Dynamic Thermal Ratings in Real-time Dispatch Market Systems

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Imagination at work.

Outline

- Introduction
- Weather-based Dynamic Line Ratings
- Real-time Security Constrained Economic Dispatch (SCED)
- Numerical Examples
- Conclusions

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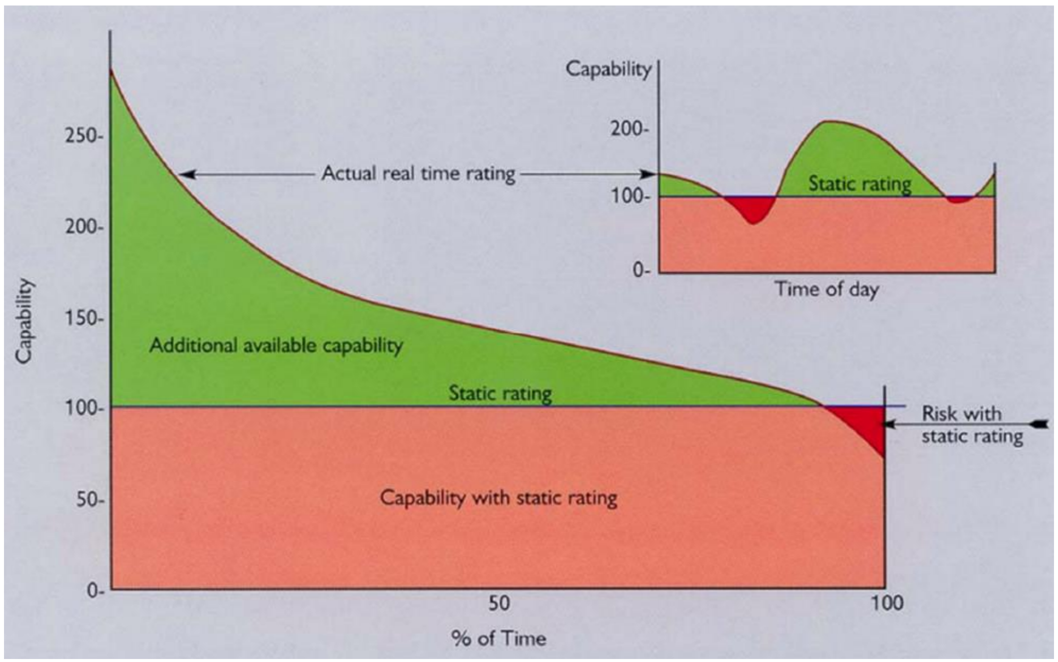
Introduction

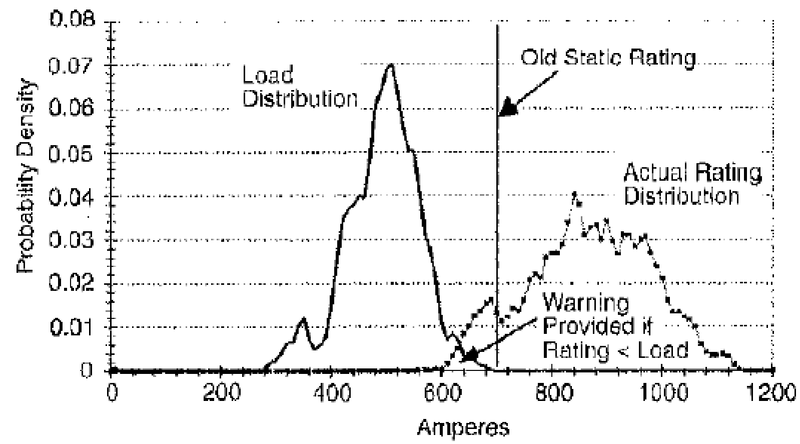
- Regional transmission organizations are heavily reliant on *security constrained* unit commitment (SCUC) and economic dispatch (SCED) to optimally dispatch their energy resources.
- With the penetration of renewable energy resources, transmission system operators are in the process of enhancing their dispatch systems with a broader capability and higher economic efficiency.
- Transmission of electric power has traditionally been limited by conductor thermal capacity defined in terms of a *static line rating* which is based upon "near" worst-case weather and pre-load conditions.
- By real-time measurements of weather conditions surrounding the conductor, dynamic line rating (DLR) has the potential to increase line rating, reduce transmission congestion and enhance market efficiency.

Dynamic Line Rating vs. Static Line Rating

- DLR enables significant amount of additional transmission capacity (Ampacity)
- DLR eliminates the risk in static rating



CAT-1 Transmission line monitoring system. The Valley Group. Available at http://www.nexans.be/eservice/Belgiumen/fileLibrary/Download_540145282/US/files/valley%20group_CAT-1.pdf



Dynamic thermal ratings realize circuit load limits
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Computer Applications in Power, IEEE
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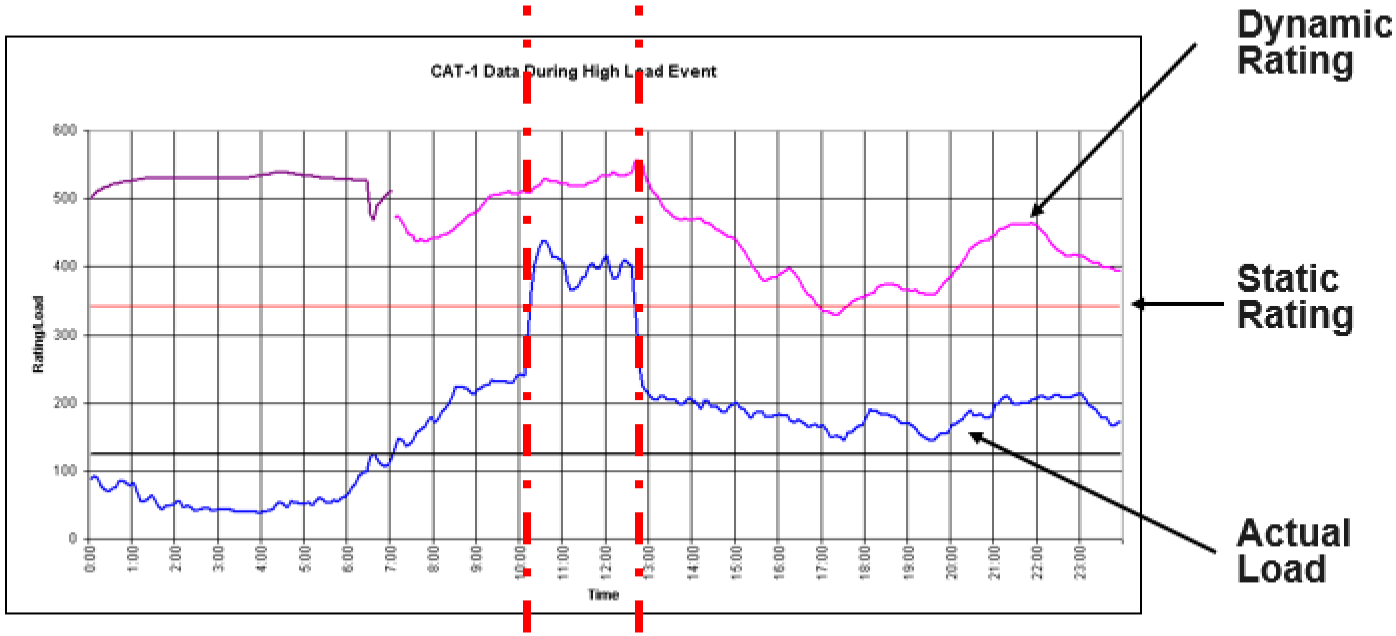
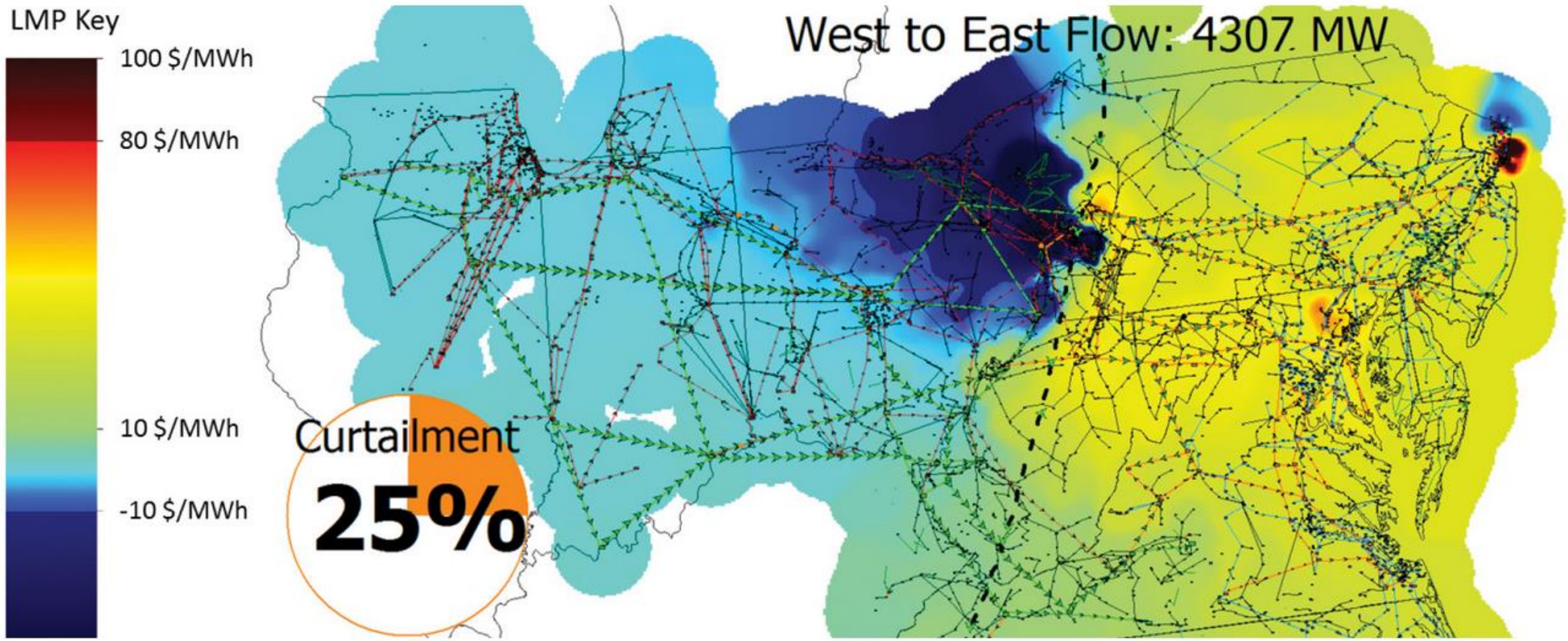
Impact on Transmission Grid Operations



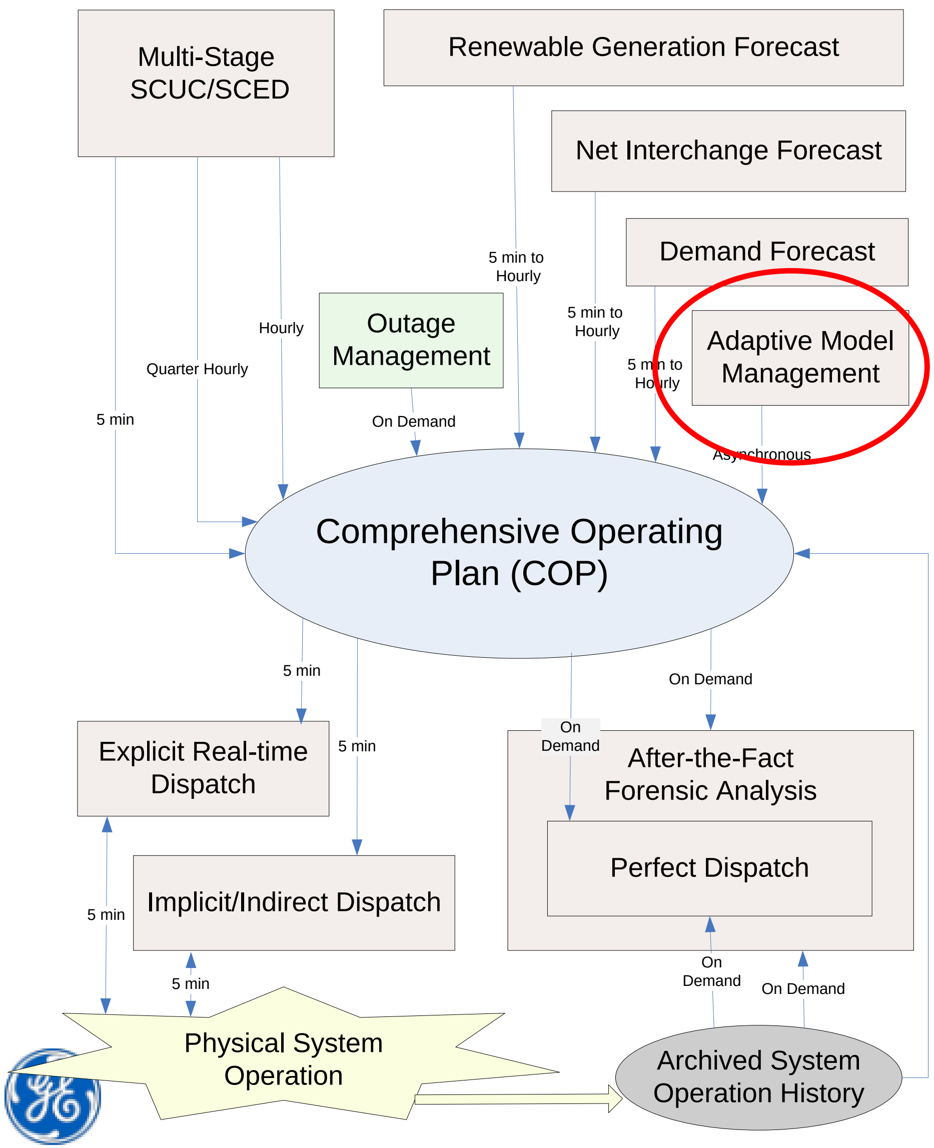
- Line was operating within limits in accordance with operating standards.
- Without dynamic rating, this event must be reported as a violation.
- The operator would have been forced to move the grid off its optimum dispatch.

Potential of Market Efficiency Improvement



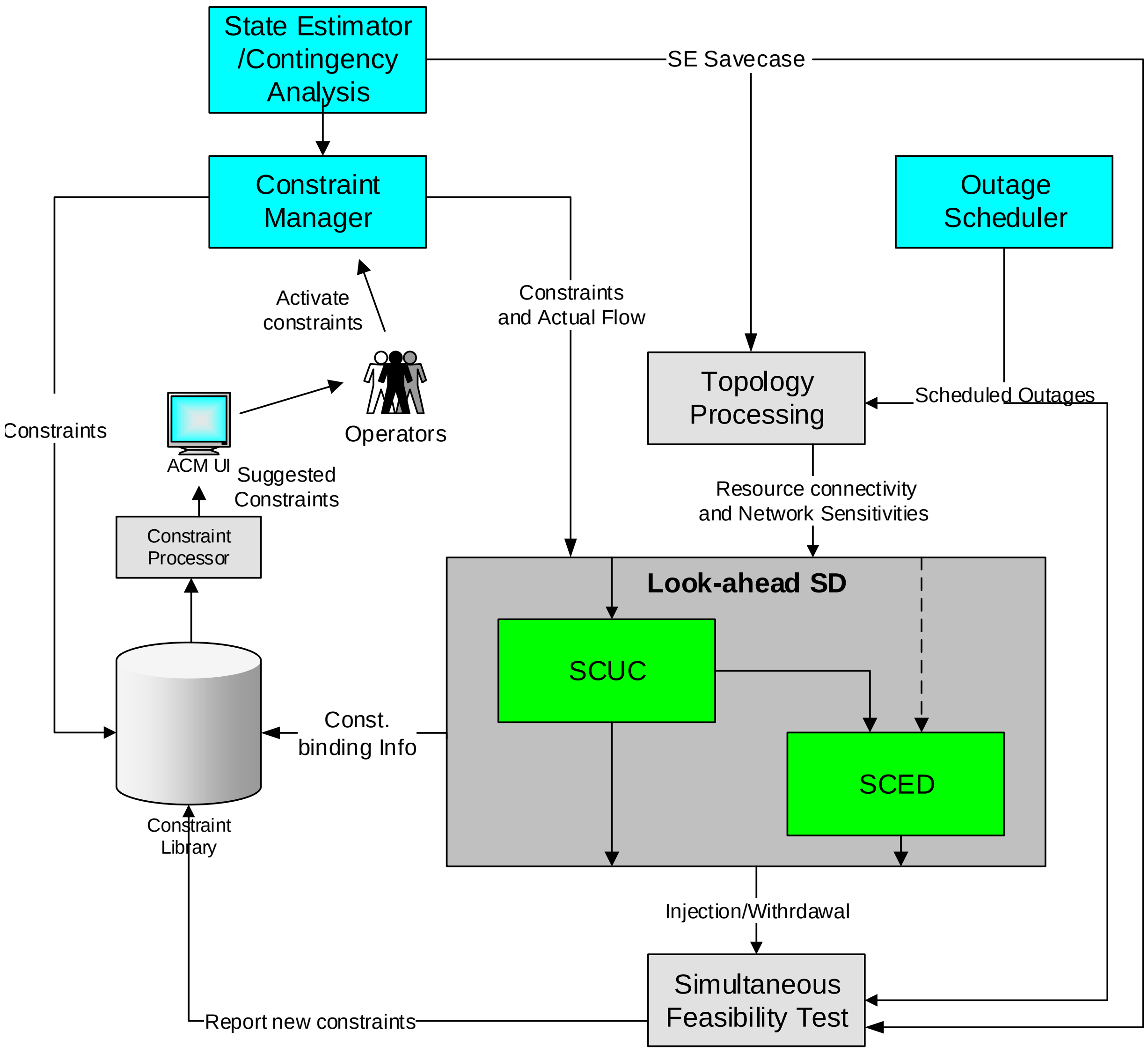
Source: The Brattle Group

GE's Smart Dispatch Solution Overview



- Multi-stage SCUC/SCED
- Outage management
- After-the-fact forensic analysis (perfect dispatch)
- Renewable generation forecasting
- Net interchange forecasting
- Demand forecasting
- Adaptive Model Management
  - Adaptive generator modeling
  - **Adaptive constraint modeling**

Transmission Constraint Management



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DLR

- In the last two decades, technologies and strategies have emerged to allow the real-time or pseudo-real-time measurement of transmission line characteristics and environmental conditions which enabled calculation of a real-time rating.
- As economic pressure builds to fully utilized the capacity of existing power equipment in both deregulated and regulated environments, dynamic line ratings can improve the efficiency of transmission operation by capturing unutilized line capacity while maintaining system reliability.
- Two key benefits of DLR over traditional static line ratings:
  1. Higher loading of equipment by developing more accurate thermal models.
  2. A better understanding of equipment thermal response is achieved resulting in higher reliability.

DLR Determination Methods

Weather-based methods

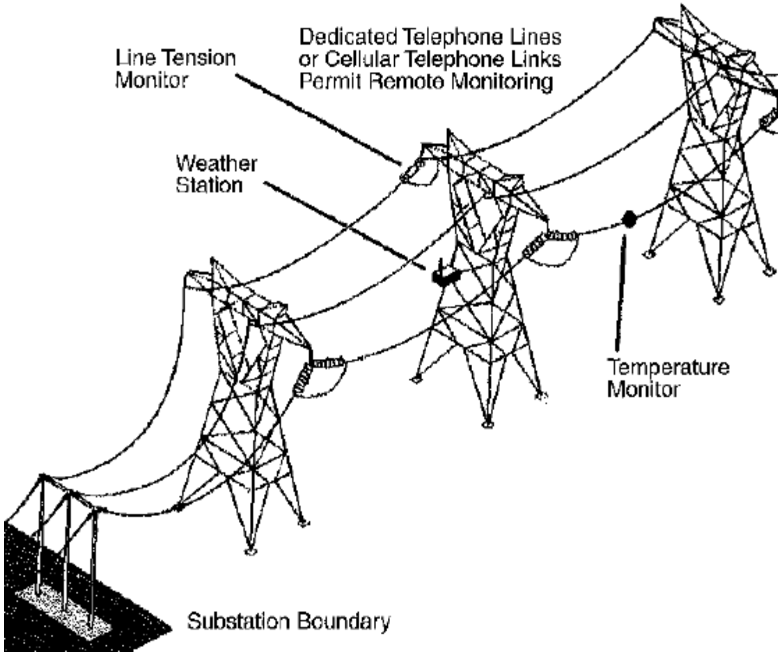
- Rely on monitoring e.g. ambient weather
- Line temperature and sag are determined by theoretical models and calculation

Temperature-based methods

- Based on direct conductor temperature measurements in combination with other measurements.

Sag monitoring methods

- Measuring some characteristic of the line (e.g. tension) to determine the sag



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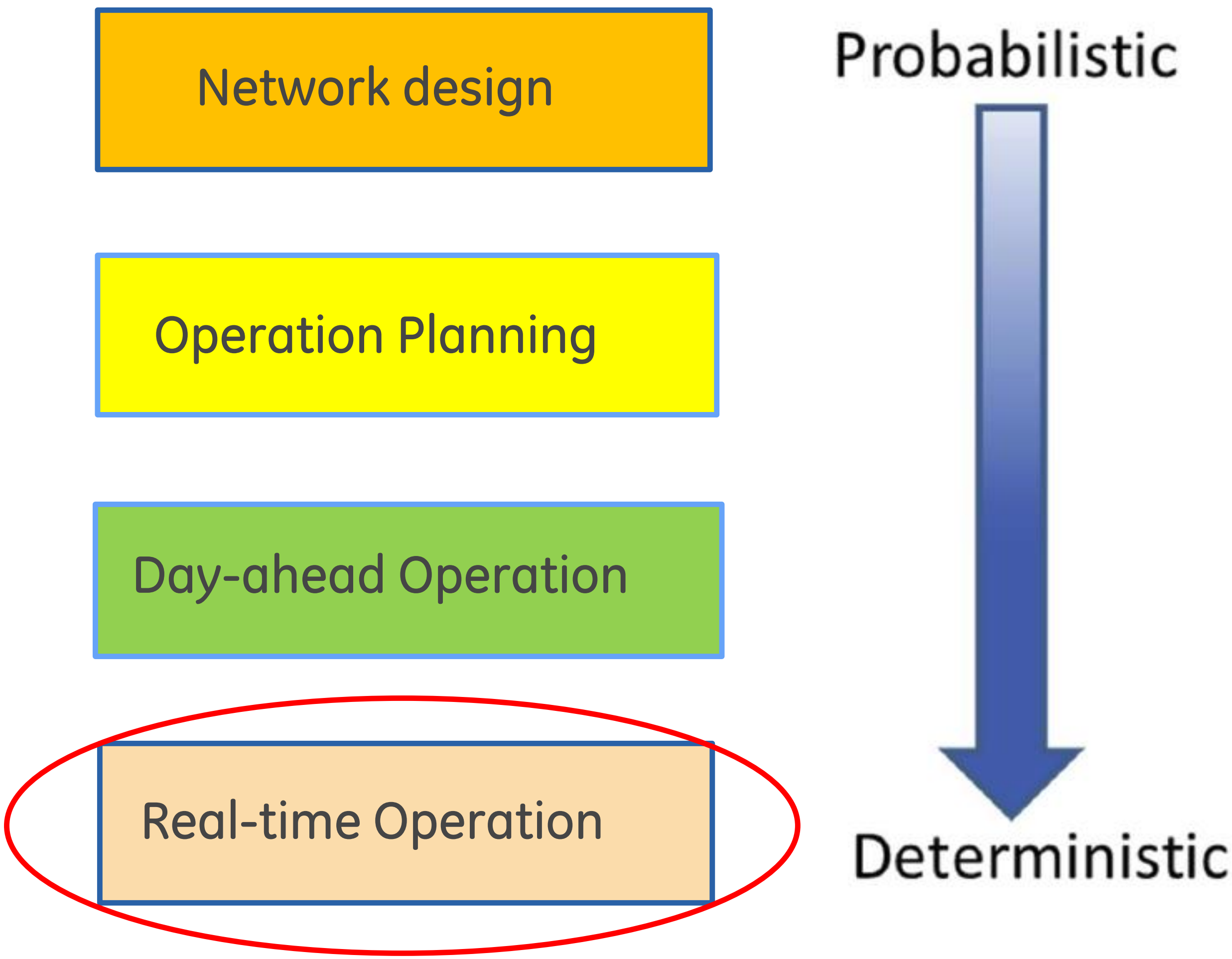
DLR Approach for Real-time Operation



Heat-Balance Model for Transmission Lines

- The line rating represents the line current which corresponds to the maximum allowable conductor temperature for a particular line without clearance infringements or significant loss in conductor tensile strength.
- Transmission line ratings are determined using the conductor's heat balance and are dependent on the cooling effect of wind, warming due to line current, air temperature and solar heating.

$$
\begin{aligned}
& q_J(T_C) + q_s + q_c \\
&= m_c c_c \frac{dT_C}{dt} + q_r(T_C, T_A) + q_k(T_C, T_A, V_S, V_D) + q_e(P, H, P_a),
\end{aligned}
$$

where

m_c :	conductor mass,	V_D:	wind direction
C_c :	conductor heat capacity,	P :	precipitation
T_C :	conductor temperature,	H :	humidity
T_A :	ambient temperature,	P_a :	atmospheric pressure
V_S :	wind speed		

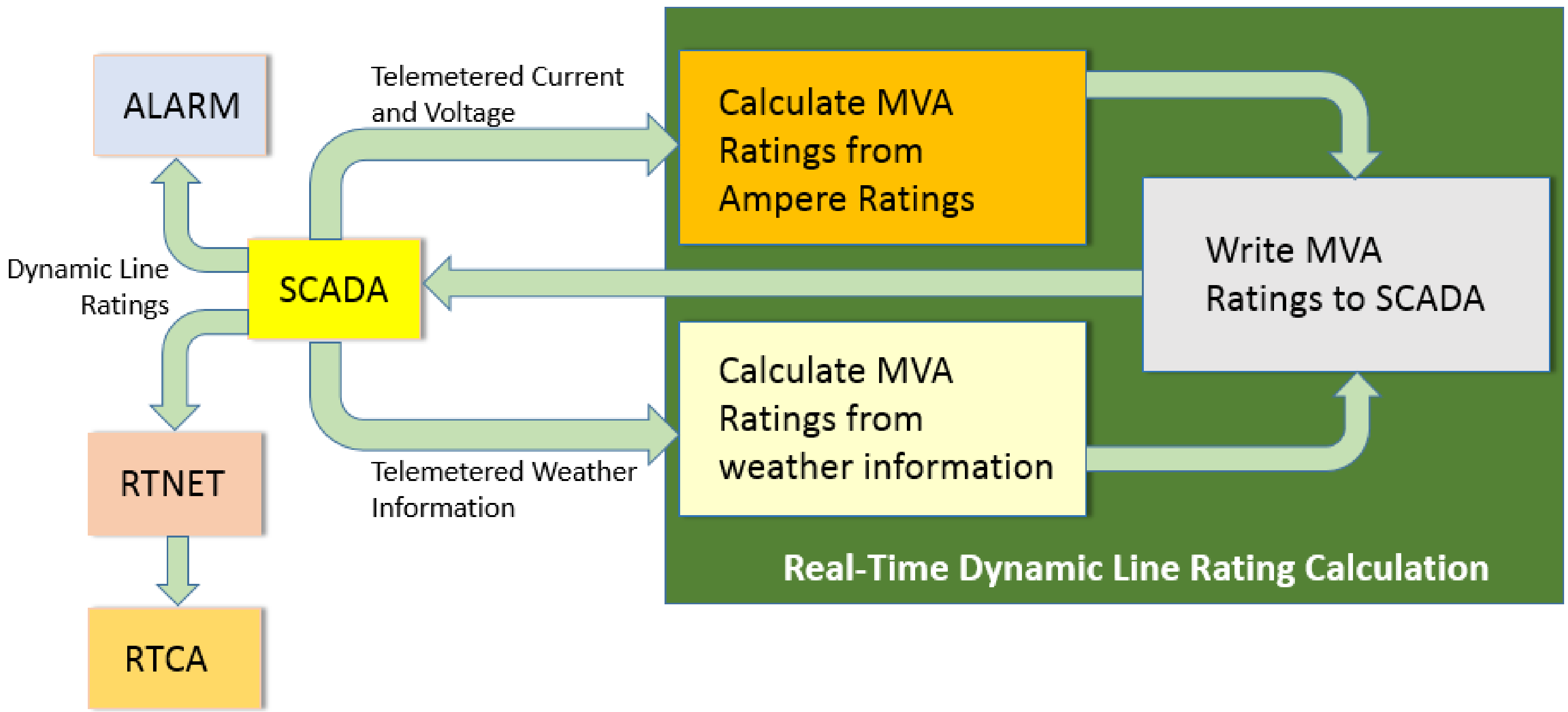
Maximum Permissible Current

- Real-time dispatch has typically a look-ahead time horizon of 15 minutes
- The thermal time constants for overhead conductor are also in the range of 10-15 minutes.
- Assumption: Quasi-steady-state thermal equilibrium is reached

$$I_{\max} = \sqrt{\frac{q_r(T_C^{\max}, T_A) + q_k(T_C^{\max}, T_A, V_s, V_D) + q_e(P, H, P_a) - q_s - q_c}{R(T_C^{\max})}}$$

T_C^{max}: conductor's maximum operating temperature

Functional Modules of DLR in EMS



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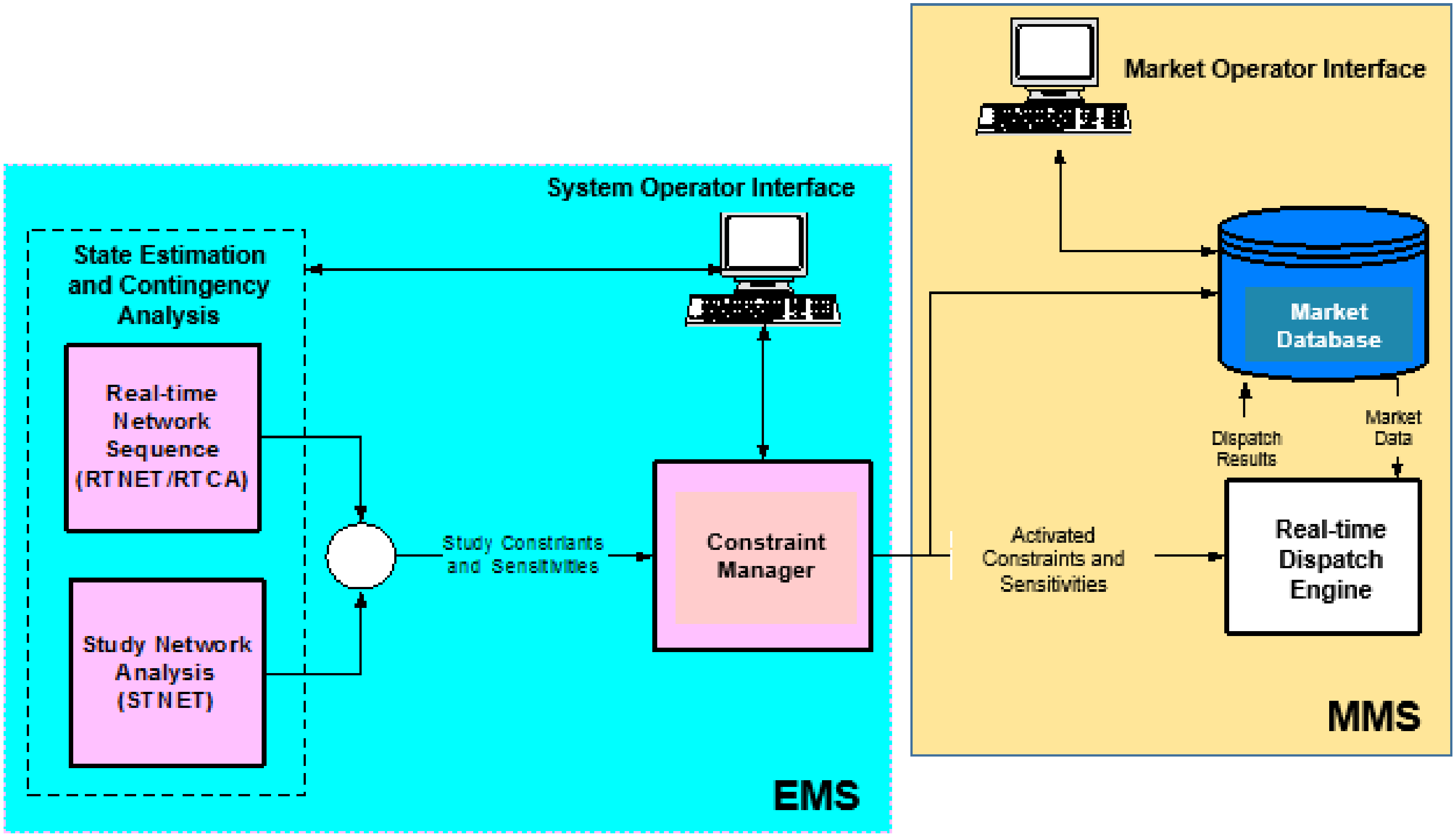
Real-time SCED System



SCED Formulation

$$\min c(P) + co(O) - cd(D)$$

subject to the following constraints:

- System power balance

  $$(\lambda) \quad \sum_i (P_i - D_i) - FD - P_L = 0$$

- Reserve requirement

  $$(\gamma_O) \quad \sum_i O_i \geq O^{\max}$$

- Generator minimum generation limit

  $$(\tau_i^{\min}) \quad P_i \geq P_i^{\min}$$

- Generator joint maximum generation limit

  $$(\tau_i^{\max}) \quad P_i + O_i \leq P_i^{\max}$$

- Price-responsive load dispatch range

  $$(\eta_i^{\max}) \quad 0 \leq D_i \leq D_i^{\max}$$

- Generator ramp-rate limit

  $$(\phi_i)| \quad |P_i - P_i^0| \leq RR_i^{\max}$$

- Grid base-case and contingency

  $$(\mu_l) \quad \sum_i a_{l,i}(P_i - D_i - d_i \times FD) \leq L_i^{\max}$$

Impacted by DLR determination

Locational Marginal Price

$$LMP_i = \lambda - \lambda \frac{\partial P_L}{\partial P_i} - \sum_l a_{l,i} \mu_l$$

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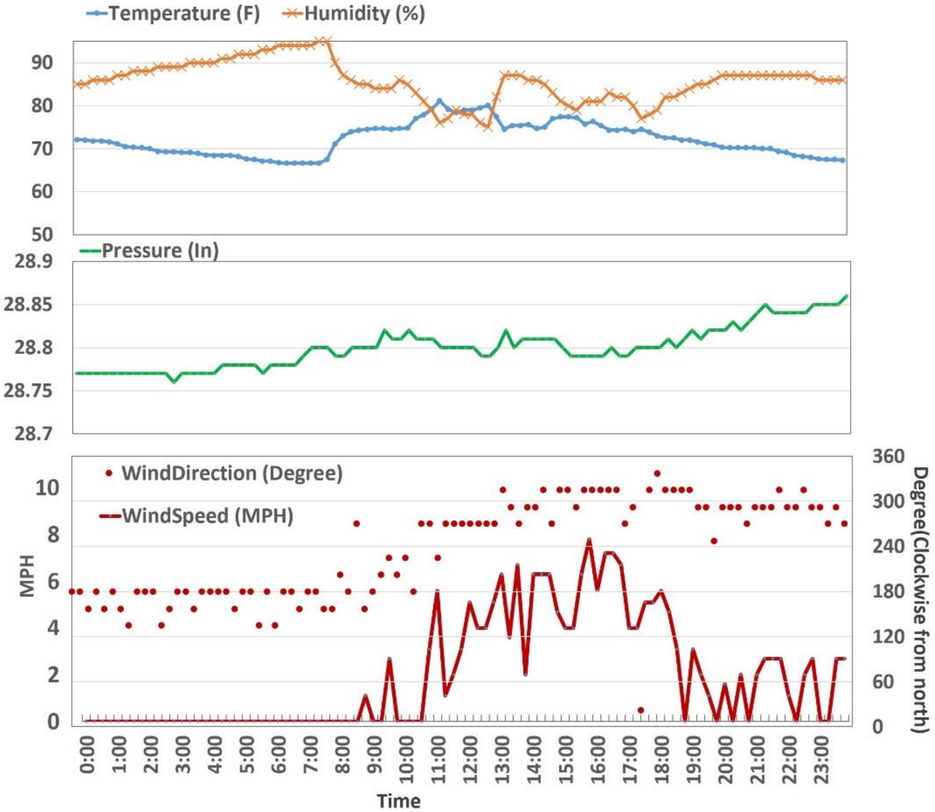
Numerical Examples

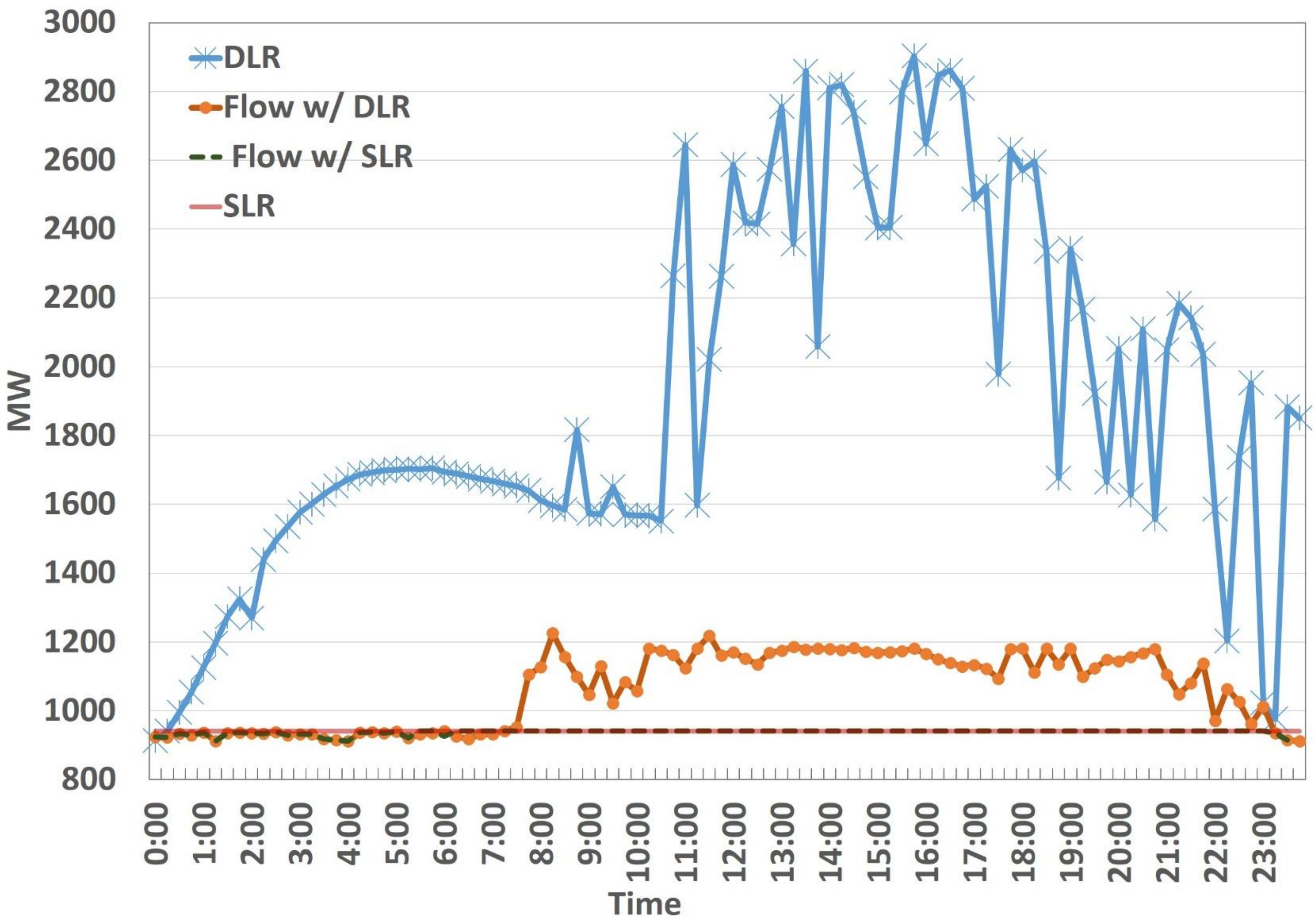
- Ambient weather conditions of a 345kV high-voltage transmission line that is about 12 km long in Ohio.

TABLE I
CORRELATION COEFFICIENTS BETWEEN DLR AND WEATHER MEASUREMENTS

	Ambient Temperature	Humidity	Atmospheric Pressure	Wind Speed	Wind Direction
Correlation w/ DLR	0.5546	-0.5104	0.1772	0.8879	0.4337

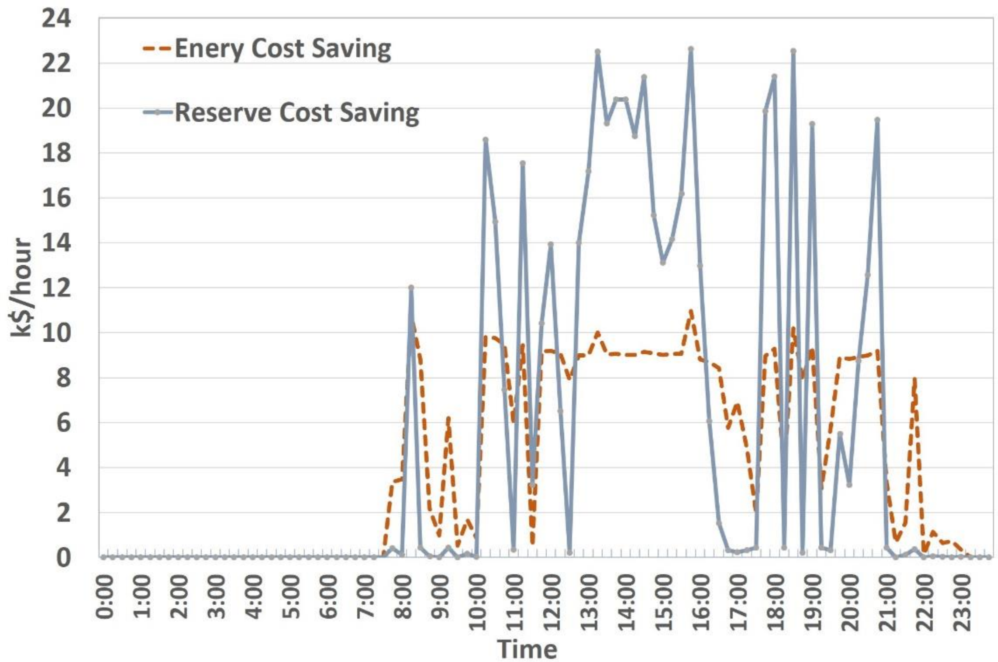


Numerical Examples (Cont'd)



Numerical Examples (Cont'd)

- Applied DLR to the RT-SCED process for a very large power system with more than 37,000 buses and 48,000 transmission lines.



Time	Solutions using Static Line Rating			Solutions using Dynamic Line Rating		
	Energy Cost ($)	Reserve Cost ($)	Reserve Scarcity Cost ($)	Energy Cost ($)	Reserve Cost ($)	Reserve Scarcity Cost($)
0:00	553179	2031	0	553179	2031	0
1:00	480005	2078	0	480005	2078	0
2:00	446669	2136	0	446669	2136	0
3:00	404903	2210	0	404903	2210	0
4:00	381255	2252	0	381255	2252	0
5:00	406548	2220	0	406548	2220	0
6:00	461884	2117	0	461884	2117	0
7:00	**609011**	**2073**	0	**608168**	**1968**	0
8:00	**832161**	**2036**	**3254**	**825842**	**1739**	**390**
9:00	**706032**	**1817**	**1727**	**703686**	**1654**	**1727**
10:00	**656503**	**1924**	**11805**	**649022**	**1745**	**1727**
11:00	**630146**	**2028**	**9449**	**623873**	**1863**	**1727**
12:00	**616593**	**1997**	**10273**	**607815**	**1874**	**1727**
13:00	**610286**	**1918**	**21583**	**601012**	**1934**	**1727**
14:00	**612961**	**1929**	**20654**	**603901**	**1924**	**1727**
15:00	**618795**	**1935**	**18218**	**609263**	**1905**	**1727**
16:00	**609657**	**2042**	**6780**	**601730**	**1869**	**1727**
17:00	**607506**	**2122**	**6692**	**601831**	**1874**	**1727**
18:00	**616534**	**2043**	**12731**	**608737**	**1899**	**1727**
19:00	**620616**	**2101**	**7889**	**613849**	**1881**	**1727**
20:00	**615093**	**1971**	**12635**	**606109**	**1881**	**1727**
21:00	**615558**	**1993**	1727	**612174**	**1759**	1727
22:00	**721318**	**1682**	1584	**720653**	**1665**	1584
23:00	**776200**	**1825**	0	**776116**	**1818**	0

Conclusions

- DLR is incorporated into the real-time dispatch process of market system operations.
- A weather-based method is proposed to calculate the DLR using a deterministic approach and the calculated DLRs are applied to a large-scale power system.
- Simulation results indicated that tremendous savings could be achieved by better utilization of actual transmission capacity without compromising any system reliability.
- Consistent framework of DLR needs to be in place for both real-time market and day-ahead market in order to avoid price order reversal between the two markets.
- Incorporating DLR with a probabilistic model in the day-ahead market would be an interesting future topic of R&D.

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