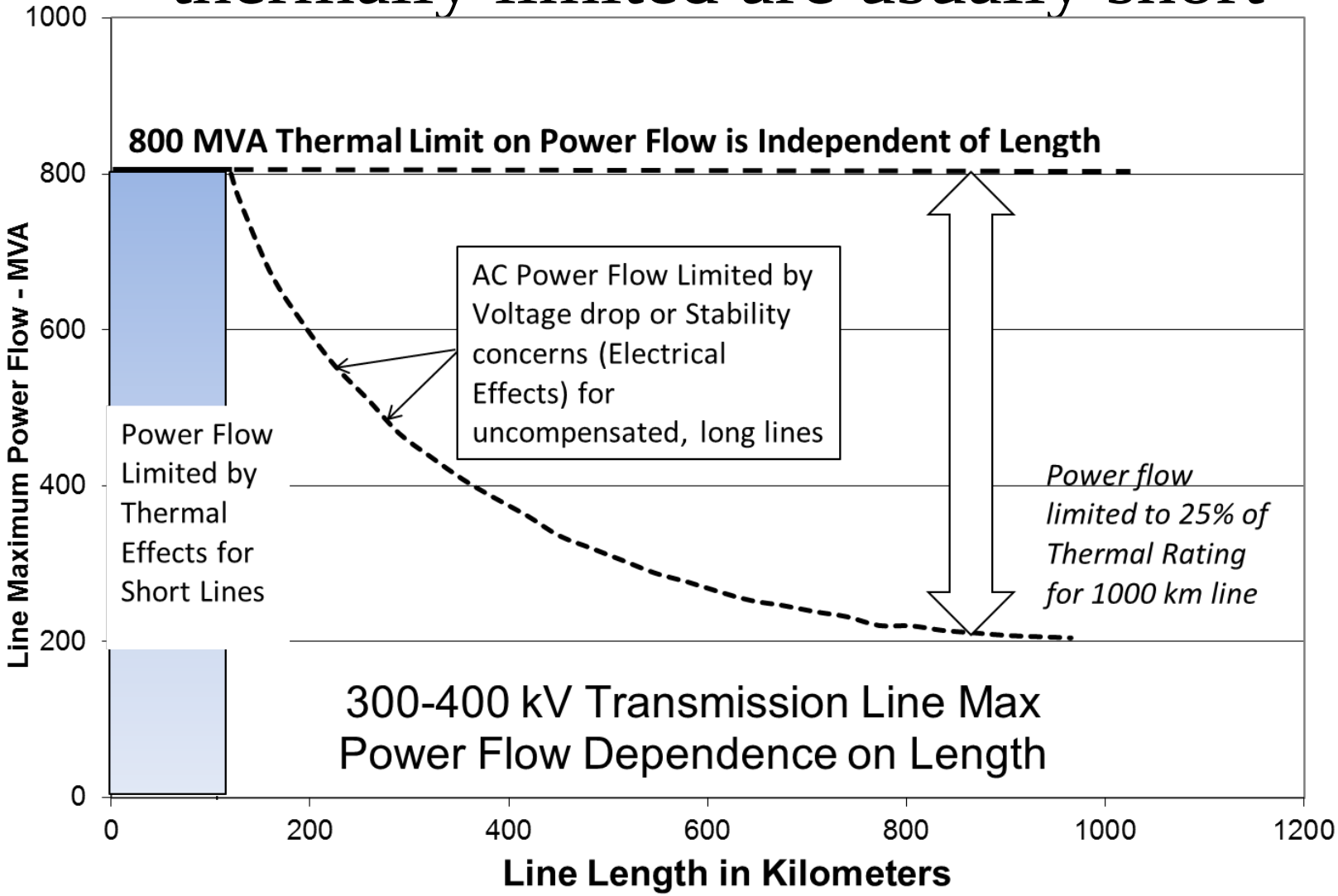
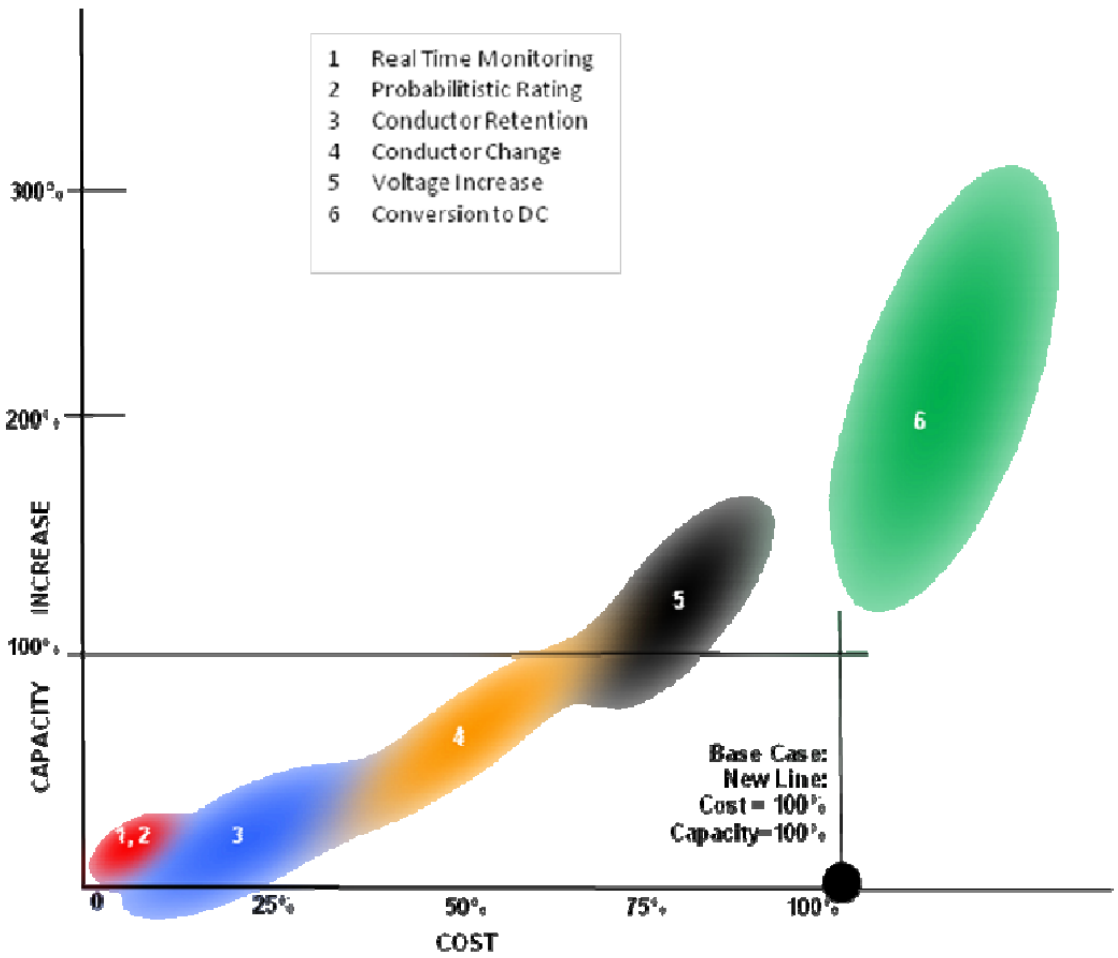
Is Power Flow Always Limited by Thermal Line Rating?

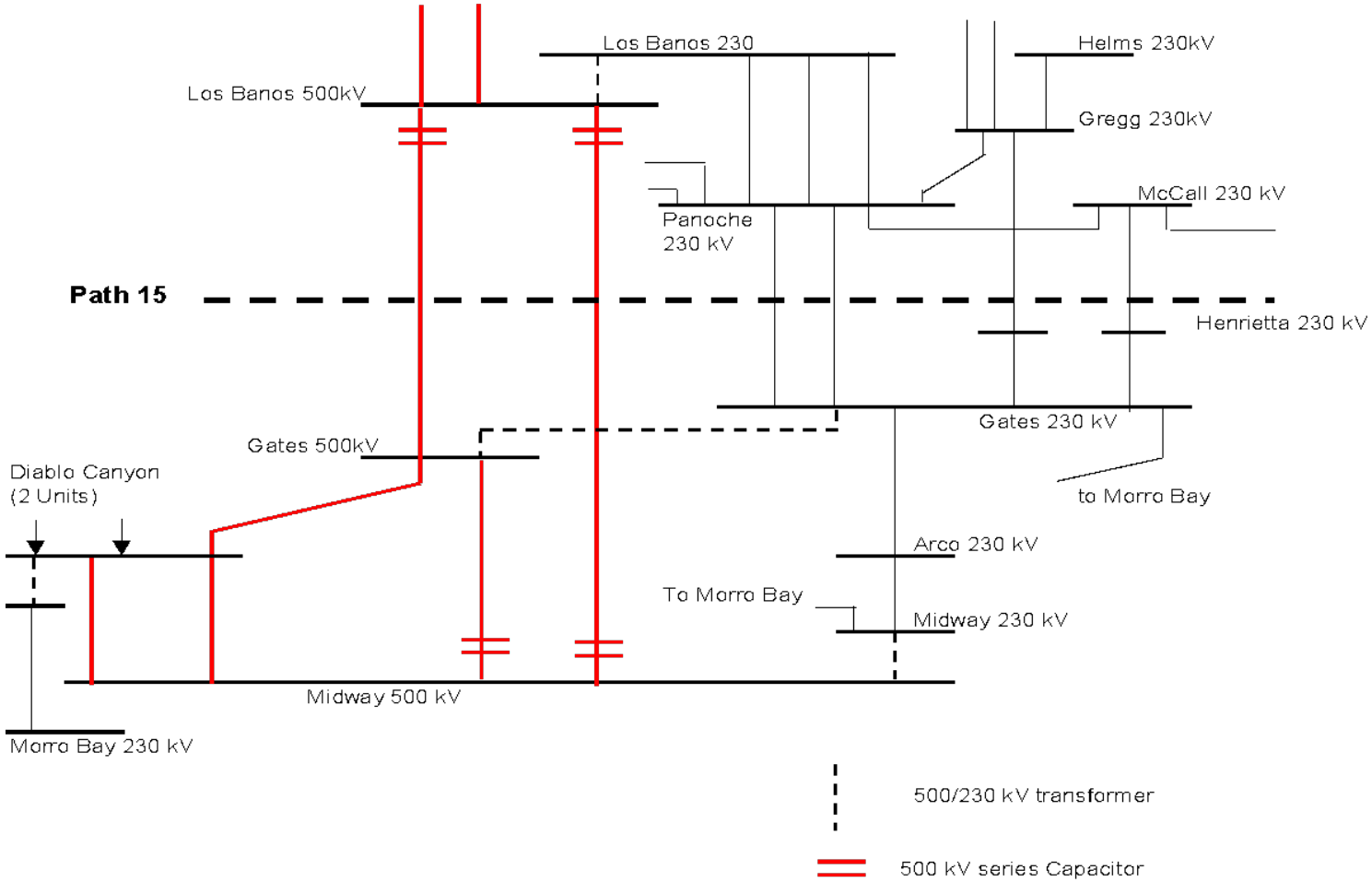
- Electrical effects (e.g. voltage drop) can limit power flow on overhead lines as well as thermal concerns (e.g. sag & annealing)
- Opening access and encouraging renewable generation has made transmission planning far more difficult
- Adding new high voltage lines (e.g. 345 kV) reduces losses & increases system normal path power flow limits but may raise N-1 emergency power flows on older, lower voltage lines (e.g. 115kV).
- Thermal limits on older lines can limit power transfer on newer higher voltage lines.
- Incremental increases in line rating (e.g. 5% to 10%) can be beneficial to Circuit & Multi-line Path Flow Limits.

AC Lines where Line power flow is thermally limited are usually short



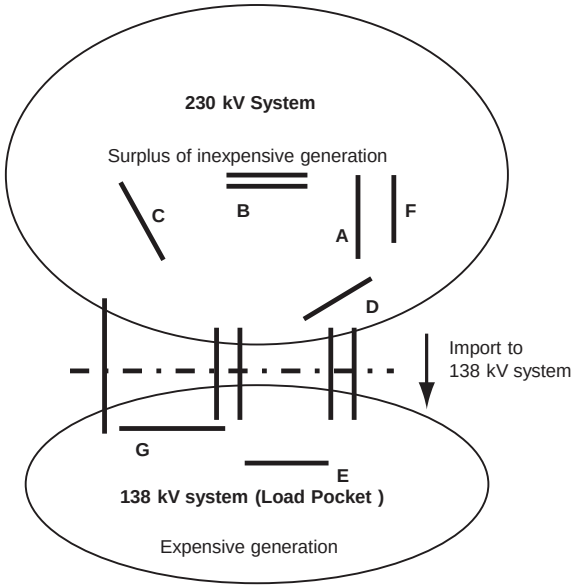
The vast majority of line upratings involve increasing thermal capacity. Voltage upgrades and conversions to DC are helpful to system operations in only a limited number of locations and are far more expensive [CIGRE TB425].





Normally, most of Path Flow is over the 500 kV lines and 230 system is lightly loaded but 500kV power flow is limited by the thermal ratings of 230 kV lines given the N-2 loss of both 500 kV lines.

The power flow into the 138 kV load pocket is limited by the rating of the 230 kV line A but a large increase in that line's rating beyond 219 MVA makes line B the limiting element. Modest increases in ratings are often sufficient to increase path flows



Transmission Facility	ID	Incremental Transfer Capability (MW)														
		50	100	150	200	250	300	350	400	450	500	550	600	650	>>>>>>	>650
A 230 kV line	A1				124		>>> 1200A to 1600A >>>									715
	A2				132		>>> Elevate conductors >>>					578				
	A3				132				>>> Reconductor >>>							1314
B 230 kV Dbl Ckt	B1					219			>>> Elevate conductors >>>							3733
C 230 kV line	C1						240		>>> 1200A to 1600A >>>							728
	C2									393 > Elevate.cond. >					614	
	C3									393		>>> Reconductor >>>>				928
D 230 kV line	D1							271	>>> Elevate conductors >>>							1835
E 138 kV line	E1						(Elevate conductors)				468	547				
	E2										468		>>> Reconductor >>>			727
F 230 kV line	F1											496	> 1200A to 1600A >			1166
G 138 kV line	G1											508	>>> Reconductor >>			892

Transfer Objective
640 MW

Power flow constraints are often the result of concerns that line thermal ratings will be exceeded during post-contingency system emergencies rather than normal system loads. Static and dynamic line uprating methods vary widely

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Line Thermal Uprating Options

Static

1. **Increase TCmax of existing line**
2. **Reconductor w larger single conductor**
3. **Make a 2-conductor bundle**
4. **High-Temp, Low-Sag (HTLS) conductors**

1. “Ambient-adjusted” ratings (TB 299)
2. Real-time monitoring (TB 498)

Comparison of Static and Dynamic Line Uprating Methods

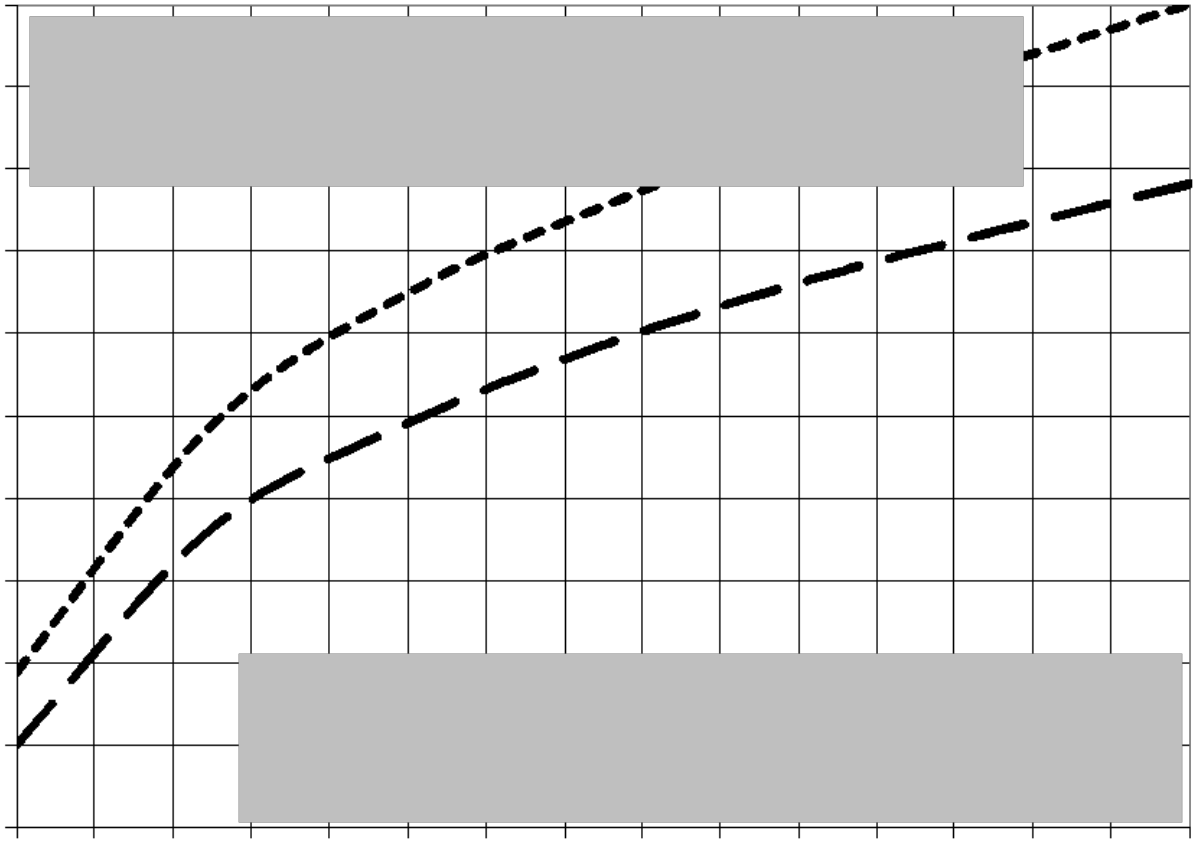
Static Methods

- Advantages
  - Relatively large rating increase (>30%)
  - Costs are sunk but often can be put in “rate base”.
  - Simple for System Ops
- Disadvantages
  - Requires an outage of a critical line.
  - Line specific

Dynamic Methods

- Advantages
  - Can cover multiple lines.
  - No outage or large cap cost
- Disadvantages
  - Requires rating prediction algorithms
  - Rating varies with time
  - Modest rating increase (<30%)

Examples of Static Uprating Options for Existing Overhead Lines



1. Increase TCmax of existing conductor - Raise Attachment Points

	Transmission Capacity (34 º C air summer, 15 ºC air winter, 0.61 m/s wind, full sun)					
	220 kV ACSR Condor (Single conductor)			400 kV ACSR Cardinal (Twin bundle)		
	MVA (50 º C)	**MVA (85 º C)**	**Δ%**	**MVA (50 º C)**	**MVA (85 º C)**	**Δ%**
Summer Rating	144	343	138	574	1399	144
Winter Rating	277	409	48	1127	1671	48

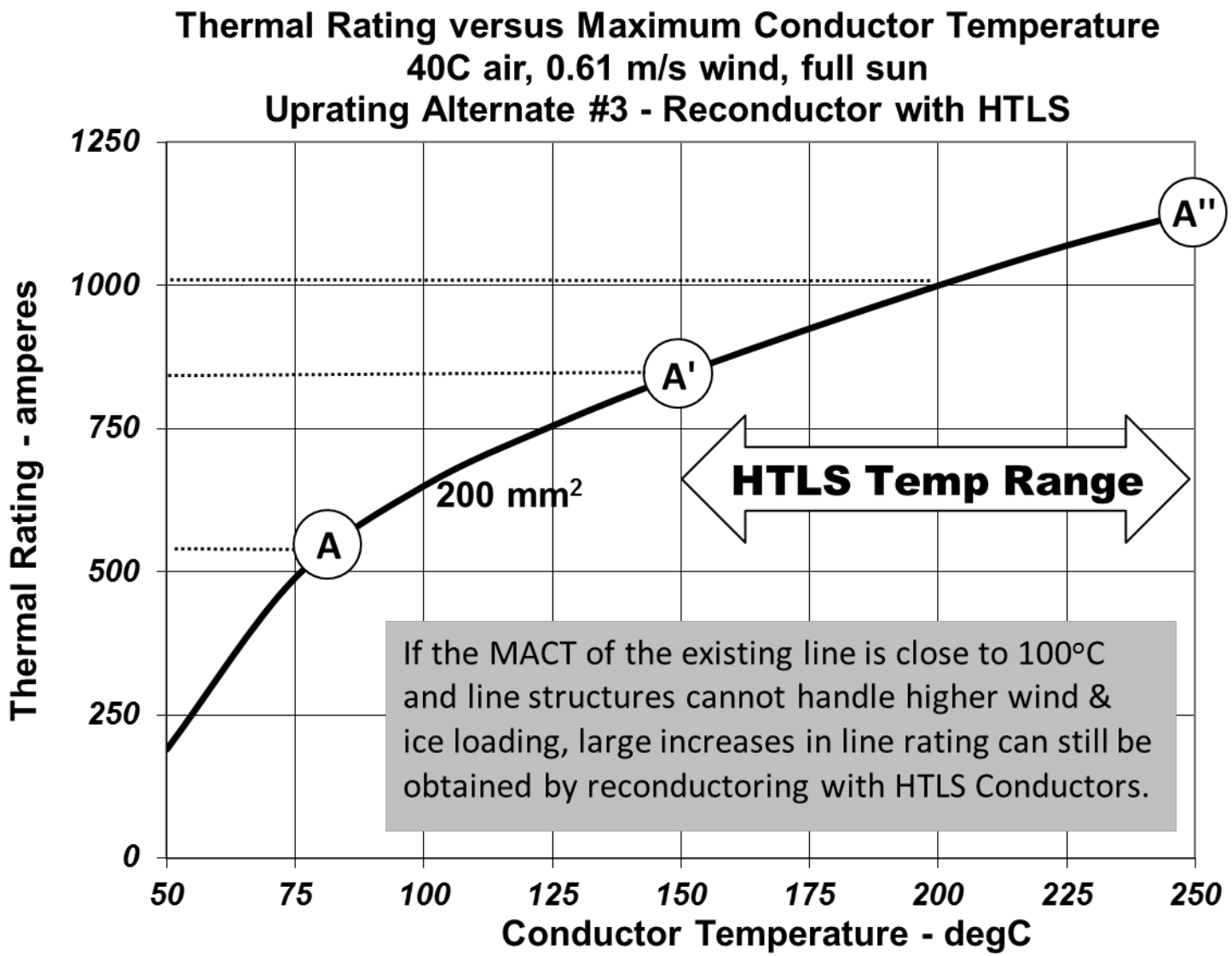
Potential problems at Higher TCmax

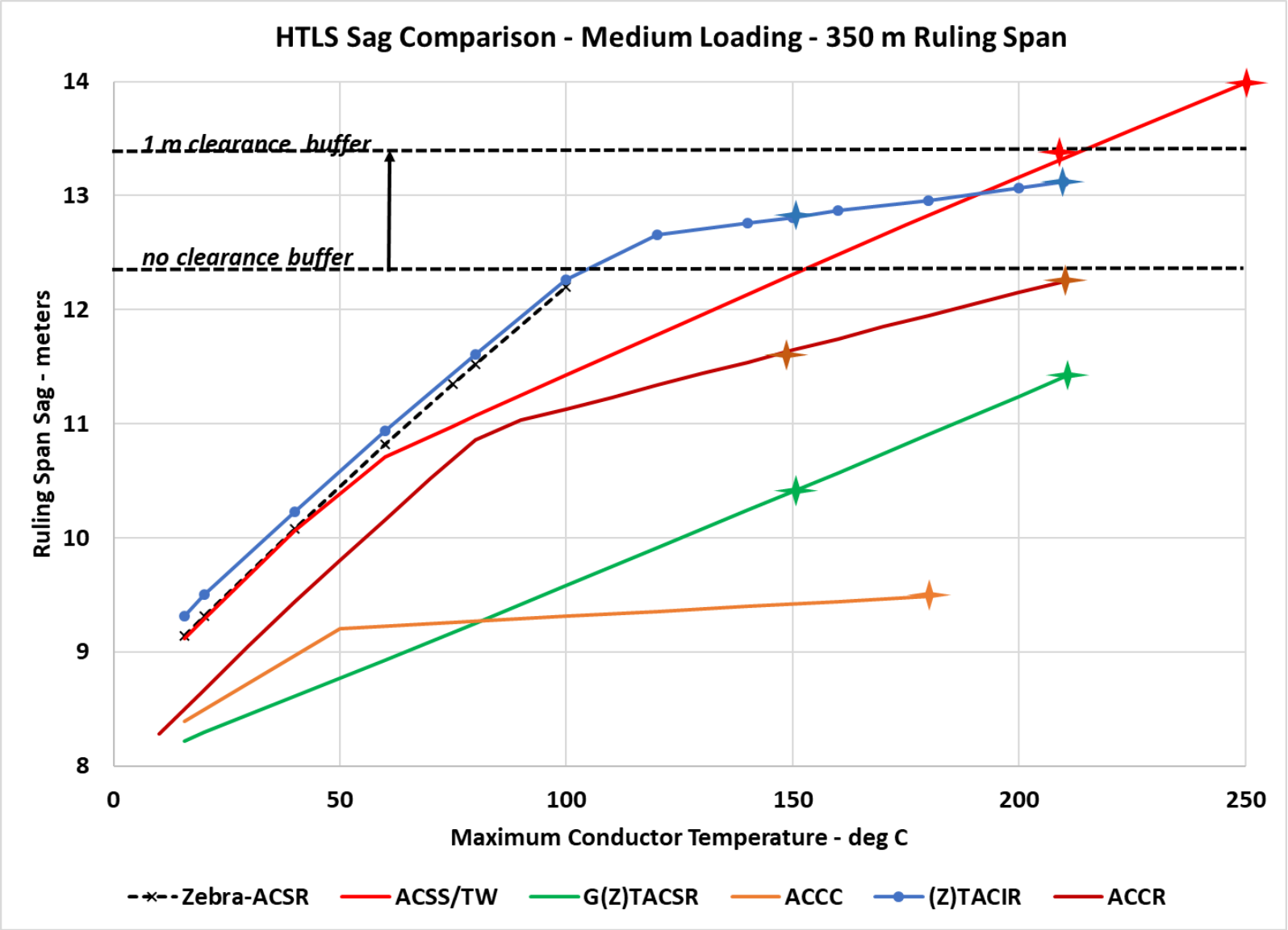
- Additional permanent elongation due to high temperature creep of aluminum strands.
- Loss of tensile strength in aluminum strands at temperatures over 100°C.
- Requires two-component conductor model
- The core may run hotter than the surface due to poor internal radial heat transfer.
- Joints may fail sooner due to thermal cycling

2. Reconductor w larger single conductor or 3. Bundle New Conductor with existing

- Increase in line rating is 100% for bundle and reactance is reduced
- Both methods probably require structure reinforcement and, at least selective, replacement. Exception for “over-designed” older lines in good condition.
- Cost of either may approach material cost of new line.
- Either method may require extensive outage time for construction.
- If the normal system load on the line is high, the electrical loss savings can be significant.

4. Replace the existing conductor with an equal OD HTLS conductor to operate at much higher temperature without modifying the existing structures.


Thermal Rating versus Maximum Conductor Temperature
40C air, 0.61 m/s wind, full sun
Uprating Alternate #3 - Reconductor with HTLS
Thermal Rating - amperes
1250
1000
750
500
250
0
50
75
100
125
150
175
200
225
250
Conductor Temperature - degC
A
A'
A''
200 mm²
HTLS Temp Range
If the MACT of the existing line is close to 100°C and line structures cannot handle higher wind & ice loading, large increases in line rating can still be obtained by reconductoring with HTLS Conductors.


HTLS Sag Comparison - Medium Loading - 350 m Ruling Span
1 m clearance buffer
no clearance buffer
Ruling Span Sag - meters
14
13
12
11
10
9
8
0
50
100
150
200
250
Maximum Conductor Temperature - deg C
Zebra-ACSR
ACSS/TW
G(Z)TACSR
ACCC
(Z)TACIR
ACCR

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Dynamic

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2. **Real-time monitoring (TB 498)**

DLR Uprating Choices

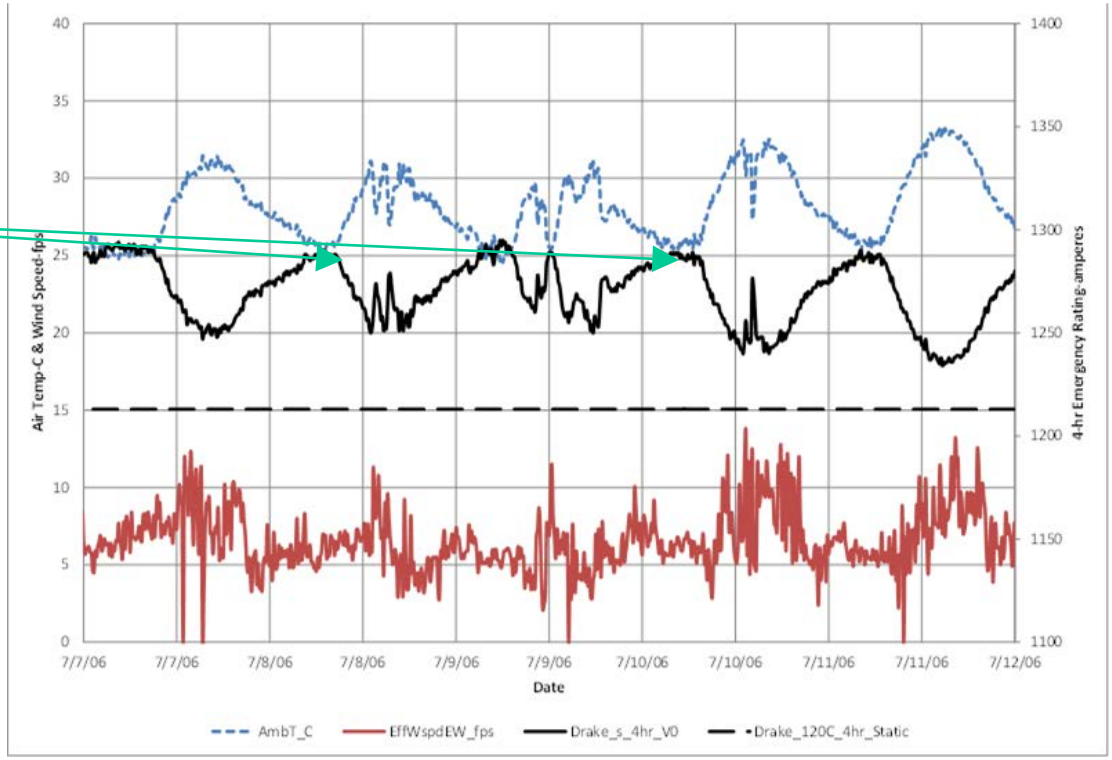
- **Risk, Volatility & Prediction Issues**
  - **System-wide DLR Methods**
    - **Seasonal Ratings**
    - **Ambient-Adjusted (AA) Line Ratings**
    - **Weather-Adjusted Line Ratings**
  - **Line-Specific DLR Alternatives**
    - **Line-corridor Weather Stations (non-contact)**
    - **Conductor Temperature Monitors**
    - **Line Sag-tension Monitors**

5. Ambient-Adjusted Line Ratings Are Widely Used

- Book (static) line ratings are routinely adjusted for air temperature by season (in northern climates), by day, and in some cases for hourly air temperature. Usually, such VLRs are called Ambient-Adjusted.
- Depending only upon air temperature, such ratings exhibit low volatility, high predictability, using real-time air temp data already available in system operation centers.

Some Issues with Ambient-Adjusted DLR

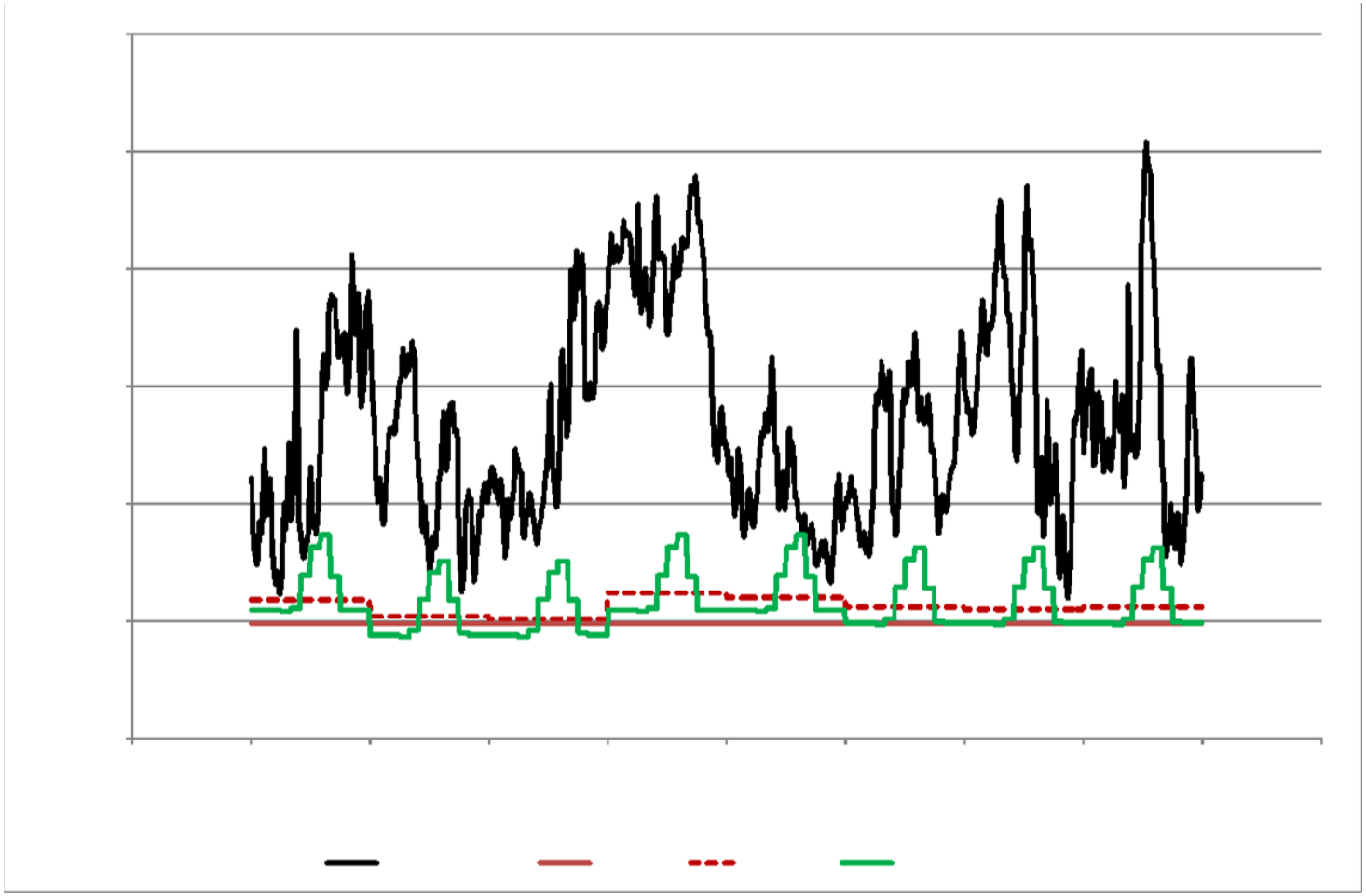
- If AA line ratings are recalculated more than once a day, they may be too high at night.
- The increase in line rating due to AA is relatively small & but if constant wind is too aggressive, AA ratings will be more so.



6. Methods of DLR with variable wind?

- Dynamic Line Rating (DLR) methods with line-corridor monitors providing real-time air temp, solar, and wind data are line corridor specific but yield higher line rating magnitude and variability.
- Disadvantages are integration into system operations and need for rating prediction.

Dynamic and Ambient-Adjusted Ratings



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Past & Present IEEE & CIGRE Activities

- IEEE (next Jan, 2018)
  - Previous
    - Numerous technical papers.
    - Line Monitoring Transaction Paper (2014)
  - Present
    - TF on Prediction of Dynamic Ratings
- CIGRE B2 (Apr, 2017)
  - Previous
    - TB 244, 299 & 601 on Mechanical Line Uprating, Selection of Static Weather, and Thermal Rating Calculations
  - Present
    - WG 55 & 59 on Line Uprating and Prediction of Dynamic Ratings

Conclusions

- Maximum power flow for short lines (<50miles) is usually limited by the line thermal rating.
- Normal line current on HV lines has been driven lower & N-1 emergency current higher by addition of higher voltage lines & open access changes in power flow.
- For many overhead lines, the conductor temperature is no more than 10C above air temp with system normal.
- Long-term power flow planning is much harder with renewables due to generator location and fluctuation.
- Growing uncertainty calls for increased flexibility in methods of uprating lines in the transmission system.