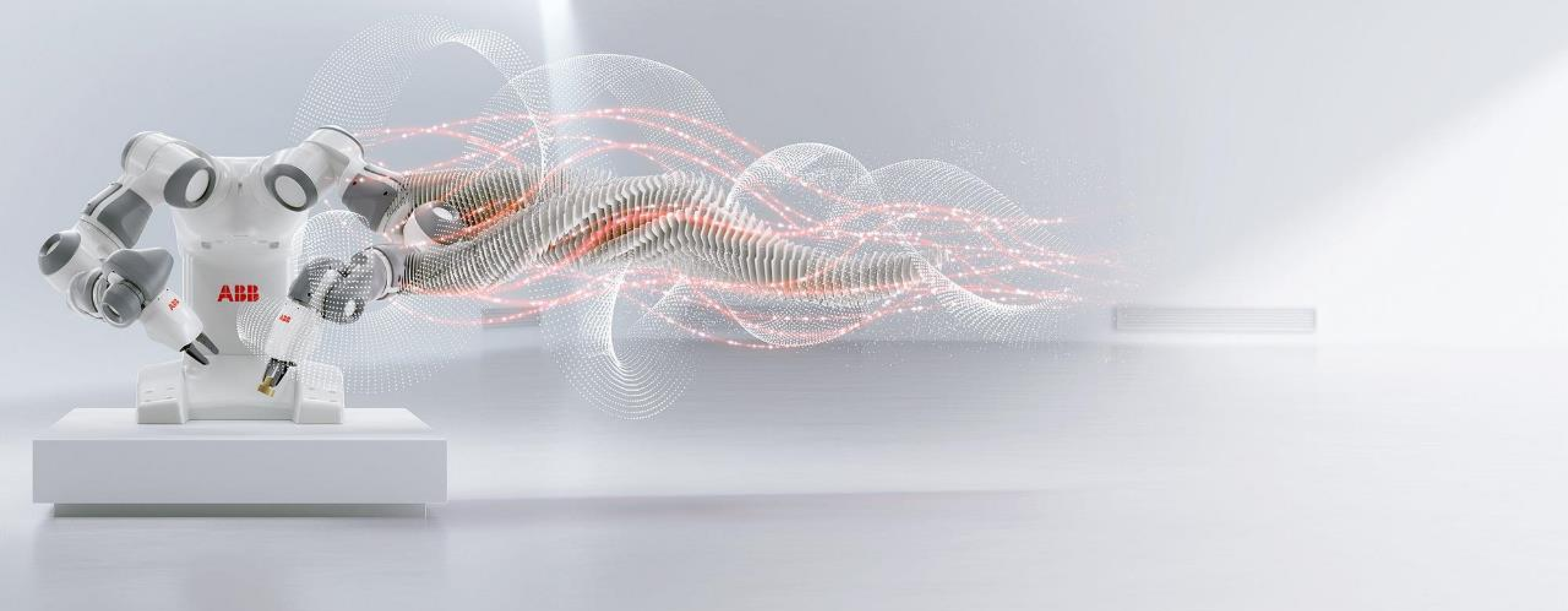


2018 FORECASTING WORKSHOP – ST PAUL, MN - JUNE 20, 2018

Panel: Integration of Probabilistic Forecasts into the EMS and MMS – Status and Prospects

A Market Management System (MMS) Perspective

Khosrow Moslehi

ABB

Outline

- Introduction
- Challenges resulting from stochasticity of load and generation resources
- Addressing challenges presented by resource stochasticity
- Forward

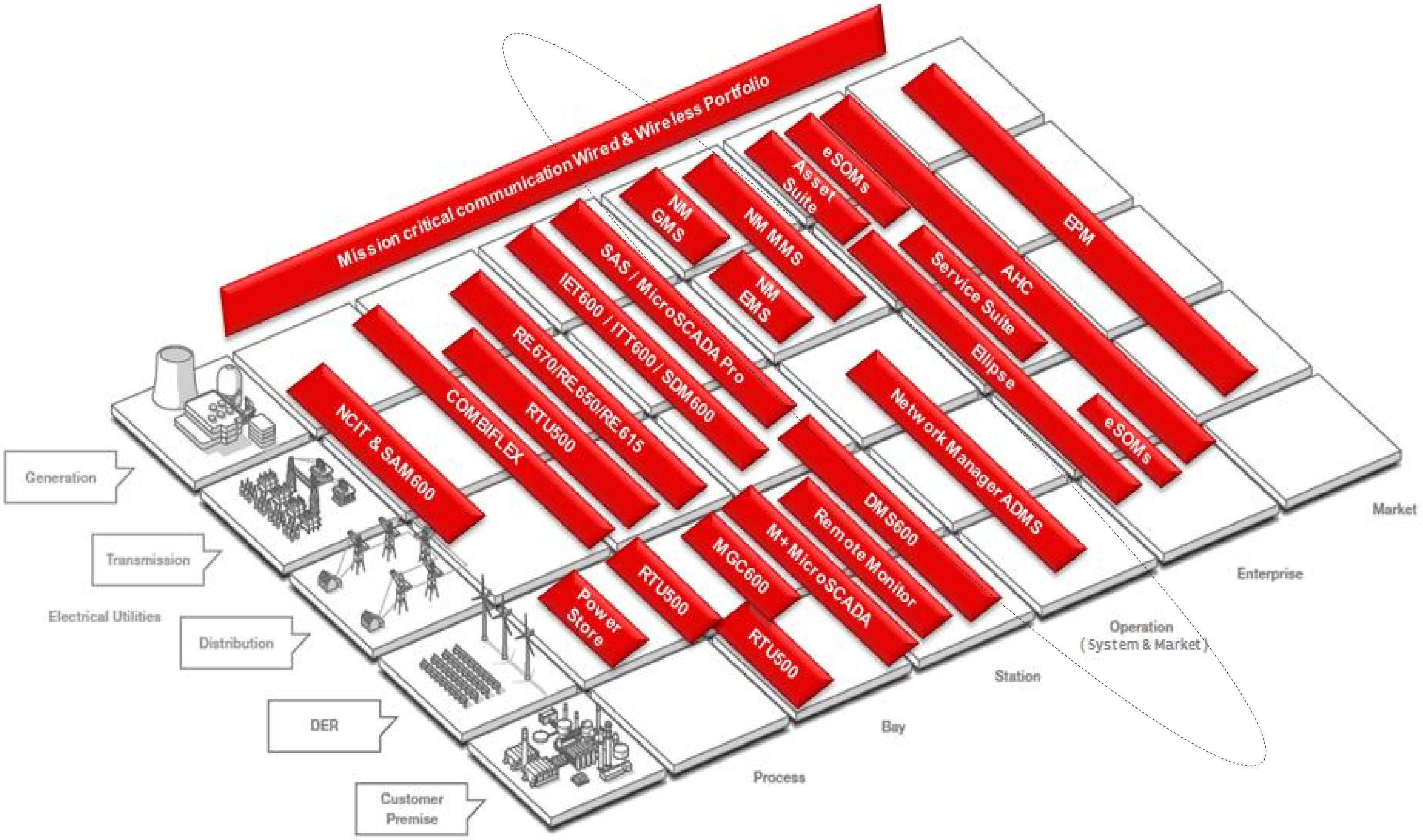
ABB Grid Automation

End to end offering

Energizing the digital grid

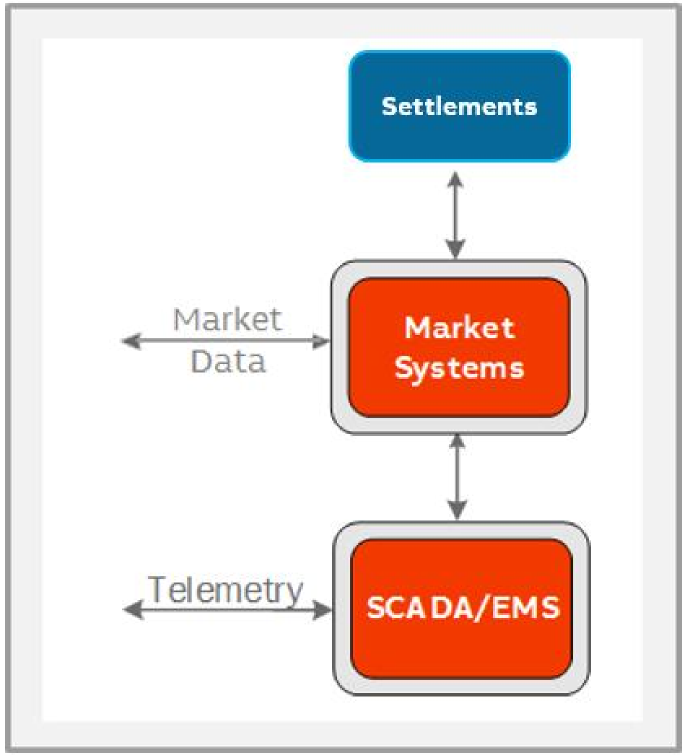
– ABB Grid Automation has the most complete digital portfolio in the industry. Offering end-to-end solutions from primary sensors to Station Level (OT) through to Enterprise Asset Health Center (IT).

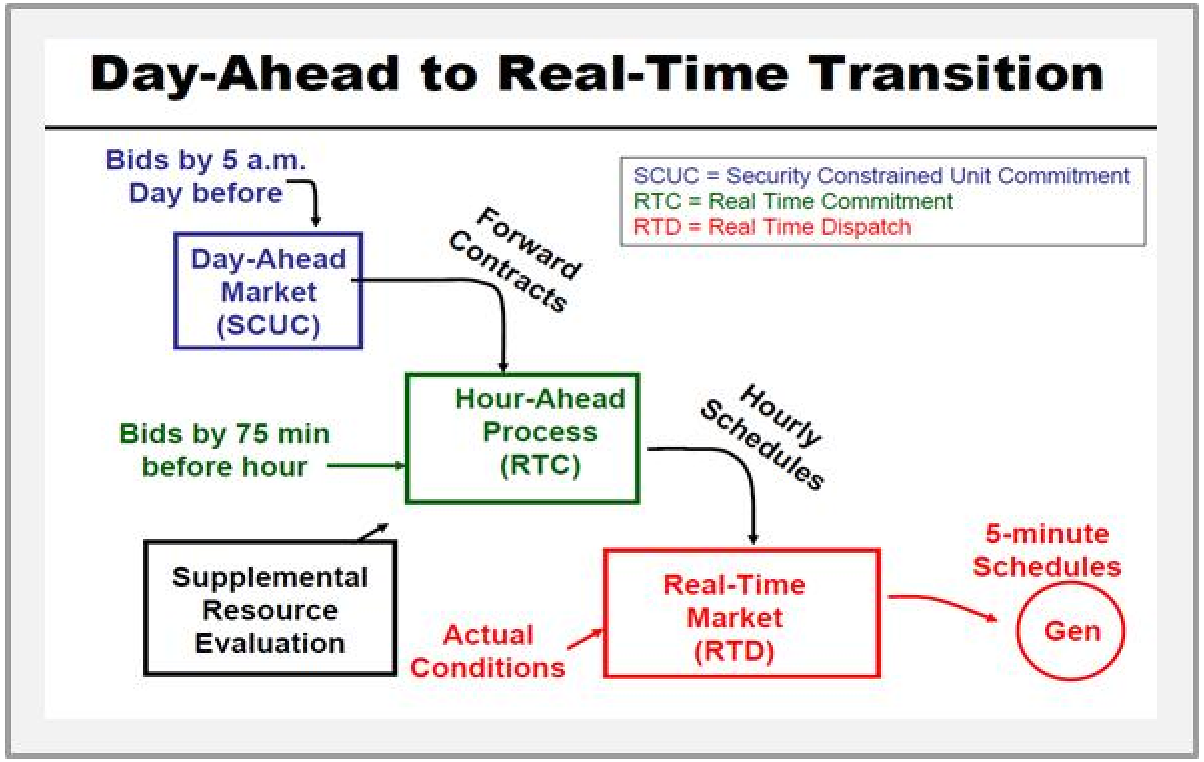
– Combining our products with our exceptional expertise makes us unique for our customers on their journey to the digital grid



NYISO EMS-MMS

Over two decades of partnership





NEW YORK INDEPENDENT SYSTEM OPERATOR | ieso Power to Ontario. On Demand. | EIRGRID | ercot | nationalgrid | Wholesale Electricity Spot Market | KPX | imo Independent Market Operator | PSE Polskie Sieci Elektroenergetyczne

Challenges Presented by Ever Increasing Integration of Renewables

Higher levels of stochasticity in power system & market operations

§ Increasing load and generation uncertainty

§ Generation variability

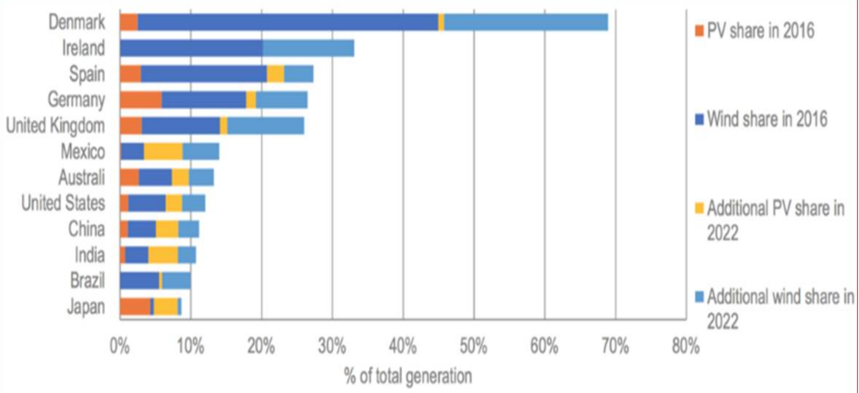
§ Non-alignment of generation and load

§ More stressed transmission

- Higher and more volatile/variable flows
- Voltage problems
- Congestion

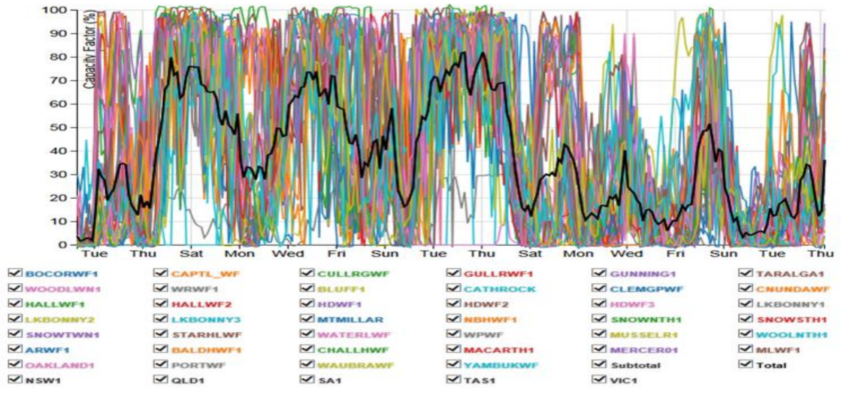
§ Others

- Larger number of resources
- Lower system inertia



Source: IEA

SE Australia Wind Energy Production During August 2017 (source: Aneroid Energy)



Addressing Resource Stochasticity Challenges

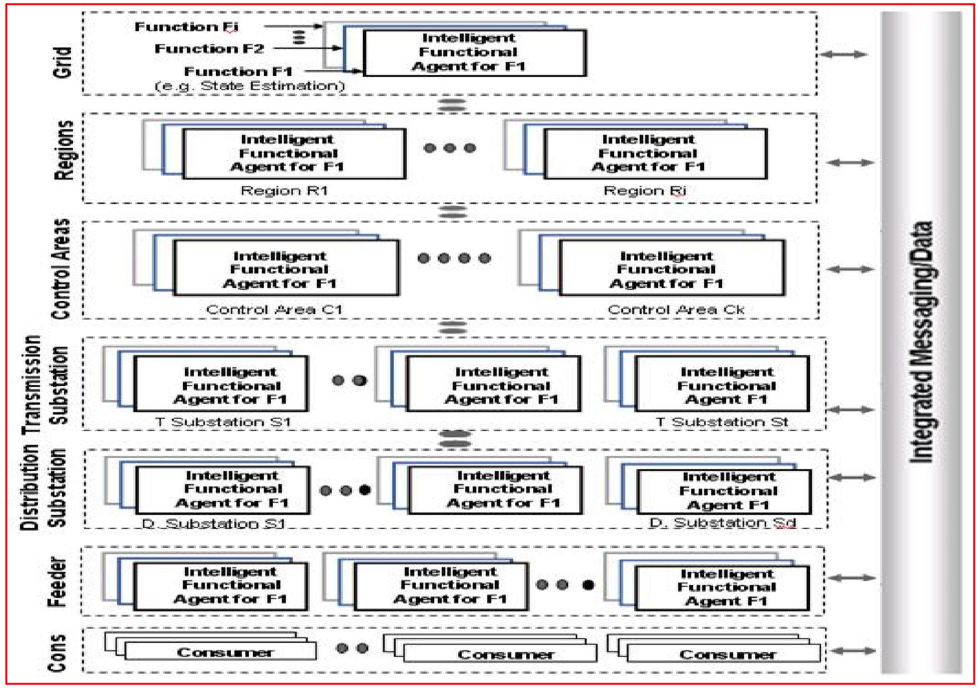
Multi-faceted approach

- Better forecasting (DX and TX)
- Better scheduling, monitoring and control
  - Look-ahead capability & shorter scheduling time intervals
  - Stochastic?
- Grid flexibility
  - Generation flexibility and ramping capability
  - Flexible demand
  - Energy storage
  - Reserves
  - Optimal utilization of the transmission assets

Better Forecasting

Very short-term, Short-term,...

- Demand, wind, solar, etc.
- Forecasting methods
  - Similar day
  - Adaptive
  - Neural-Networks based
  - etc.
- Distributed forecasting / bottom-up
  - Utility scale
  - Substation / plant / farm
  - Feeder / meter level
  - etc.



1. *"Distributed Autonomous Real-Time System for Power System Operations - A Conceptual Overview," K. Moslehi, et al – IEEE PSCE2004-000684 – Oct 2004*
2. *"A Reliability Perspective of the Smart Grid ," K. Moslehi & R. Kumar – IEEE Transactions on Smart Grid, Vol. 1, No. 1, Jun 2010*

Look-Ahead Capability

Multi-interval optimization

§ Market scheduling & dispatch

- Day Ahead
- Intra-Day
- Real-Time

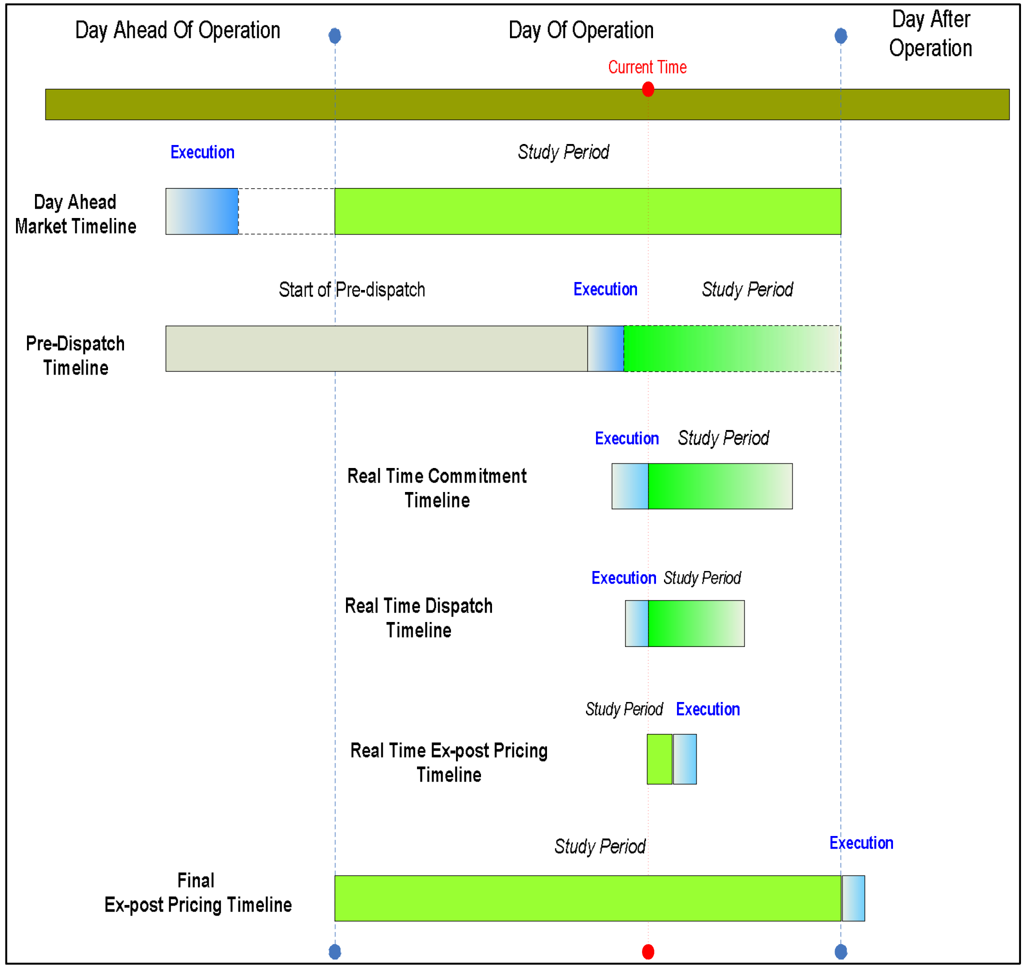
§ Co-optimization of energy, ancillary services, etc.

§ All market designs

- Central Dispatch or Balancing Market

§ Reliability Scheduling

- Multi-day, multi-week, etc.



Generation Flexibility

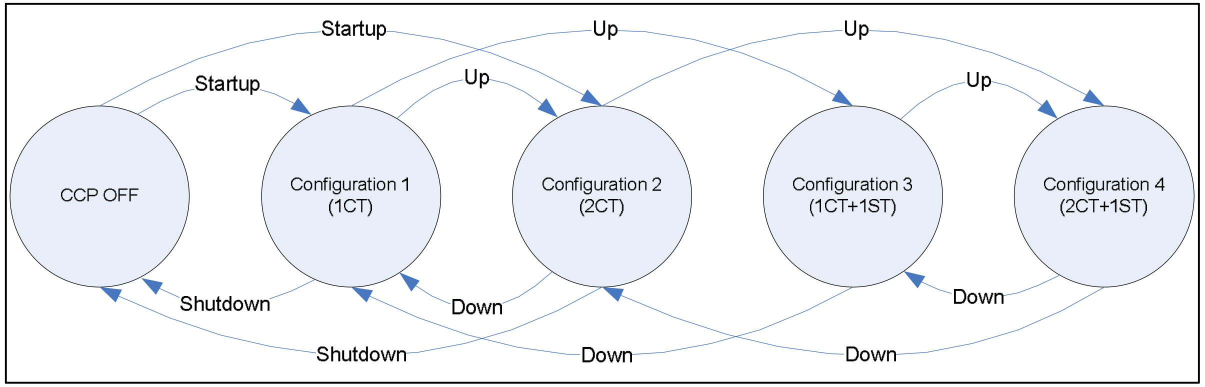
Combined Cycle Plants and Fast Start Units

§ Combined Cycle Plants (CCP)

- Model all plant configurations
- Cost Curves, Min / Max MW Limits, Up / Down Times, Reserve, Ramp Rates, etc.
- Optimal configuration is determined by MMS

§ Fast Start Units

- Gas Turbines, etc.



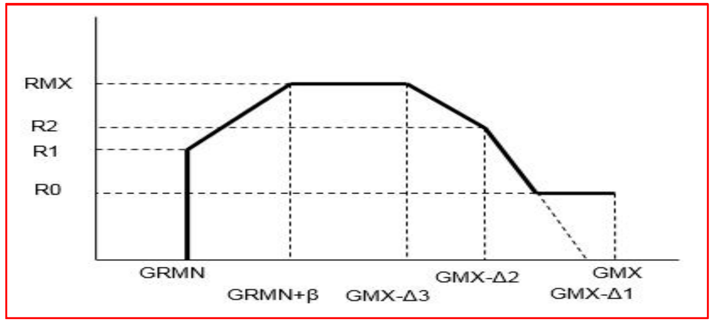
Reserves and Generation Ramping

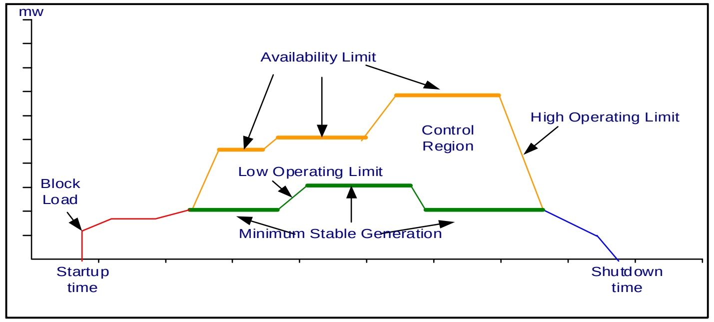
§ Reserves

- Operating, spinning, regulation, fast, inertia response, etc.
- Complex reserve models
  - MW dependent reserve capability
  - Non-convex reserve-generation curve
- Reserve constraints

§ Ramping

- MW change rate a function of generation level
- Start-up and shut down characteristics
- Forbidden regions





Energy Storage Resources (ESR)

Flexible resources

- Limited Energy Storage Resources (LESR)
  - Batteries
  - Flywheels

  Fast response, low energy capacity, ideal for AS/regulation
- Large Storage Resources
  - Pumped Storages
  - Batteries
  - Hydro plants
- Various energy limits for individual/group of resources

ESR Parameter	Unit	Description
Upper Storage Limit	MWh	Maximum energy the Asset is willing to store.
Lower Storage Limit	MWh	Minimum energy the Asset is willing to store.
Minimum Load	MW	Minimum MWs the unit can withdraw.
Maximum Load	MW	Maximum MWs the unit can withdraw.
Minimum Withdrawing Time	Hours	Minimum time the Asset can withdraw energy. Taken as a consecutive interval.
Maximum Withdrawing Time	Hours	Maximum time the Asset can withdraw energy. Taken over an entire operating day.
Maximum Run Time	Hours	Maximum time Asset can inject energy. Taken over an entire operating day.
Transition Time	Hours	Minimum time required to switch between injecting and withdrawing states.
Start Up Load Cost (Start Down Cost)	$	Amount of money needed to begin withdrawing energy from an offline state. Can be submitted as an incremental cost curve.
Minimum Load Cost	$	How much it costs to remain at minimum load rate. Is an hourly rate.
Additional Response Rate(s)	MW/min	How quickly the Asset can respond to NYISO-given signals under specific conditions. The need for new response rates is still being evaluated.
Withdrawing Conversion Losses	%	Used to determine the round trip efficiency and monitor the Energy Level of the resource when it is withdrawing energy.
Injecting Conversion Losses	%	Used to determine the round trip efficiency and monitor the Energy Level of the resource when it is injecting energy.
Throughput	MWh/day	How much energy the Asset is willing to inject on a daily basis.
Energy Level/State of Charge Flag	Yes/No	Does the Asset want to exchange an energy level signal with the NYISO? If yes, the NYISO will honor its Upper and Lower Storage Limits. The FERC calls energy level "State of Charge" (SoC).
Beginning Energy Level	MWh	Initial SoC expected for beginning of the day. Parameter for use in the DAM optimization only.
Storage Target Level	*MWh*	*Ending storage target level for scheduling period the scheduling period*
Multiple Units @ the same Storage		

Energy Storage Integration: Market Design Concept Proposal – Dec 2017 - NYISO

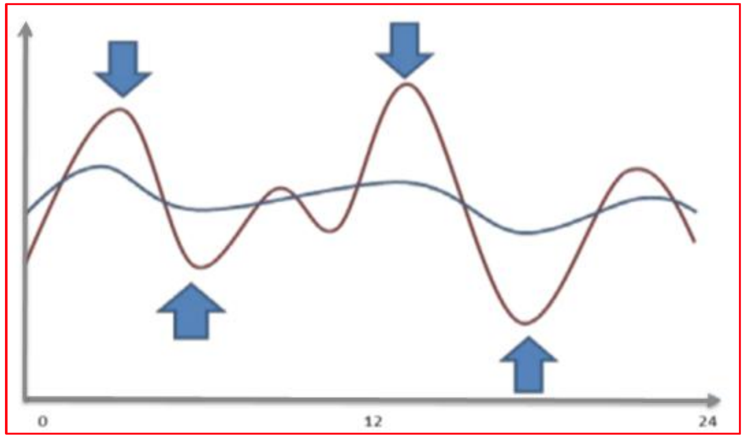
Flexible Demand & Renewables

§ Demand

- Responsive Demand / Dispatchable Loads
- Interruptible Load
- Demand Side Unit

§ Renewables:

- Can bid into the market
- Can be modeled as price takers
- Can be treated as dispatchable units



Optimal Utilization of Transmission Resources

Enabling higher levels of scheduling flexibility

- Network modeling and analysis
- Phase Angle Regulators (PAR) and HVDC modeling
- Contingency modeling
  - All single and selected multiple contingencies
    - *RES-based contingencies*
  - Protection schemes and remedial actions
- Post Contingency Correctives
  - Higher levels of transmission efficiency

Market Coordination and Integration

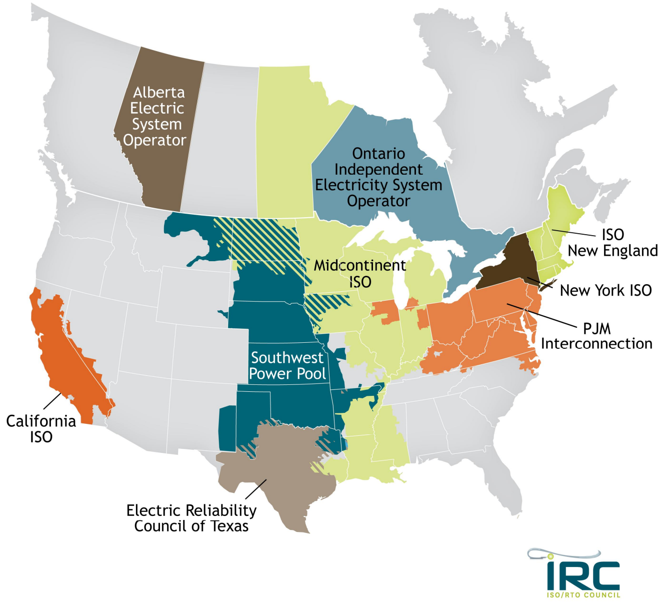
Coordinated exchanges to securely & economically address congestion and variability

North America

- § Congestion Coordination
  - Market to Market Coordination to re-dispatch to solve congestion at a lower cost
- § Coordinated Transactions
  - 15-min frequency
  - 5-min frequency?
- § Regional Balancing

Europe

- § Interchange coordination and single energy market
- § Frequency restoration and balancing coordination (in progress)

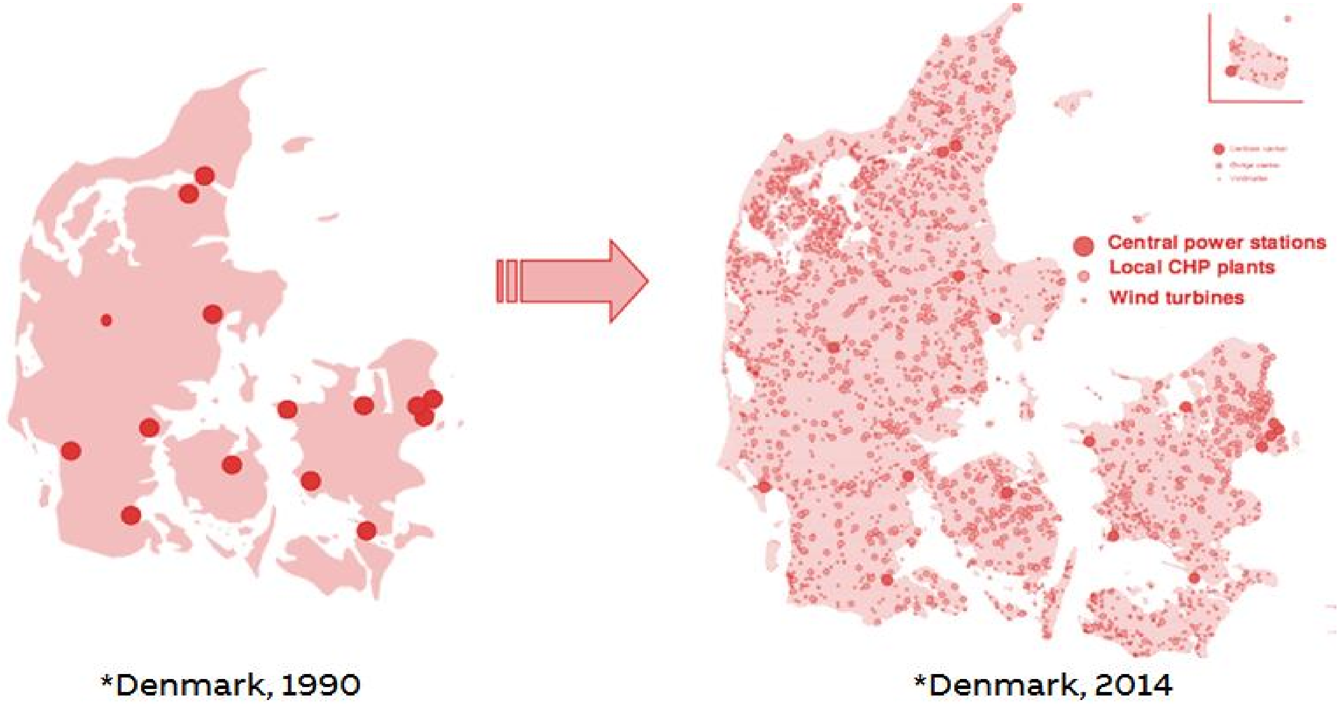


Larger number of resources and more variability and uncertainty

Higher modeling complexities

§ Higher solution performance - scheduling / optimization

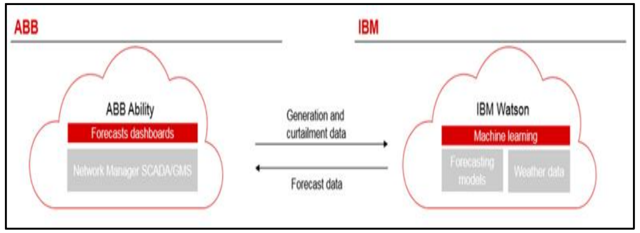
- MIP – problem formulation, etc.
- Hybrid algorithms and methodologies



Summary

Addressing resource variability and uncertainty

- Ever increasing challenges: modeling, optimization and forecasting
- ABB MMS solutions provide a wide range of deterministic solution capabilities across different market implementations
- On-going and forward focus
  - Higher solution performance as the problem size and modeling complexity increases
  - Better forecasting
- Stochastic optimization?
  - Longer term R&D projects – Example: “Hybrid Markovian and Interval Unit Commitment”



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