Ambient-Adjusted Rating for Improved Market Efficiency: Design and Implementation

Kwok Cheung
KC-Exousia Consulting

FERC Technical Conference 2024
July 9-11, 2024
Washington DC

KC-Exousia CONSULTING

Outline

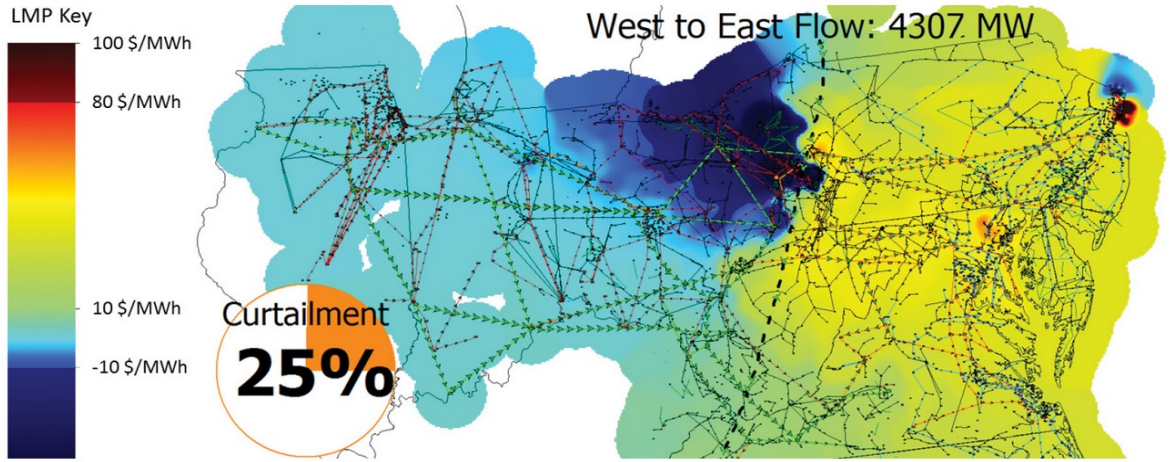
- Introduction
- FERC Order 881: Ambient Adjusted Ratings (AAR)
- Dynamic Line Ratings (DLR): Model and Calculations
- Applications of DLR/ARR: Design and Implementation
- Conclusions

Outline

- Introduction
- FERC Order 881: Ambient Adjusted Ratings (AAR)
- Dynamic Line Ratings (DLR): Model and Calculations
- Applications of DLR/ARR: Design and Implementation
- Conclusions

Introduction

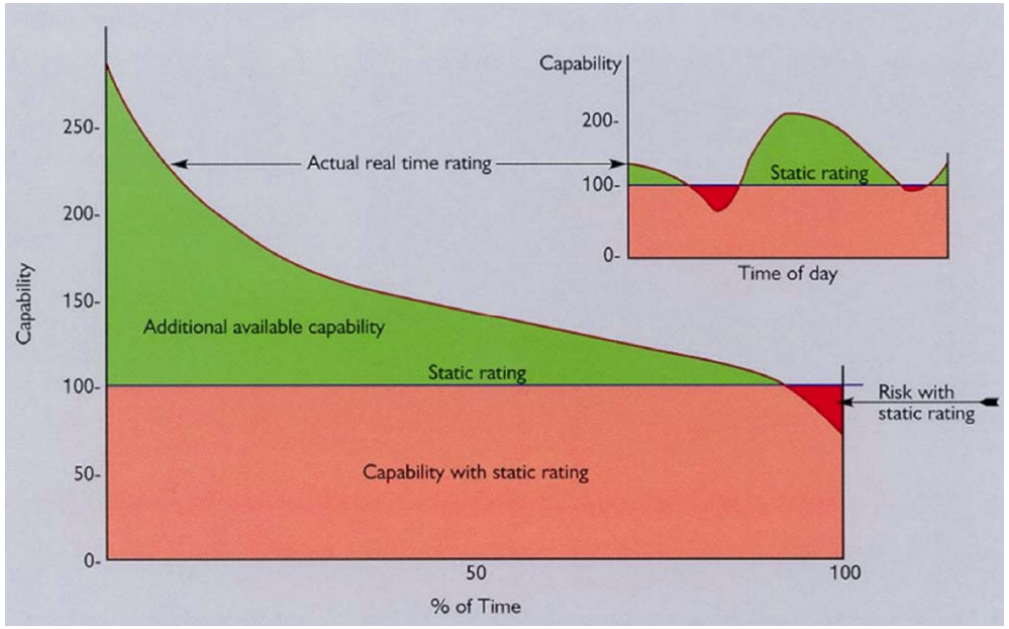
- Regional transmission organizations are heavily reliant on *security constrained* unit commitment (SCUC) and economic dispatch (SCED) to optimally dispatch their energy resources.
- With the penetration of renewable energy resources, transmission system operators are in the process of enhancing their 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.
- Dynamic line rating (DLR) has the potential to increase line rating, reduce transmission congestion and enhance market efficiency.



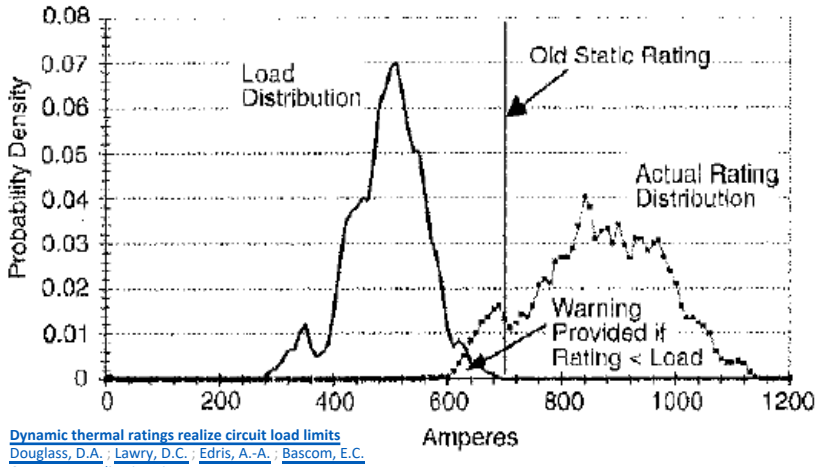
Source: The Brattle Group

Introduction [Cont'd]

- 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, enabling real-time and forecast rating calculation.
- As economic pressure builds to fully utilize existing power equipment's capacity 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. Enables significant amount of additional transmission capacity (Ampacity)
    2. **E**liminates the risk in static rating



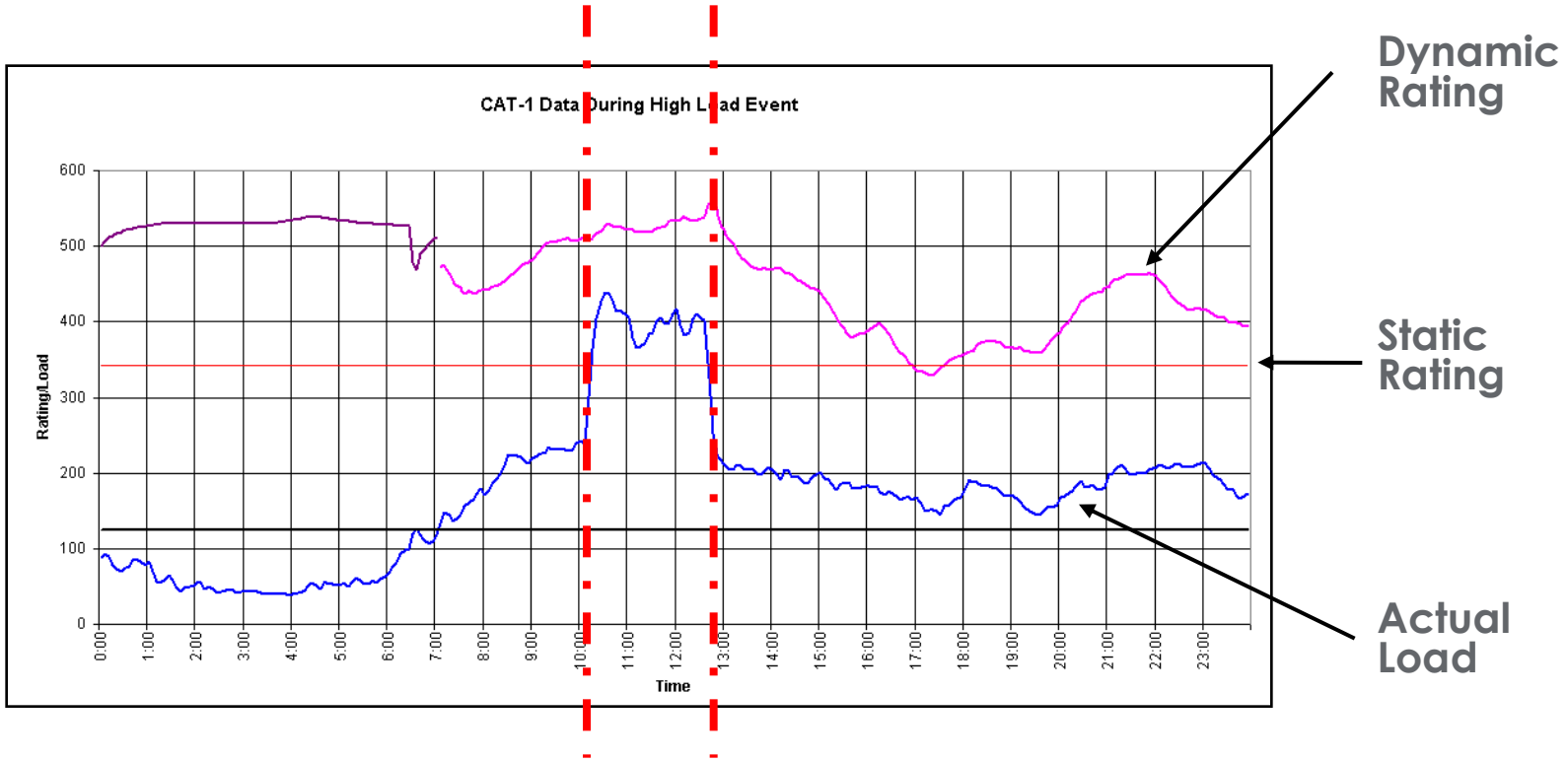
CAT-1 Transmission line monitoring system. The Valley Group. Available at http://www.nexans.be/eservice/Belgiumen/fileLibrary/Download_540145282/US/files/valley%20group_CAT-1.pdf



Dynamic thermal ratings realize circuit load limits
Douglass, D.A. ; Lawry, D.C. ; Edris, A.-A. ; Bascom, E.C.
Computer Applications in Power, IEEE
Volume: 13 , Issue: 1

KC-Exousia CONSULTING

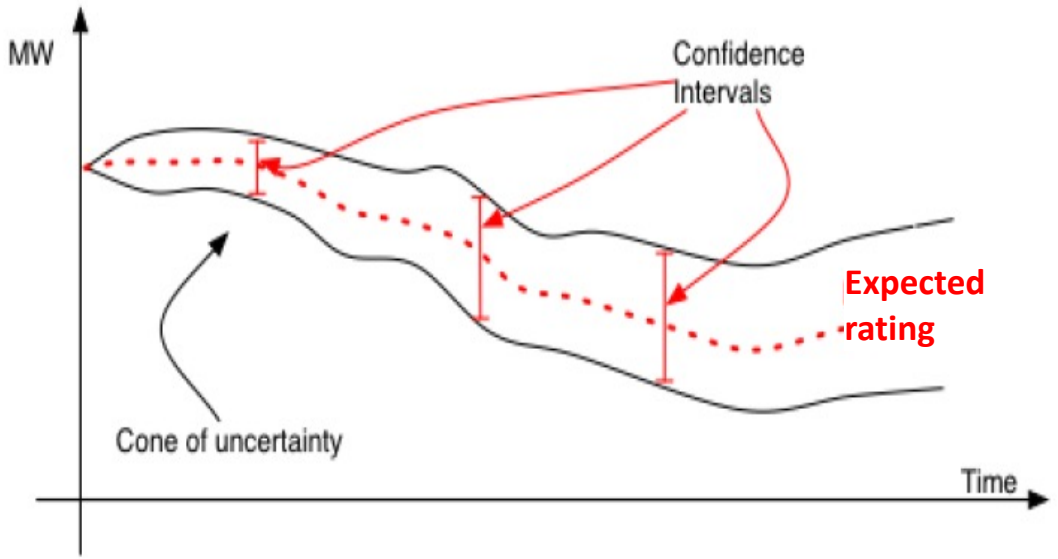
Impact On Transmission Grid Operations



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

KC-Exousia CONSULTING

DLR Approach for System Operations



Network design

Operation Planning

Day-ahead Operation

Real-time Operation

Probabilistic

Deterministic

KC-Exousia CONSULTING

Outline

- Introduction
- FERC Order 881: Ambient Adjusted Ratings (AAR)
- Dynamic Line Ratings (DLR): Model and Calculations
- Applications of DLR/ARR: Design and Implementation
- Conclusions

FERC Order 881 – Ambient-Adjusted Ratings (AAR)

- The order released in December 2021 and is expected to be effective by summer 2025
- All transmission providers (TP) need to use the ambient-adjusted ratings for their transmission lines to evaluate requests for transmission service that will end within ten days of the request.
- TPs such as RTOs/ISOs need to establish the systems and procedures to allow transmission owners (TO) to electronically update their transmission lines' ratings at least hourly and to accommodate even more accurate ratings, such as DLRs, if transmission owners wish to implement them.
- TPs need to use "uniquely" determined emergency ratings for operational contingency analyses and in post-contingency simulations of constraints.
- TOs need to share transmission line ratings and methodologies with their respective TPs and respective market monitors.
- TPs need to maintain a database of each TO's transmission line ratings and methodologies on a password-protected website.

KC-Exousia CONSULTING

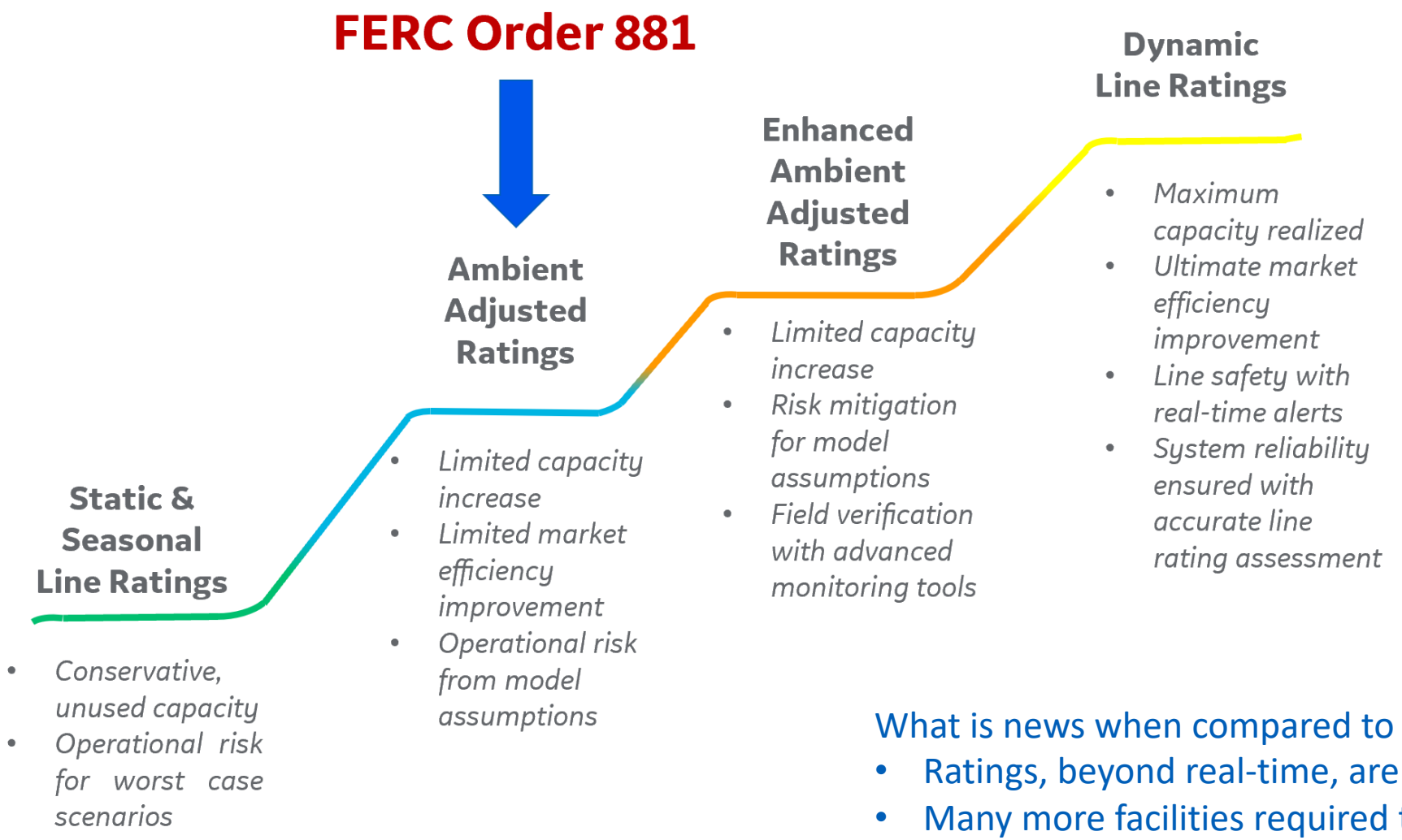
Dynamic Line Rating vs Ambient Adjusted Rating

- **Ambient-Adjusted Ratings (AARs):** a transmission facility rating that: (1) applies to a time period of not greater than one hour; (2) reflects an up-to-date forecast of ambient air temperature across the time period to which the rating applies; (3) reflects the absence of solar heating during nighttime periods where the local sunrise/sunset times used to determine daytime and nighttime periods are updated at least monthly, if not more frequently; and (4) is calculated at least each hour, if not more frequently.

- **Dynamic Line Ratings (DLRs):** a transmission facility rating that: (1) applies to a time period of not greater than one hour; and (2) reflects up-to-date forecasts of inputs such as (but not limited to) ambient air temperature, wind, solar heating intensity, transmission line tension, or transmission line sag.

KC-Exousia CONSULTING

FERC Order 881 – DLR/AAR



What is news when compared to current practices?

- Ratings, beyond real-time, are hourly forecasted 10-day ahead
- Many more facilities required to have AAR

KC-Exousia CONSULTING

FERC Order 881 – DLR/AAR [Cont'd]

FERC Order No. 881 mandates that ISOs/RTOs implement ambient adjusted ratings in:

- Real-time congestion management processes
- Real-time and look-ahead market commitment processes, as well as look-ahead reliability studies
- Evaluation and curtailment of near-term transmission service (10 days or less)

FERC Order No. 881 sets the following criteria for Ambient Adjusted Ratings (AARs):

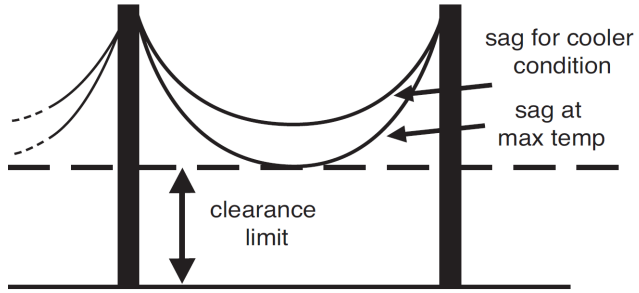
- Applicable for periods not exceeding one hour.
- Incorporates the most current forecast of ambient air temperature for the applicable period.
- Accounts for the absence of solar heating during nighttime, adjusting for day/night solar heating variations.
- Calculated at least once per hour.
- Monthly updates to sunrise and sunset times used in calculations.
- Adjusts ratings with every five-degree Fahrenheit change in temperature.
- Considers the interaction of AARs with system voltage and stability limits, remedial action schemes, and system operating limits.

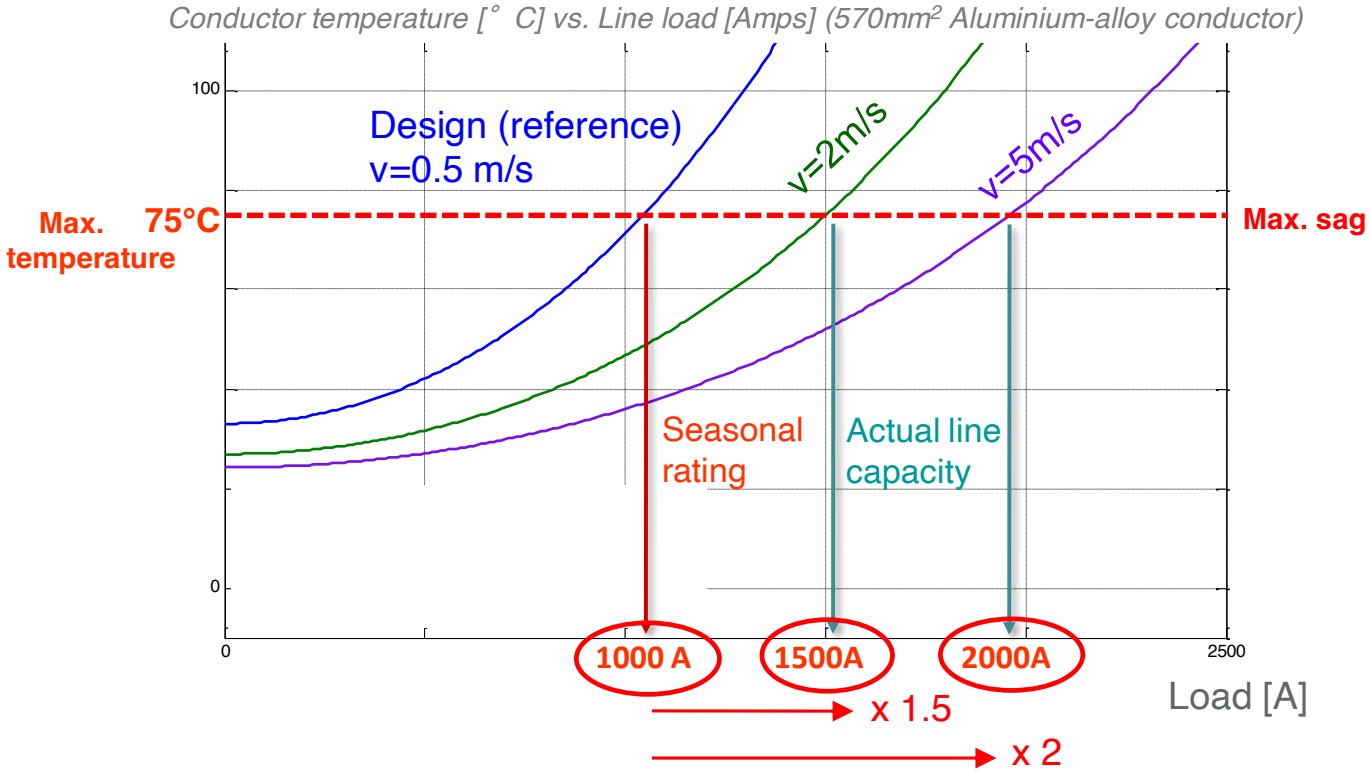
Outline

- Introduction
- FERC Order 881: Ambient Adjusted Ratings (AAR)
- Dynamic Line Ratings (DLR): Model and Calculations
- Applications of DLR/ARR: Design and Implementation
- Conclusions

Dynamic Line Rating

Key Question: "What is the **maximum current (thermal rating)** that can transfer through a line, and still keep the **conductor temperature** below its limit, and therefore keep the conductor below its **maximum sag?**





Reference: Finding Hidden Capacity In Transmission Lines, BY DAN LAWRY & BERNIE FITZGERALD, North American Wind Power Online, reprinted from April 2007 Edition

KC-Exousia CONSULTING

DLR Determination Methods

Weather-based methods

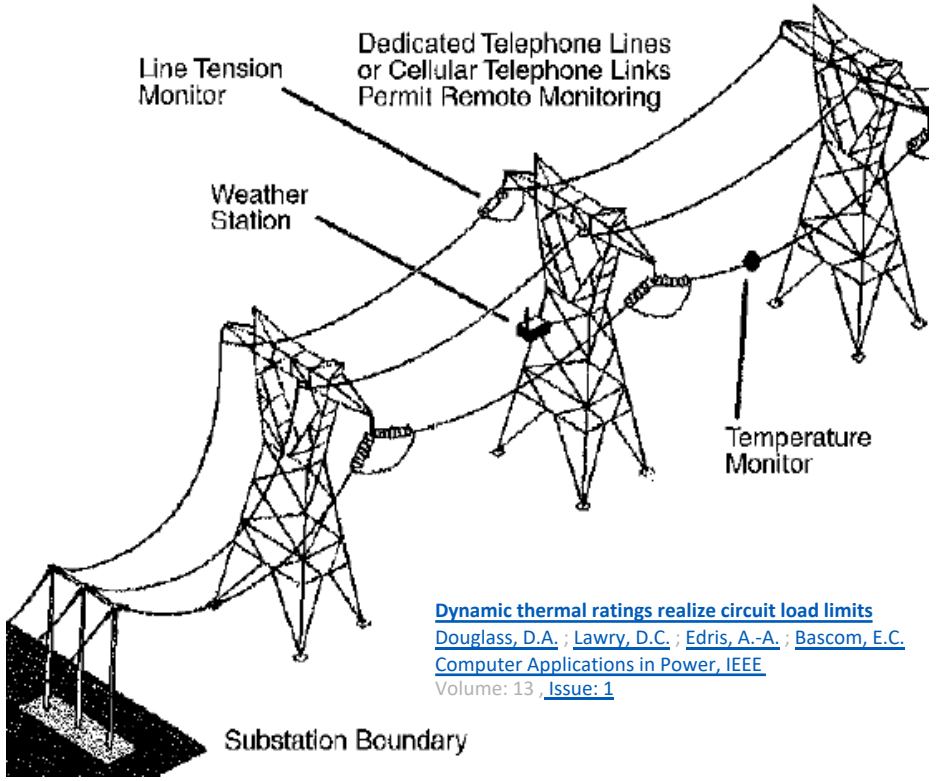
- Rely on monitoring e.g. ambient weather
- Line temperature and sag are determined by theoretical models and calculations

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



Dynamic thermal ratings realize circuit load limits
Douglass, D.A. ; Lawry, D.C. ; Edris, A.-A. ; Bascom, E.C.
Computer Applications in Power, IEEE
Volume: 13 , Issue: 1

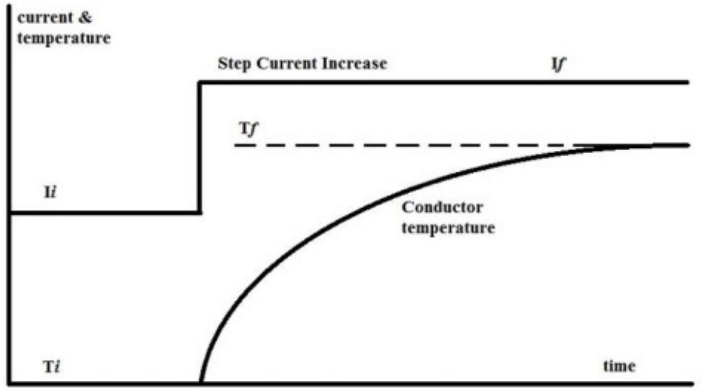
DLR Model and Calculations

- 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.

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

- 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.
- **Maximum Permissible Current** Calculation (Assumption: Quasi-steady-state thermal equilibrium)

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



where

m_c :	conductor mass,
C_c :	conductor heat capacity,
T_C :	conductor temperature,
T_A :	ambient temperature,
V_S :	wind speed
V_D:	wind direction
P :	precipitation
H :	humidity
P_a :	atmospheric pressure
T_C^{max} :	conductor's maximum operating temperature

KC-Exousia CONSULTING

Outline

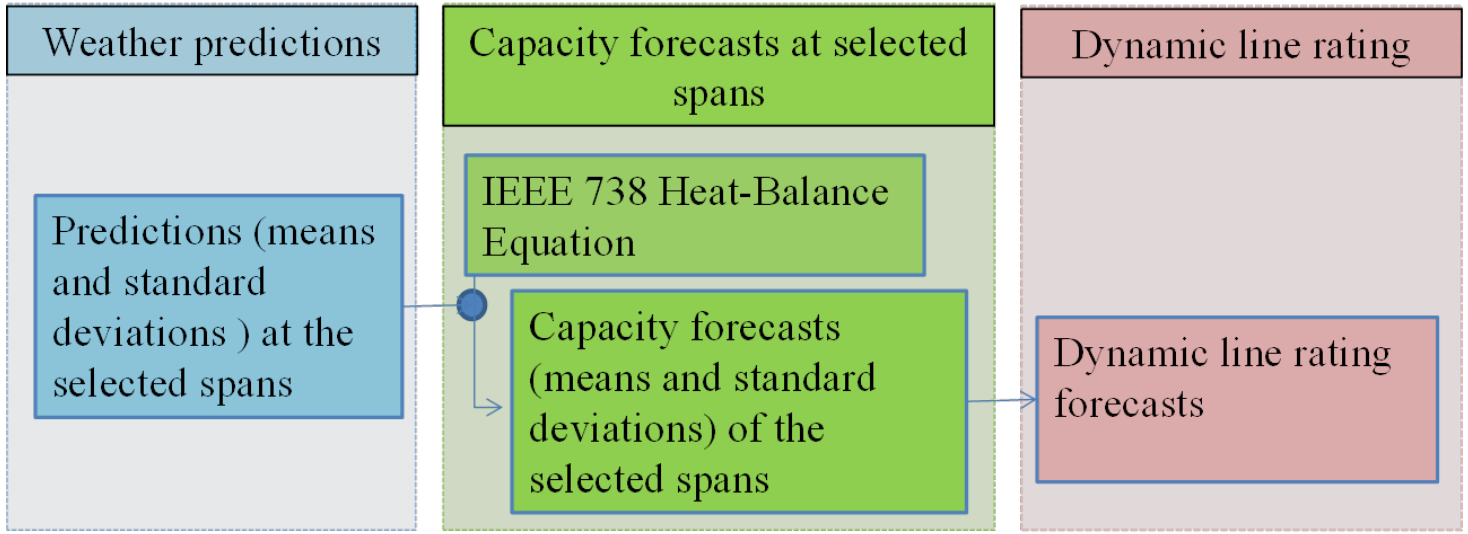
- Introduction
- FERC Order 881: Ambient Adjusted Ratings (AAR)
- Dynamic Line Ratings (DLR): Model and Calculations
- Applications of DLR/ARR: Design and Implementation
- Conclusions

Applications of DLR/AAR

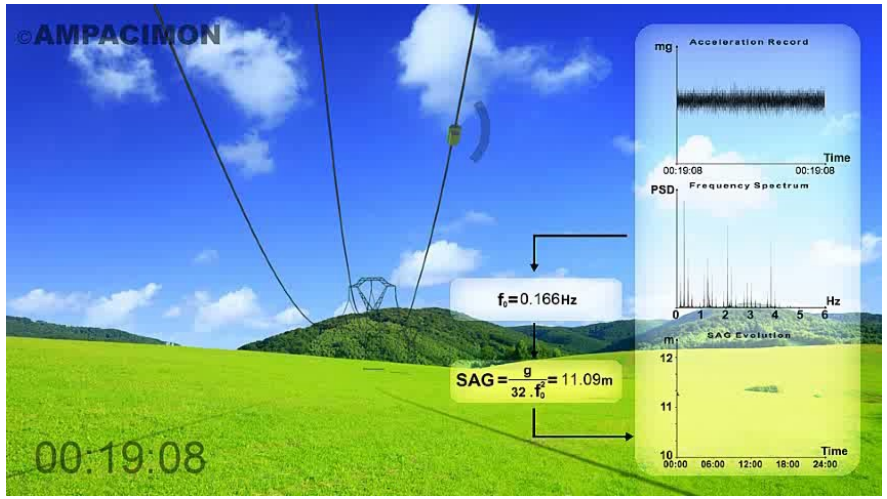
DLR/AAR Forecasting

Use Case: Weather-based probabilistic DLR method

1. Introduced weather forecasting models to provide probabilistic weather forecasts at selected spans.
2. Steady-state heat-balance equation is used to calculate line capacity based on thermal behavior of the overhead transmission line's conductor
3. Rating for an entire line is limited by the critical span

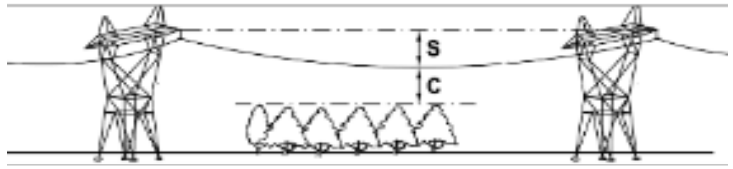


Real-time and Forecast Dynamic Rating Determination

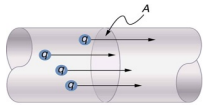


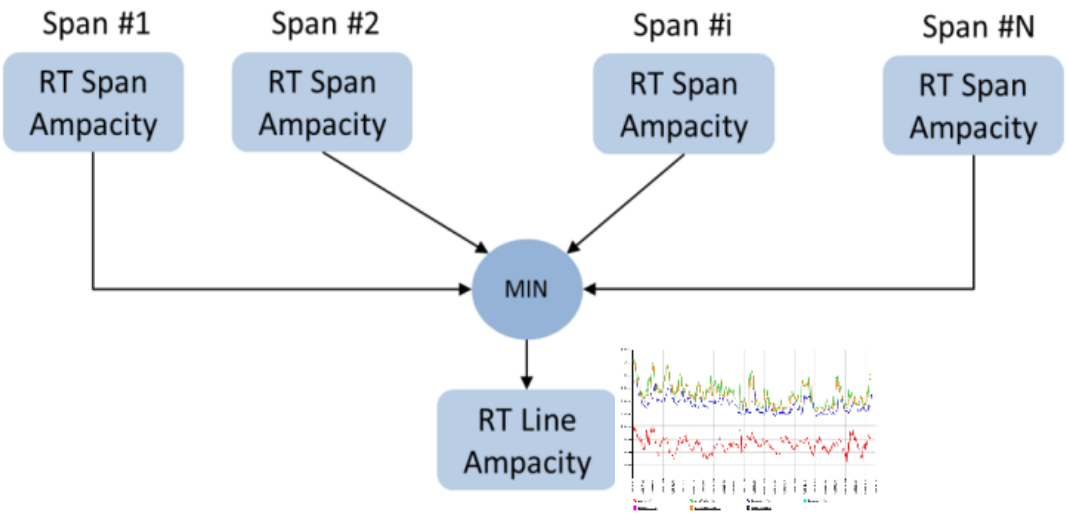
Sensor's 3D Vibration measurements yield sag and real wind speed as seen by the conductor

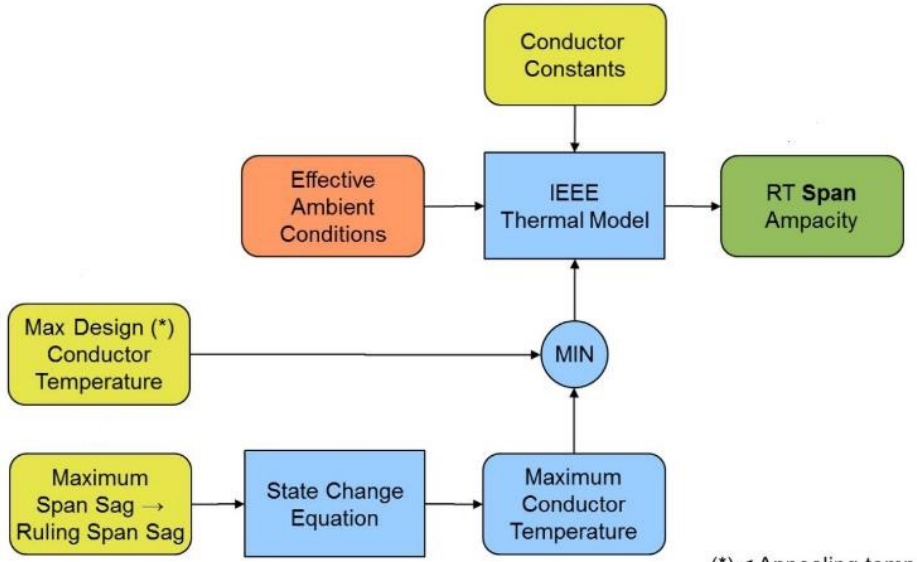
Sag



Wind speed | Temperature | Line current



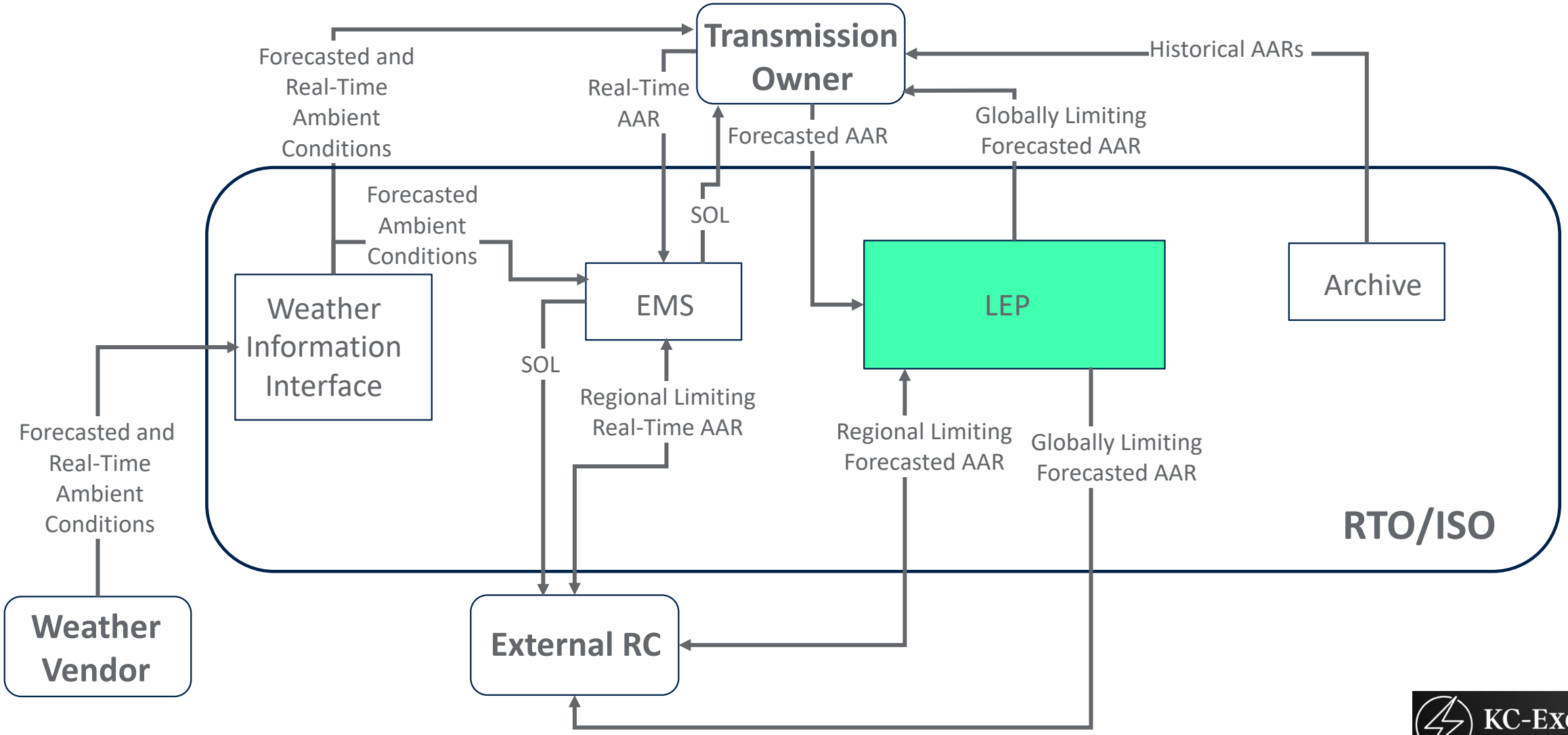




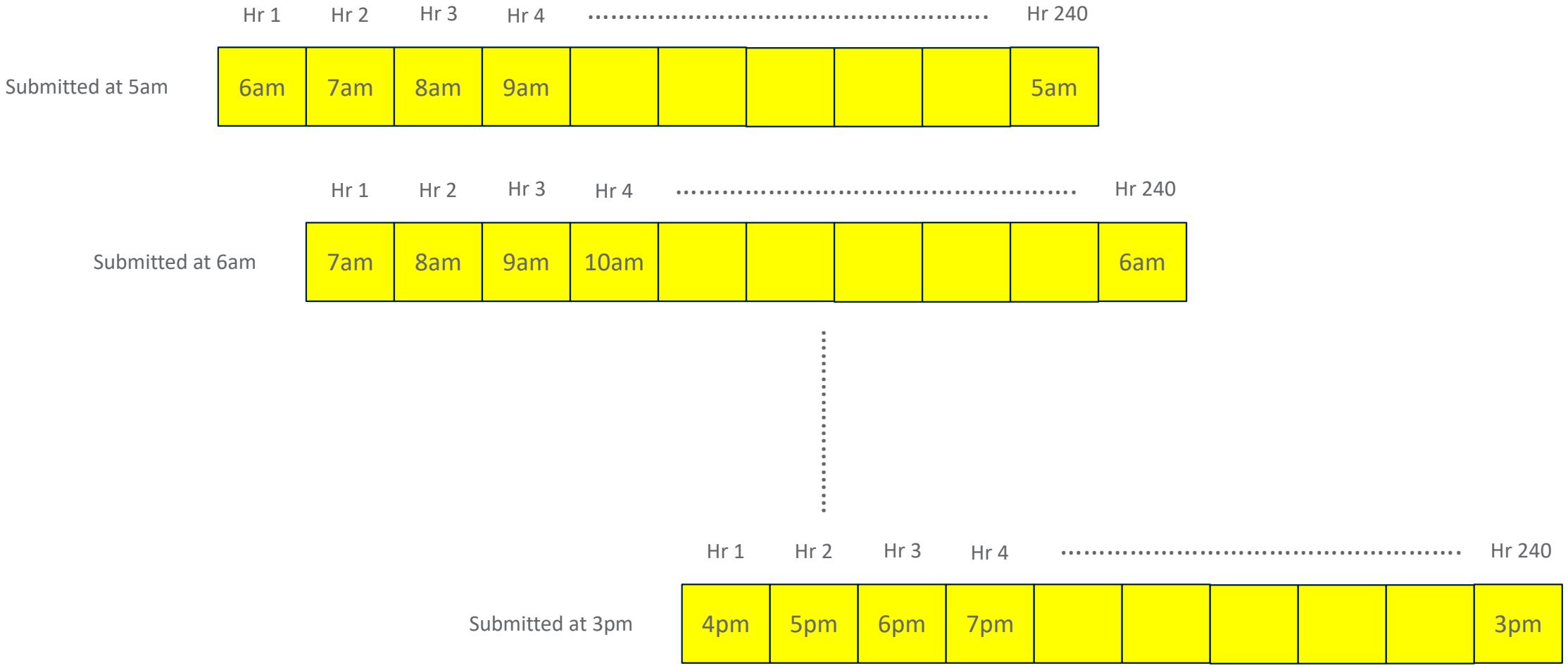
KC-Exousia CONSULTING

Applications of DLR/AAR

Limit Exchange Portal (LEP)



Look-ahead DLR/ARR Rolling Time Horizon Submission



Implementation of LEP

TROLIE (Transmission Ratings and Operating Limits Information Exchange)

- TROLIE - LF (Linux Foundation) Energy Project
  - Initiated by MISO and GE Vernova
  - Intend to establish a vendor-neutral specification and an inclusive community
  - Define an API specification for the exchange of ratings and ratings-related information to support organizations working to comply with FERC Order 881
  - A conformance program to provide vendors a means to demonstrate their compatibility with the defined specification and signal their commitment to maintaining compatibility
  - An open commons for the development of clients of the API specification

LFENERGY TROLIE

Search...

- Forecasting
  - GET Limits Forecast Snapshot
  - GET Obtain the status of the Ratings Provider's proposal
  - PATCH Submit a Forecast Proposal
- Real-Time
- Operating Snapshots
- Rating Proposals
- Seasonal Rating Snapshots
- Temporary AAR Exceptions
- Temporary Seasonal Ratings

Limits Forecast Snapshot

Obtain the Limits Forecast the Transmission Provider is currently using in Operations, relative to the current time. Clients SHOULD perform Conditional `GET` using the `If-None-Match` header and the `ETag` of a previous `GET` response. This operation uses media types to control verbosity of the data fetched. The default media type, `application/vnd.trolie.forecast-limits-snapshot.v1+json`, simply includes the rating data. For applications that need it, the media type `application/vnd.trolie.forecast-limits-detailed-snapshot.v1+json` may be requested, which also references the source proposals used to generate the snapshot, as well as reporting data from the ratings clearing process.

AUTHORIZATIONS: > *oauth2-primary-flow*

QUERY PARAMETERS

`offset-period-start`

string <date-time> (period-start) <= 25 characters

Example: `offset-period-start=2025-07-12T03:00:00-05:00`

Rather than return the entire forecast from the beginning, i.e., the next operating period, instead return a subset of the forecast starting with the period starting at `offset-period-start`.

`period-end`

string <date-time> (period-start) <= 25 characters

Example: `period-end=2025-07-12T03:00:00-05:00`

Specifies the end of a period for which a filter specifies. Periods will only be returned that start prior to this time.

`monitoring-set`

string (generic-identifier) <= 250 characters ^(.){0,250}$

Examples:

- `monitoring-set=X-AMPL` - A NERC id that nominates a `monitoring-set`.

Only return ratings or limits for facilities of the associated `monitoring-set`. The identifier for a `monitoring-set` is pre-coordinated, but using the NERC id of the associated Ratings Provider is recommended.

`transmission-facility`

string (generic-identifier) <= 250 characters ^(.){0,250}$

Examples:

- `transmission-facility=86753_1` - A typical AC line identifier

Only return limits for this transmission facility.

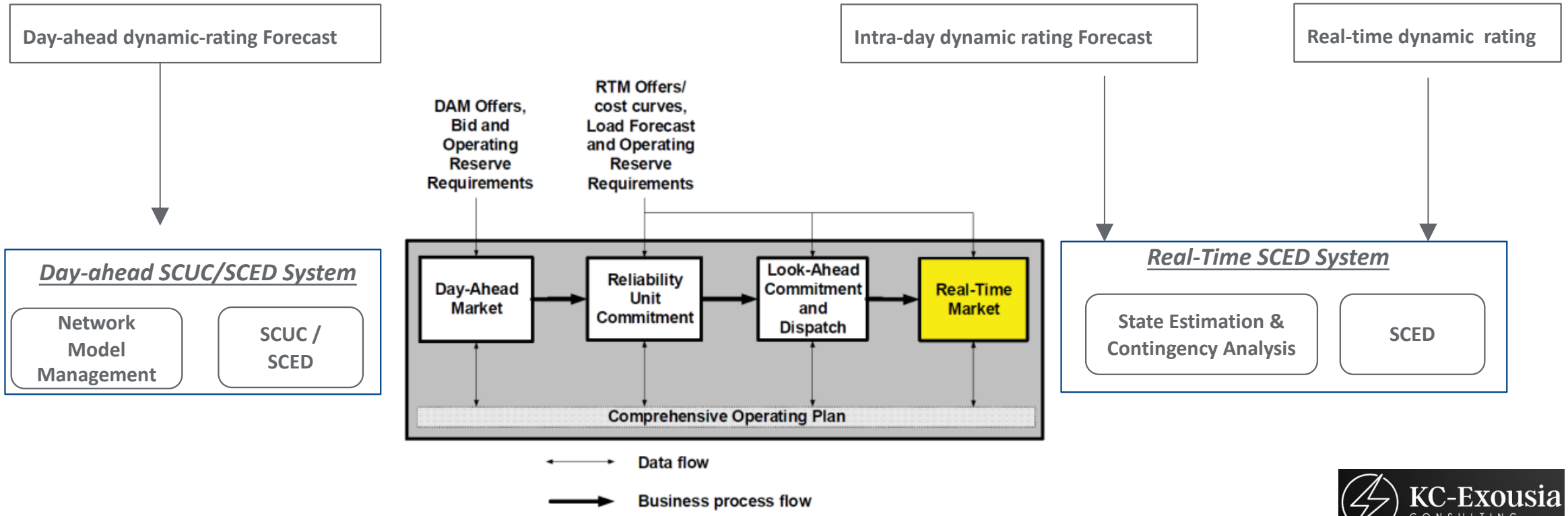
TROLIE APIs

https://trolie.energy/spec#tag

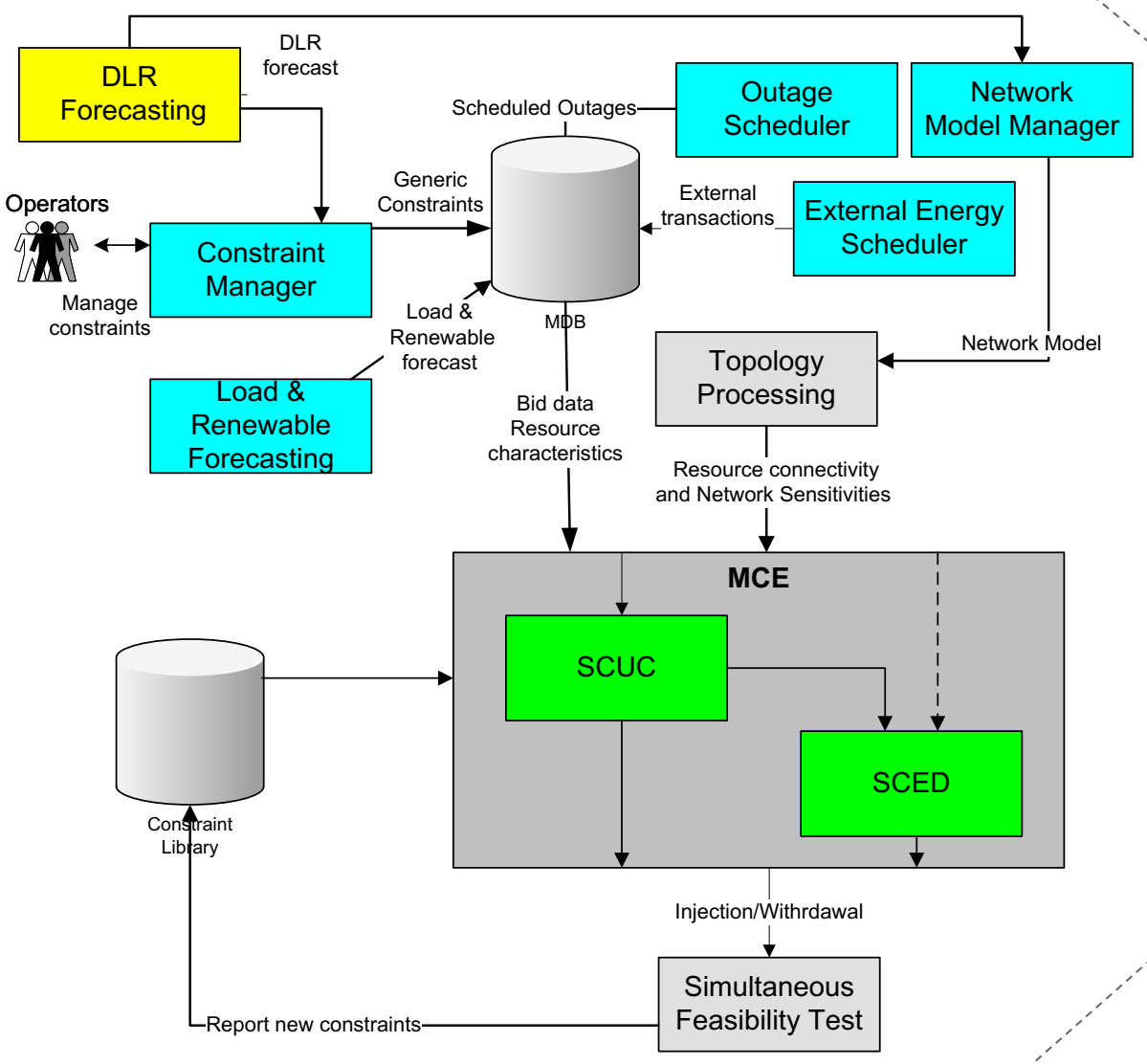
KC-Exousia CONSULTING

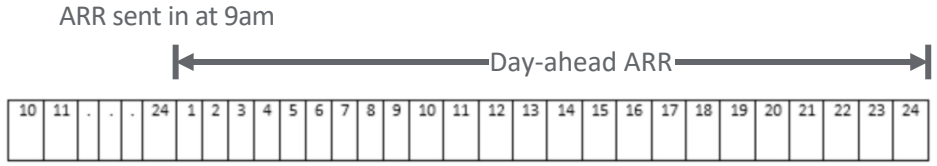
Applications of DLR in Market Operations: Technical Solutions

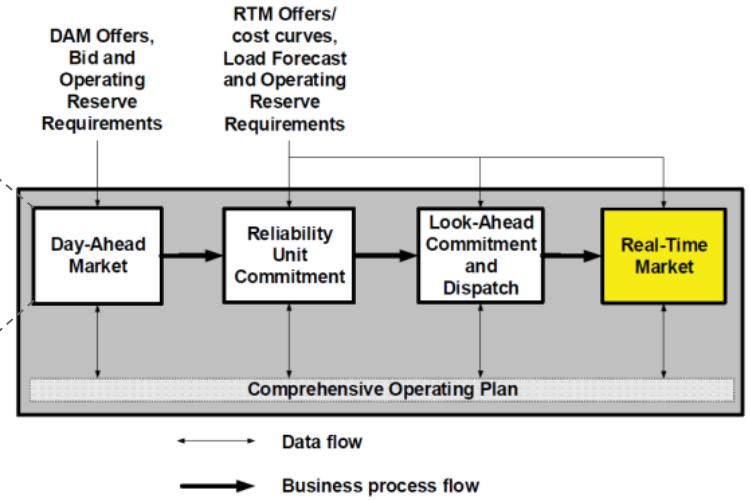
- Network model data will be available in Network Model Manager (NMM)
- TOs submit the normal, emergency, highest emergency and ambient adjusted ratings and the corresponding durations
- Data submitted to NMM will be used in the market and reliability processes
- Real time ratings can be submitted directly to EMS using ICCP
- New reports for displaying/reporting the real time ratings and ratings used in the market runs
- LEP/Graphical User Interface to submit and/or retrieve transmission line ratings
- LEP/Web Services interface to programmatically submit and/or retrieve ratings
- Data validations, including reasonability checks, will be enforced
- Standard certificate-based authorization and authentication protocols



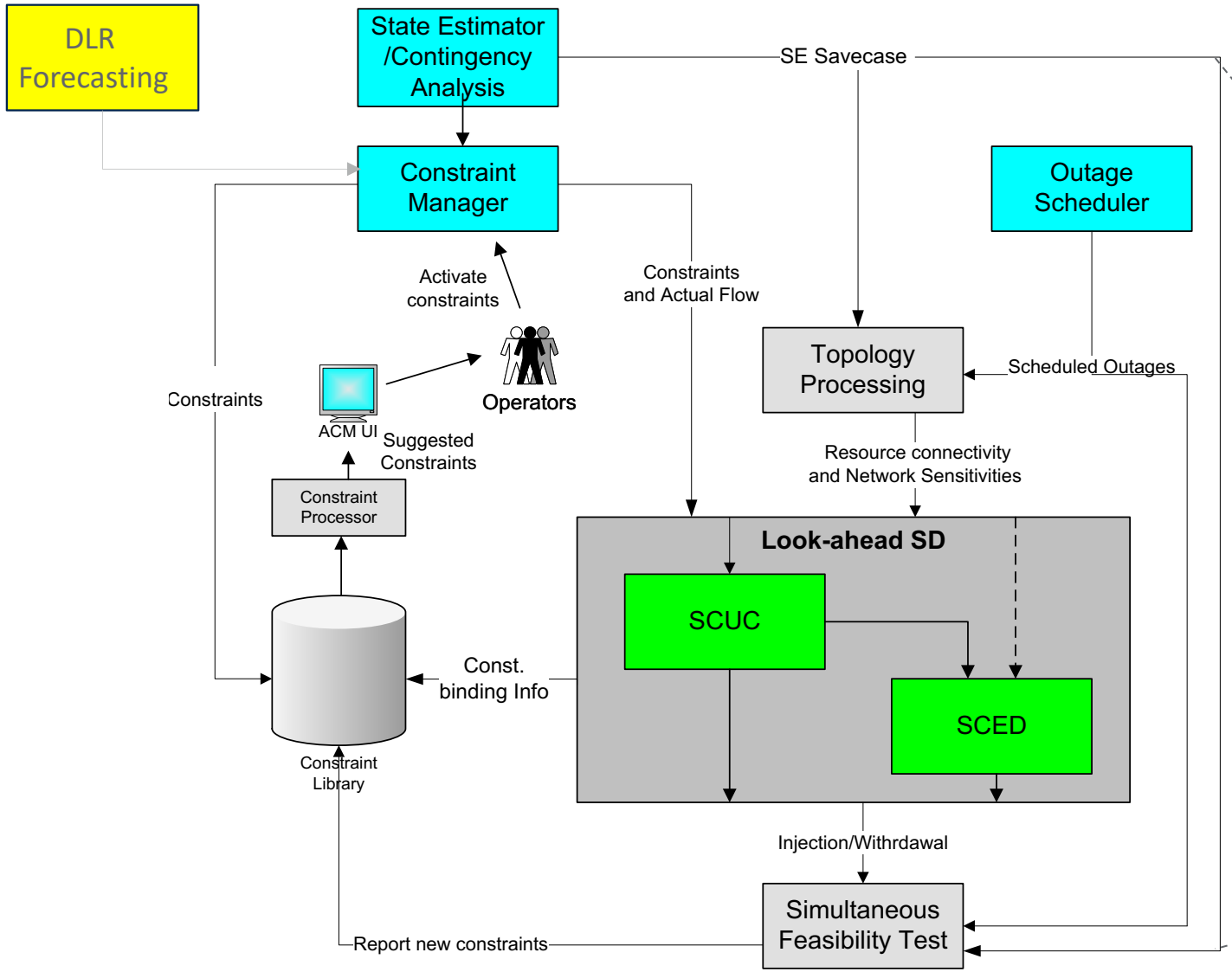
Day-ahead Market SCUC/SCED System with Incorporation of DLR

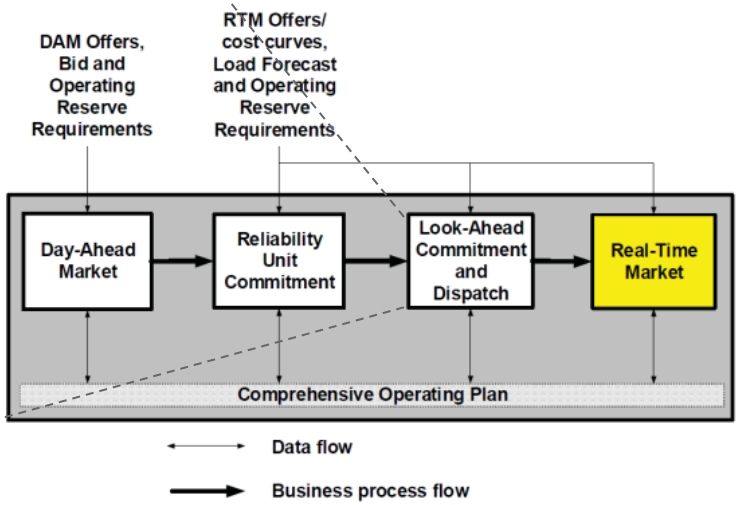




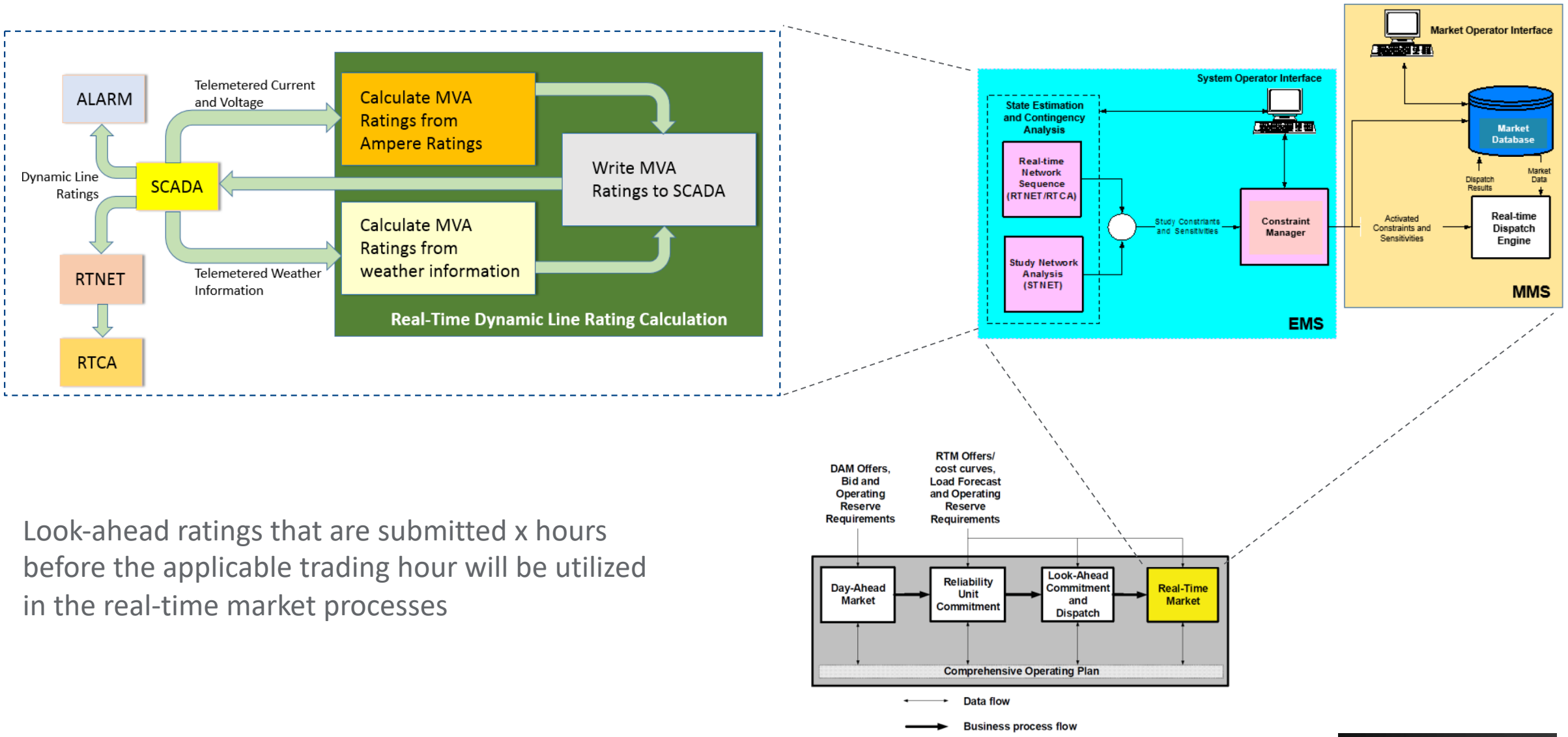


Near Real Time (Look-Ahead) Transmission Constraint Management





Real-time Market - Functional Modules of DLR in EMS



Look-ahead ratings that are submitted x hours before the applicable trading hour will be utilized in the real-time market processes

KC-Exousia CONSULTING

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

Locational Marginal Price

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

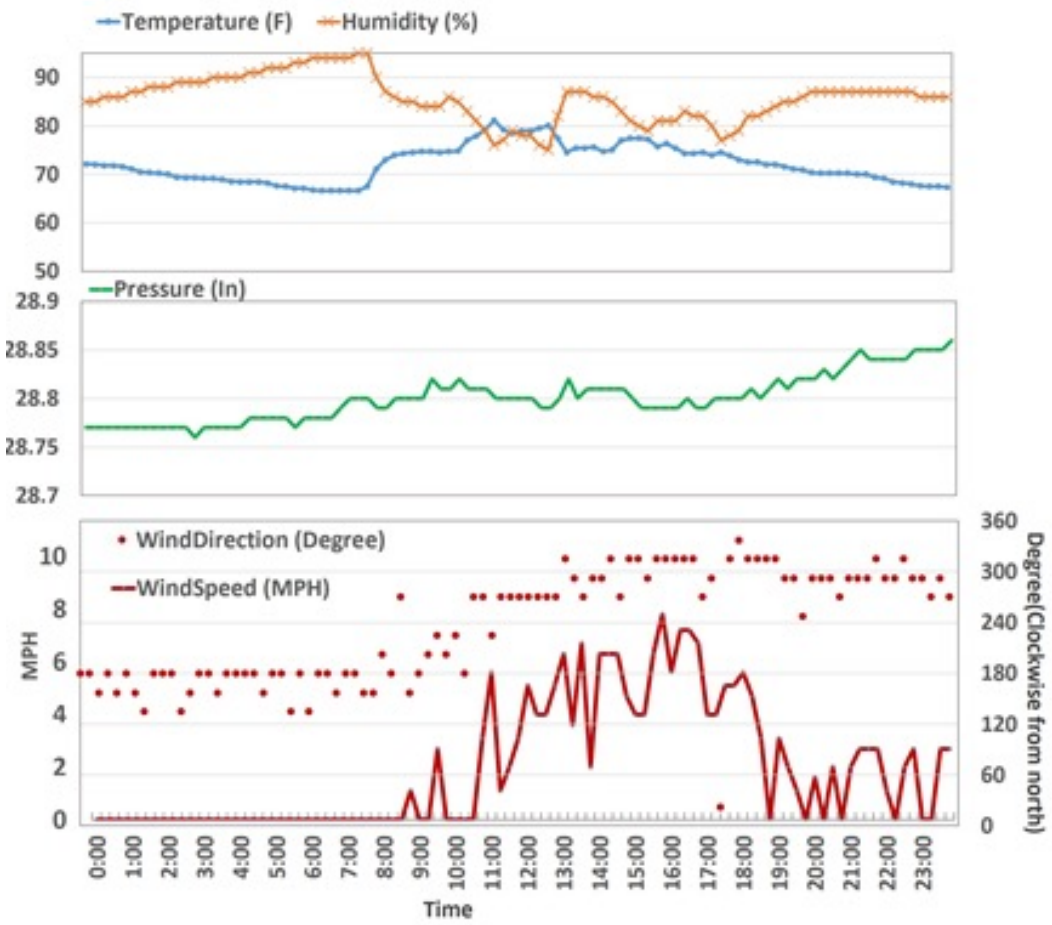
Impacted by DLR determination

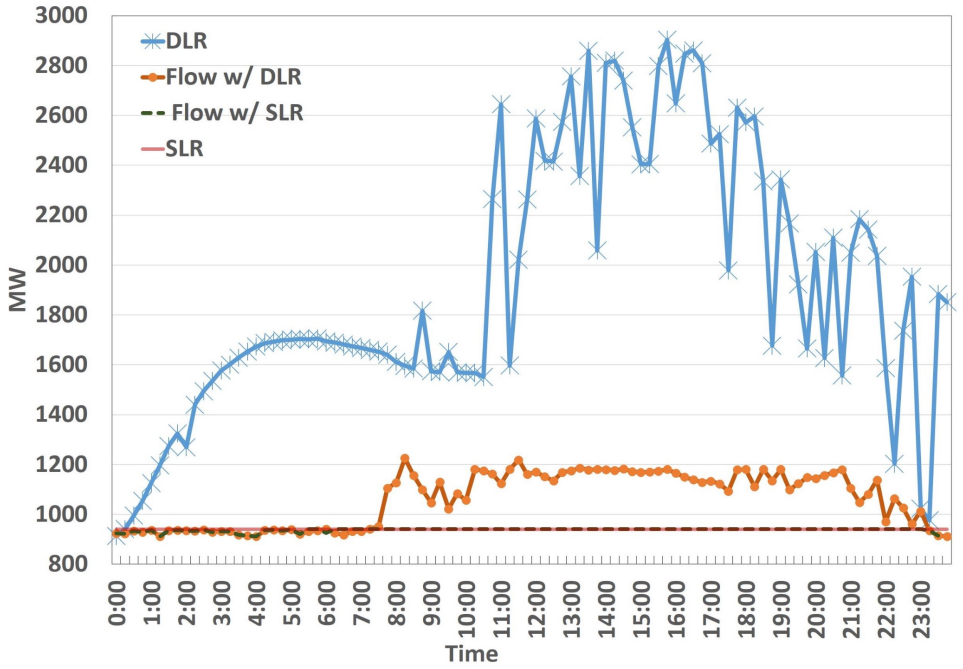
KC-Exousia CONSULTING

Numerical Examples

- Applied DLR/ARR to the real-time market for a very large power system with more than 37,000 buses and 48,000 transmission lines.

Typical weather measurements for real-time DLR calculation





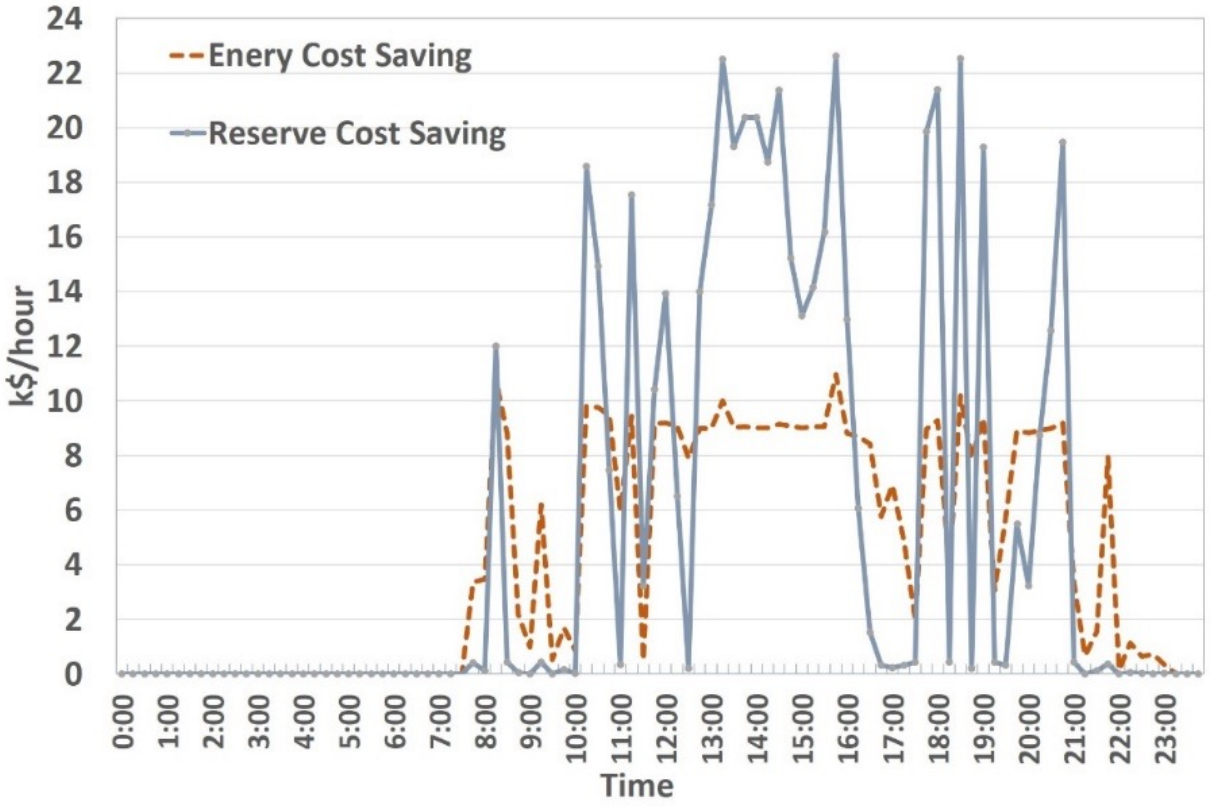
CORRELATION COEFFICIENTS BETWEEN DLR AND WEATHER MEASUREMENTS

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

KC-Exousia CONSULTING

Numerical Examples [Cont'd]

DLR/SLR (Static Line Ratings) Scarcity Cost Comparison and Energy and Ancillary Services Cost Savings



Time	DLR Total Scarcity Cost ($)	SLR Total Scarcity Cost ($)	Energy Cost Saving ($)	Ancillary Service Cost Saving ($)
0:00	0	0	0	0
1:00	0	0	0	0
2:00	0	0	0	0
3:00	0	0	0	0
4:00	0	0	0	0
5:00	0	0	10	-8
6:00	0	0	0	0
7:00	0	0	867	98
8:00	1560	1560	3613	142
9:00	6908	6908	2345	163
10:00	6908	47220	7481	10257
11:00	6908	37796	6273	7887
12:00	6908	27144	6535	5167
13:00	6908	6908	155	0
14:00	6908	22076	4661	3861
15:00	6908	72872	9532	16521
16:00	6908	6908	2429	87
17:00	6908	6908	2012	354
18:00	6908	50924	7796	11148
19:00	6908	31556	6767	6383
20:00	6908	50540	8984	10998
21:00	6908	6908	3384	234
22:00	6336	6336	666	16
23:00	0	0	749	14

KC-Exousia CONSULTING

Outline

- Introduction
- FERC Order 881: Ambient Adjusted Ratings (AAR)
- Dynamic Line Ratings (DLR): Model and Calculations
- Applications of DLR/ARR: Design and Implementation
- Conclusions

Conclusions

- Some basic requirements of FERC Order 881 are reviewed
- A weather-based method to calculate the AAR using a deterministic approach is discussed
- A key application of Limit Exchange Portal and its APIs is discussed
- DLR/AAR is incorporated into the business processes of market operations
- Simulation results illustrated that tremendous savings could be achieved by better utilization of actual transmission capacity without compromising any system reliability
- More advanced measurement equipment and AI/ML analytics for DLR/ARR forecasting could further maximize realized capacity and enhance market efficiency
- Incorporating DLR/AAR with a probabilistic model in the day-ahead market would be an interesting future topic of R&D