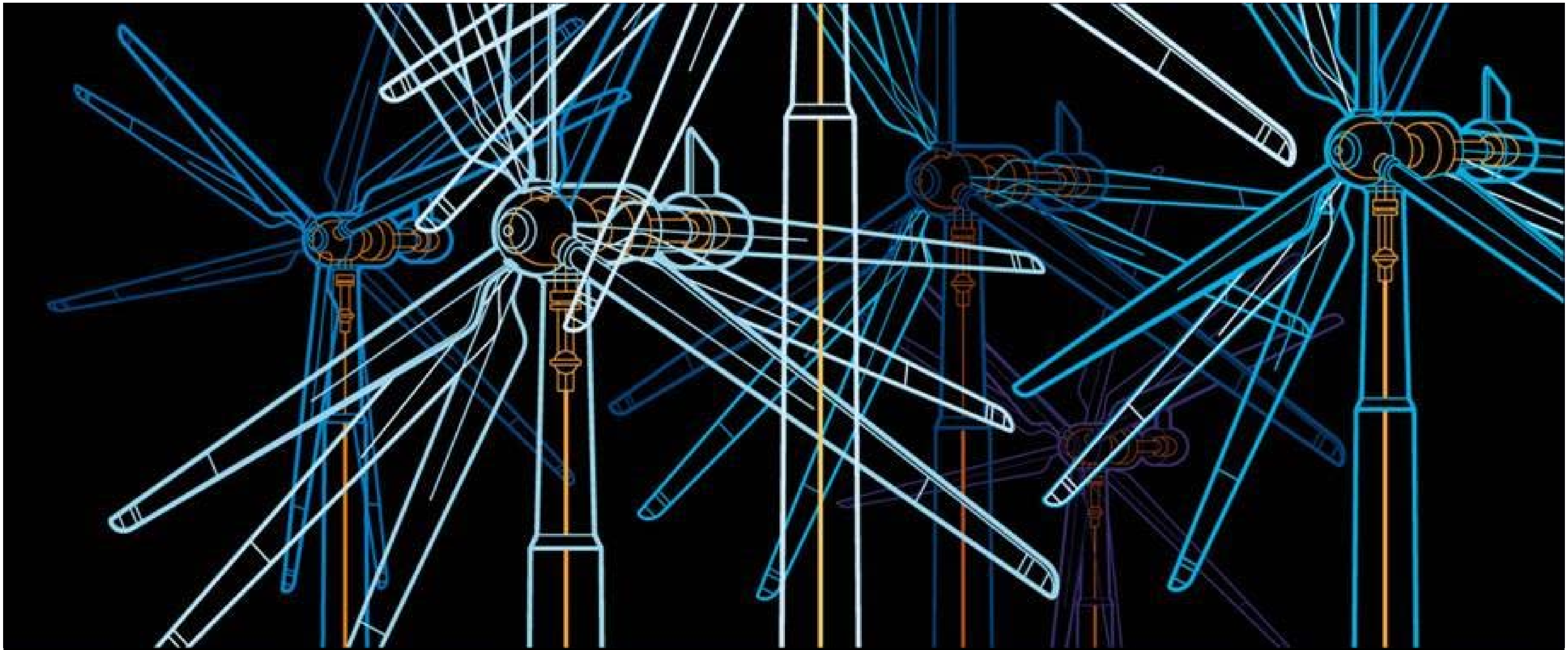

Transformation of the Electric Grid - A Network Efficiency Perspective

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International Workshop on Electric Power Control Centers (EPCC)
Bled, Slovenia
May 18-20, 2015

Outline

- Transformation of the grid
- Increasing need for optimal utilization of the grid
- Better determination of the network limits
- Capability to optimally and securely schedule the grid to its limit

Transformation of the Grid
1990’s to Present

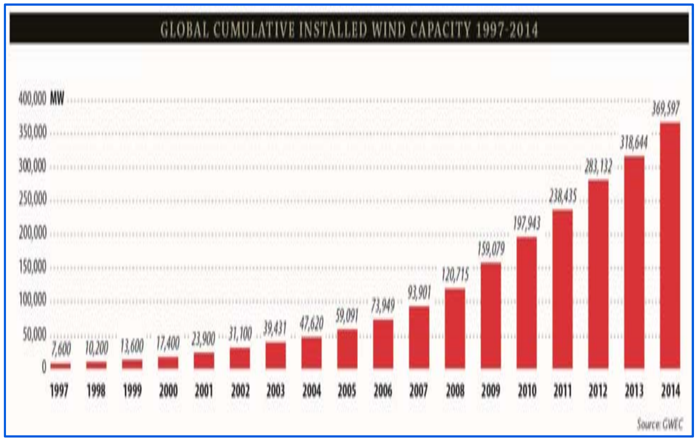
- Restructuring – 1990’s
  - Unbundling of vertically integrated utilities
- Utility Landscape – 2000’s
  - Proliferation of “smart grid” resources
- Business Model – 2010’s
  - Ever increasing distributed energy resources and digitization

Transformation of the Grid
Restructuring

- Options
  - Regulatory reform
    - Performance-based vs. cost-based
    - Open transmission
  - Unbundling of integrated utilities
    - Market-based generation and retail
    - Regulated wires
- Converging market designs
  - Balanced Schedule
  - Central Dispatch

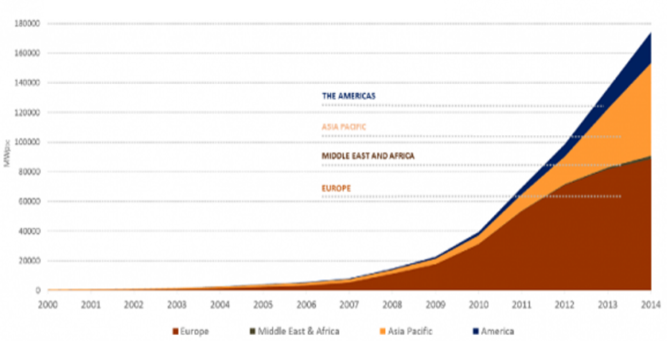
Transformation of the Grid
Utility Landscape

- Smart Grid Resources
  - Renewable energy (wind, etc.)
  - Demand response
  - Storage
- Driving Forces
  - Regulatory actions and legislation
  - Emissions reduction
  - Efficiency targets



Transformation of the Grid
Business Model

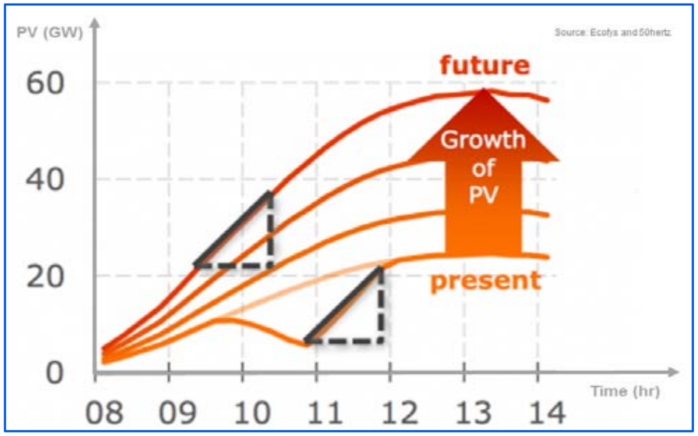
- Deeper and wider deployment of “distributed” resources
  - On-site power supplies and storage
  - Active demand
  - Microgrids
- “Distribution System Platform Providers”
  - “…Independent Distribution System Operator (IDSO)…”
  - “Transactive Energy”
- Grid issues
  - Two-way grid
  - Intermittency
  - Voltage problems
  - Congestion



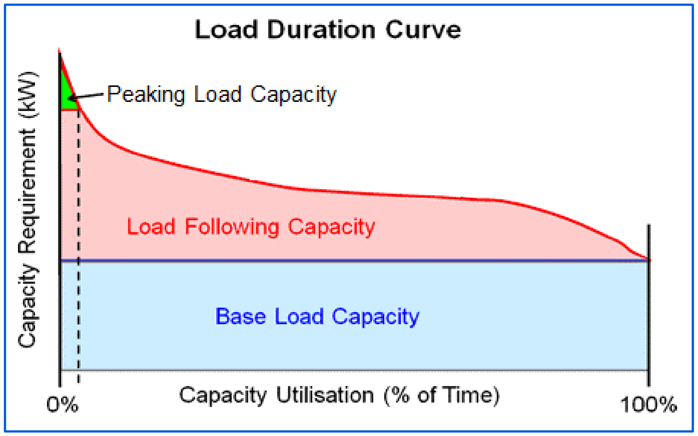
Evolution of Regional PV Installations (MW) – Source IEA

Increasing Renewables
Larger Balancing Needs and More Congestion

- During sunrises in 2030, the scale of Germany's solar installations could drive an increase in power supply as steep as the rebound phase of 2015's eclipse

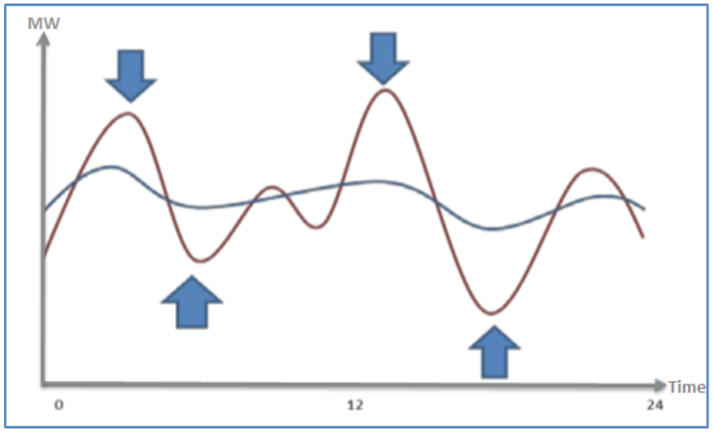


- Demand Response (DR), Virtual Power Plants, Storage and other smart grid solutions can be utilized to reduce the peaking load

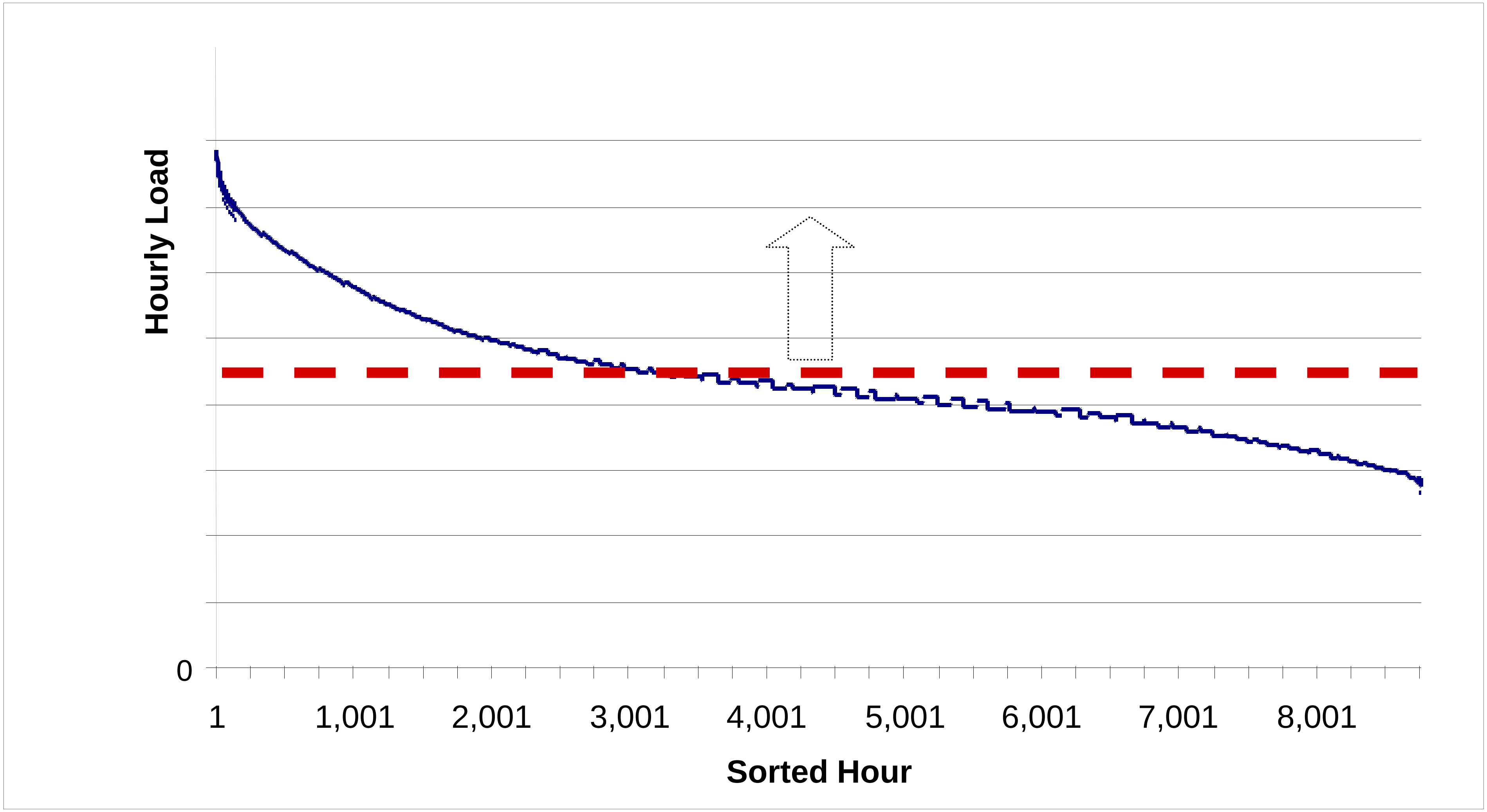


Proliferation of Demand Response, Storage, etc.
Observation

- Ideally, various smart grid resources can be coordinated to lower peak and nearly flatten the load profile
- Initially, the lower peak and the flattened profile help to improve congestion
- Eventually, the grid is pushed to its limits most of the time!

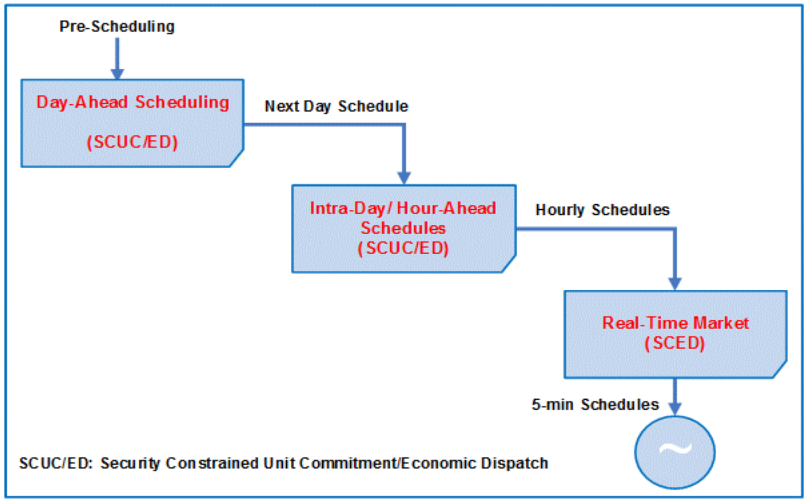


Proliferation of Demand Response, Storage, etc.
Congestion May Even Get Worse!



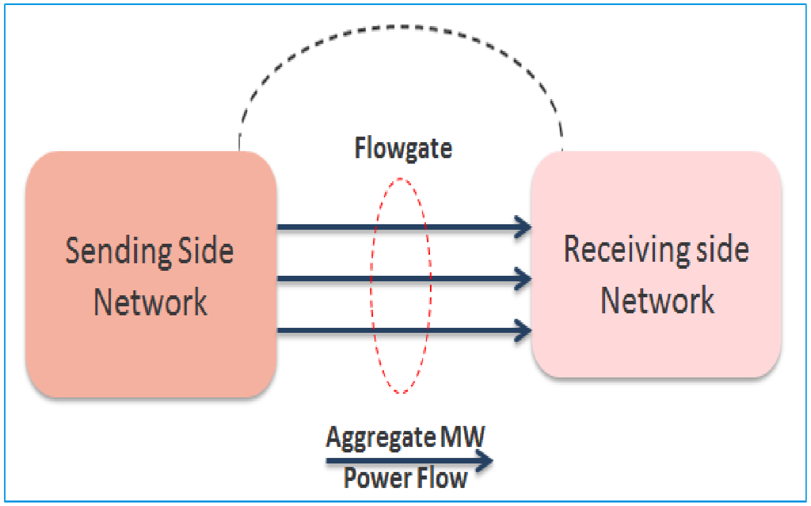
Optimal Utilization of Transmission Resources
Integrated Scheduling and Congestion Management

- Scheduling Timeline
  - Day-Ahead
  - Intra-Day/Look-Ahead
  - Real-Time/Balancing
- Security Constrained Optimization
  - Typical security limits include:
    - Line limits
    - Corridor/flow-gate limits
- Network limit types
  - Thermal, stability, etc.
- Operational challenge
  - What are the limits?
  - How close to the limit?



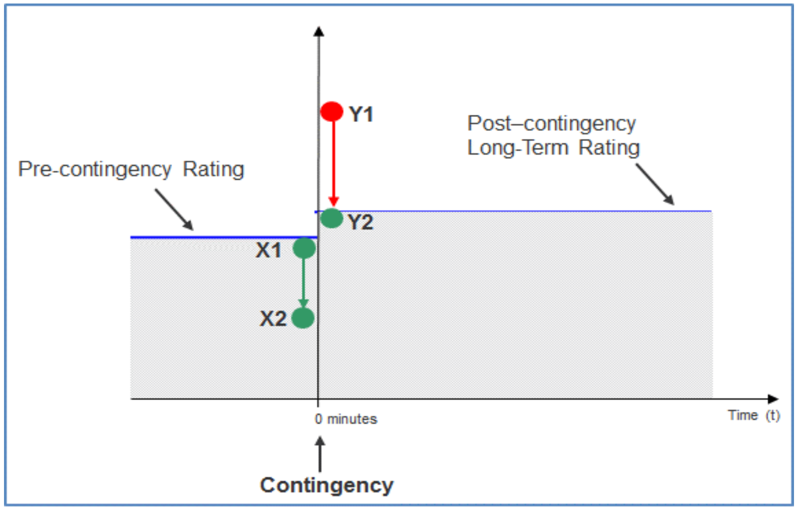
What are the Limits?
Improved Voltage Stability Limits

- On-line voltage stability monitoring to enable efficient utilization of transmission capacity to improve economic efficiency while maintaining reliability
- Real-time update of transfer capability (PV-curves) for each corridor by identifying low voltage limits
- Multi-port Thevenin equivalents
- State-estimation /PMU data
  - Real-time/near real time
  - With contingency - minutes
  - No contingency - seconds



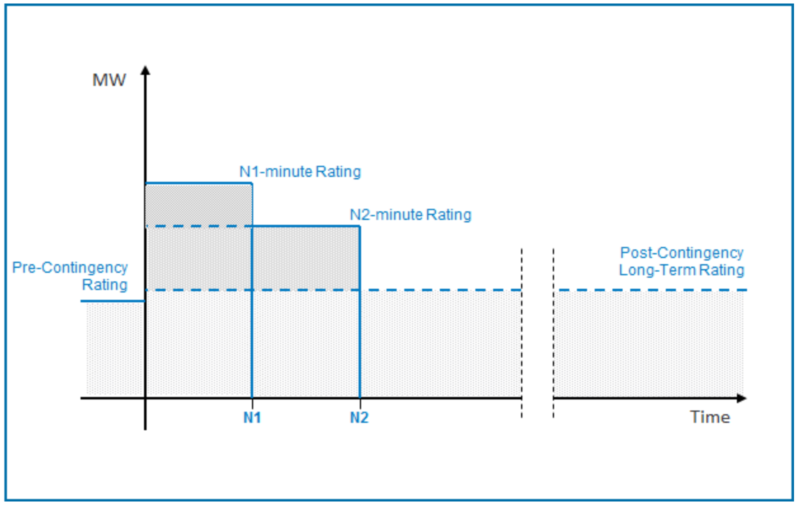
How Close to the Limits?
Conventional Security Constrained Scheduling - Preventive

- Determines optimal schedule subject to satisfying thermal security criteria including:
  - Pre-contingency transmission thermal ratings
  - Post-contingency long-term transmission ratings
- Preventive actions
  - MW output from generation/demand resources:
    - Generators
    - Demand resources
    - Interconnectors
  - Phase shifter flows and tap settings
  - HVDC link flows



How Conservative are the Limits?
Short-Term vs. Long-Term Post-Contingency Ratings

- Post-fault ratings give time for actions to be taken after a fault/contingency
- Ratings decrease with time, reflecting heating
  - Shorter term ratings are higher but with less time to take actions
  - Longer term ratings are lower but with more time to take actions

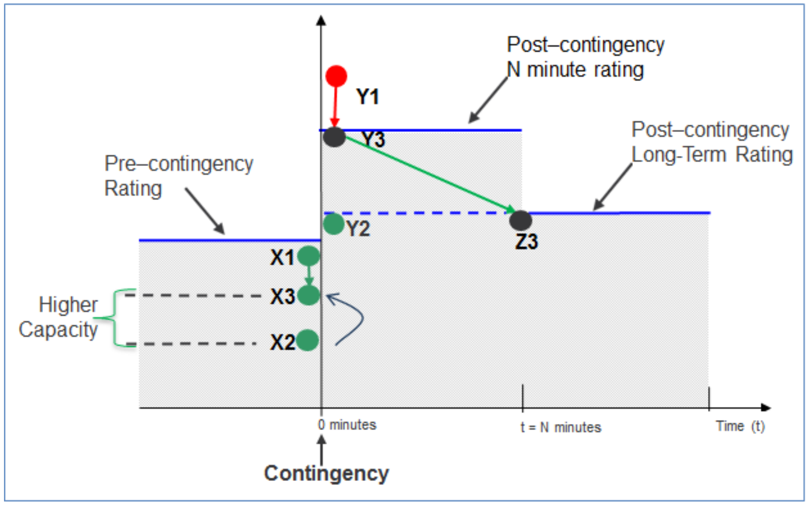


Security Constrained Scheduling - Preventive/Corrective
Optimal Transmission Utilization

- Secure each contingency using all available post fault correctives, only use pre-fault preventative actions when post fault actions are insufficient

- **X3** = flow immediately before contingency
- **Y3** = flow immediately after contingency
- **Z3** = flow N minutes after contingency
  . with corrective action

X3 -----▸ Y3 -----▸ Z3



Security Constrained Scheduling - Preventive/Corrective
Pre-defined Corrective Actions

- Pre-defined Corrective Actions (Physical Model)
  - Special Protection Scheme (SPS) / Remedial Action Plan (RAP)
  - Executed automatically when triggering conditions are met or manually
- SPS/RAP can change:
  - Generating unit status, MW output
  - Load status, MW output
  - Phase shifter status, Tap position, MW flow
  - Internal HVDC link status, MW flow
  - Interconnector status, MW flow
  - Switch status
  - A network element's status (e.g., a line going from in service to out of service)

Security Constrained Scheduling - Preventive/Corrective
Auto Corrective Actions

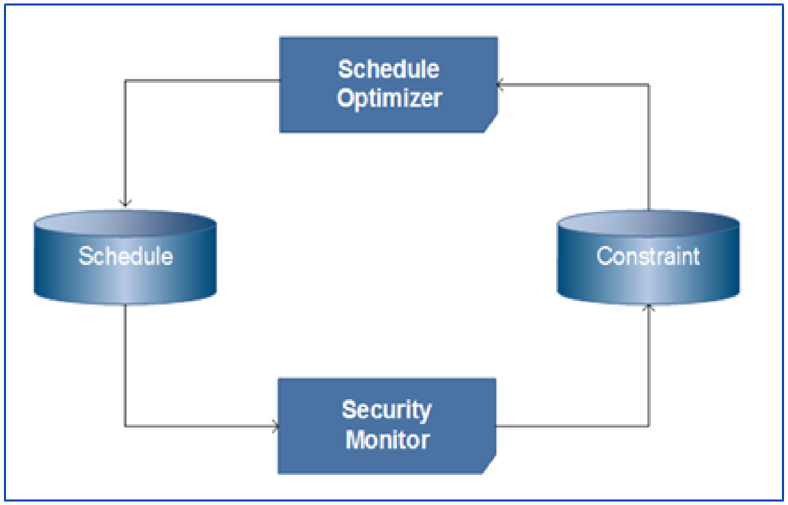
- Automatic identification of additional post-fault actions that:
  - Can be manually instructed and executed within N-minutes of the occurrence of a fault and
  - Meets a variety of other criteria designed to ensure safe operation of the transmission network.
- Auto Corrective Actions (Market/Economic Model)
  - Change of a generator’s MW output
  - Change of a demand resource’s MW output
  - Change of an interconnector’s MW flow
  - Change of a phase shifter’s tap position / MW flow
  - Change of an internal HVDC link’s MW flow

Security Constrained Scheduling - Preventive/Corrective
Pre-defined and Auto Corrective Actions

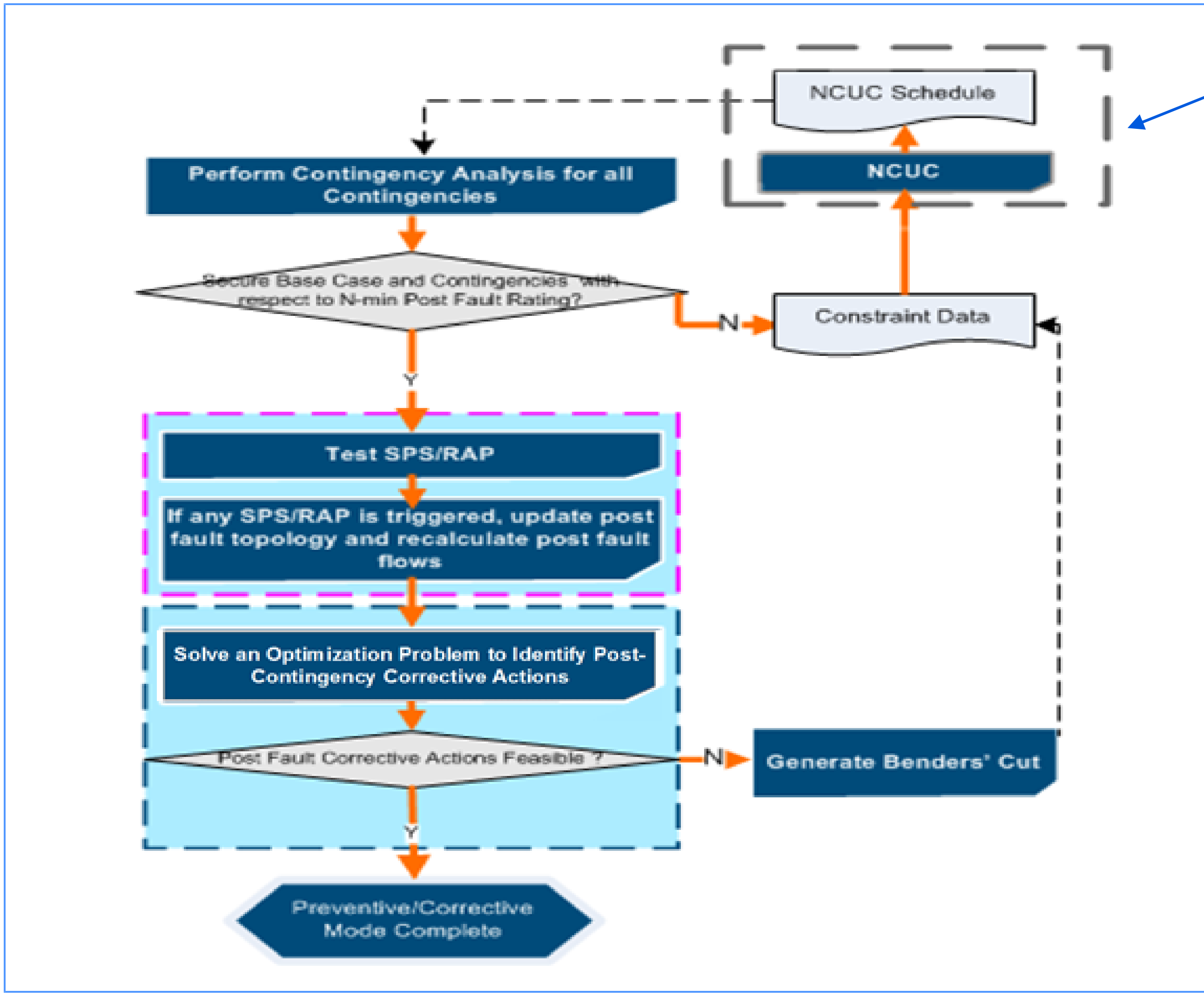
- Two stages
  - Preventive scheduling to comply with N-minute post-contingency rating
  - Corrective scheduling to comply with post-contingency continuous rating by accessing available pre-defined and auto corrective actions within N-minute interval
- Benefit:
  - Achieve the same level of transmission security
  - Higher efficiency

Security Constrained Scheduling
Solution Engine

- Security Constrained Unit Commitment (SCUC)
  - Network Security Monitor (NSM)
    - Performs security monitor and determines limiting constraints
  - Network Constrained Unit Commitment (NCUC)
    - Solves the master problem
- Two modules iterate until the optimal solution is reached
  - Greater algorithm complexity
    - NCUC indicates correctives available to NSM
    - NSM calculate effectiveness of generators after correctives



Integrated Preventive/Corrective Scheduling
Process Flow



Schedule Optimizer

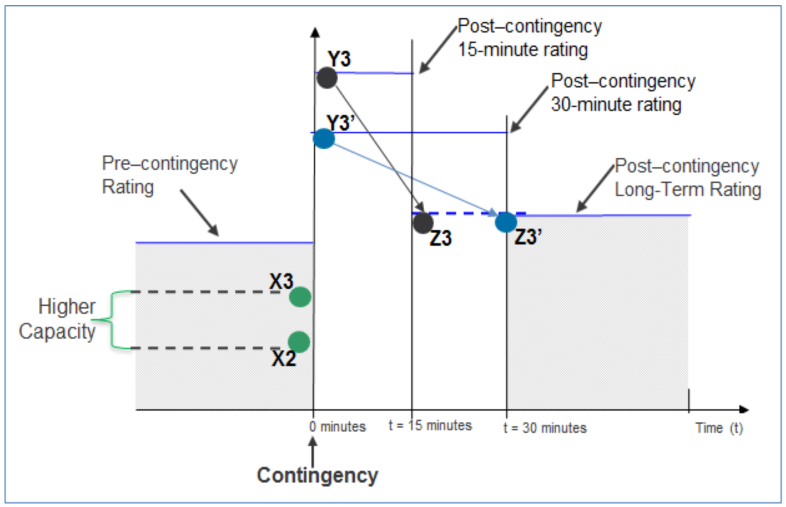
Identifying Auto Post-Contingency Corrective Actions
Optimization Problem

- Objective: Minimize (feasibility violation)
- Subject to:
  - Power balance
  - Network flow constraints (i.e. post-contingency flow less than post-fault continuous rating after corrective actions)
  - Ramp up/down limit on control
  - Control upper/lower limit
  - Limit on # of actions (upward or downward)
  - Limit on # of control actions that can be issued within N minutes per power station or control engineer

Preventive/Corrective Scheduling

Choice of N-minute Rating

- Multiple short-term ratings allowed in operation
- Typical ratings: N1=10min and N2= 30min
  - N1: higher short-term rating with smaller corrective action capability
  - N2: lower short-term rating with more corrective capability
- Corrective Action Time
  - Either synchronized with protection equipment or determined by the solution logic

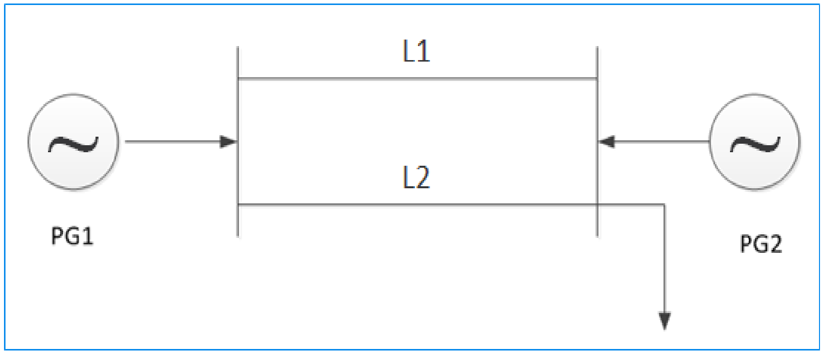


Post-Contingency Corrective Actions
Illustrative Example

Generators	Max MW	Min MW	Cost ($/MW)	15-min Ramp	30-min Ramp
PG1	200	50	1	20	40
PG2	120	0	2	10	20

Line	Pre-Contingency	15-min Post-Contingency	30-min Post-Contingency	Post-Contingency Long-Term
L1	100	180	150	120
L2	100	180	150	120

Mode	PG1	PG2	Cost
Unconstrained	200	0	**200**
Preventive	120	80	**280**
15-min Post-Contingency Corrective Active	130	70	**270**
30-min Post-Contingency Corrective Active	140	60	**260**



Summary
Transmission Efficiency Challenges and Solutions

- Grid transformation and efficiency forces accentuate ever increasing need for better grid utilization
- Need for processes and tools for
  - Better determination of the limits
  - Ability to optimally schedule and reliably operate closer to the identified limits
- Advanced tools are developed for improving secure grid utilization
  - On-line calculation of voltage stability margins using real-time data including PMU measurements (NYISO)
  - Preventive/corrective security constrained optimization (NG UK)
  - Expect major cost savings/efficiency improvement

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