Inclusion of Post-Contingency Actions in Security Constrained Scheduling

Peng Peng, Show Chang – ABB/Ventyx

Julian Dyer – National Grid, UK

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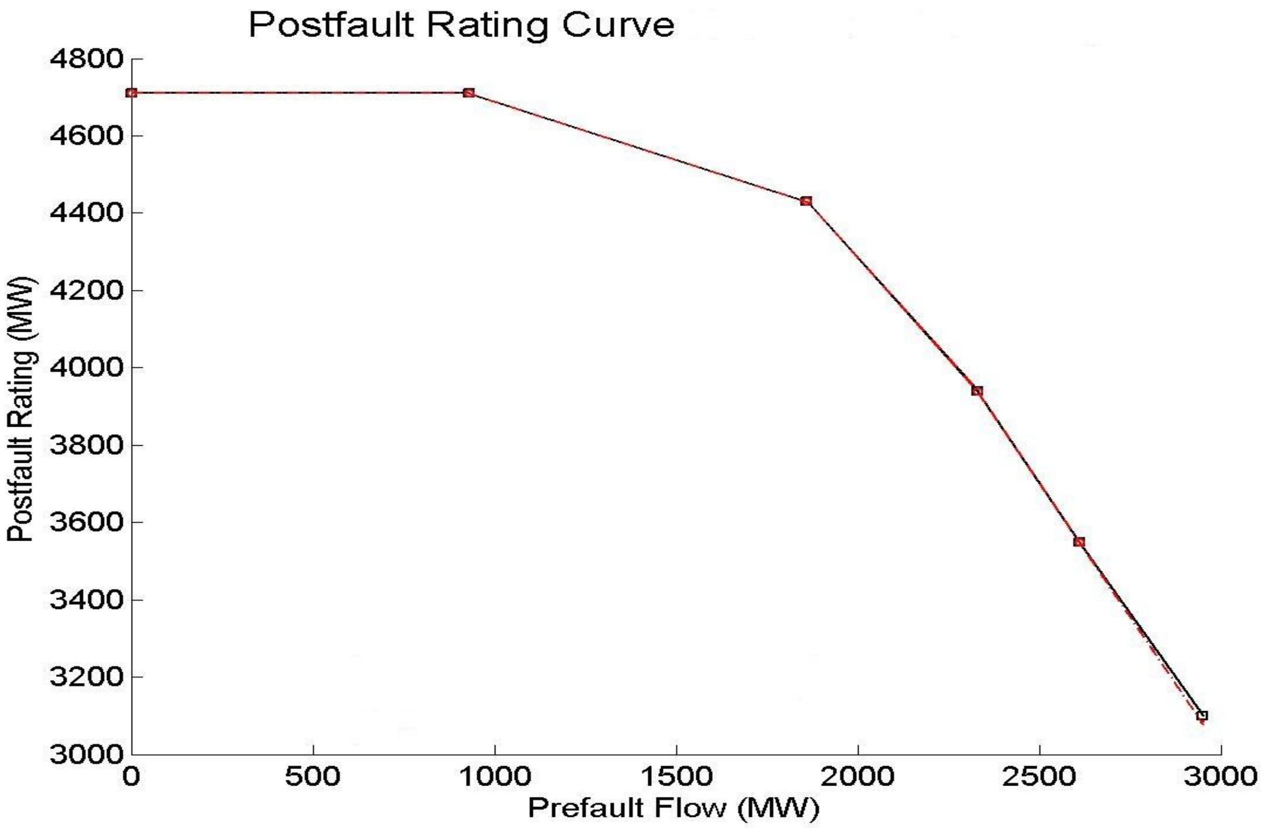
Agenda

- Thermal Security Rating in Practice
- Security Constrained Scheduling
  - Preventive Scheduling
  - Preventive/Corrective Scheduling with Post-Contingency Action
    - Pre-defined Corrective Action (SPS/RAP)
    - Automatically Identified Corrective Action
- An Integrated Process of Including Post-Contingency Corrective Action in Security Constrained Scheduling
  - Security Constrained Unit Commitment (SCUC) Engine
  - Process Flow of Preventive/Corrective Scheduling
  - Formulation of Automatic Post-Contingency Corrective Action
- Illustration of Post-Contingency Corrective Action
- Challenges

Thermal Security Rating in Practice

- Post-contingency rating is a function of pre-contingency flow



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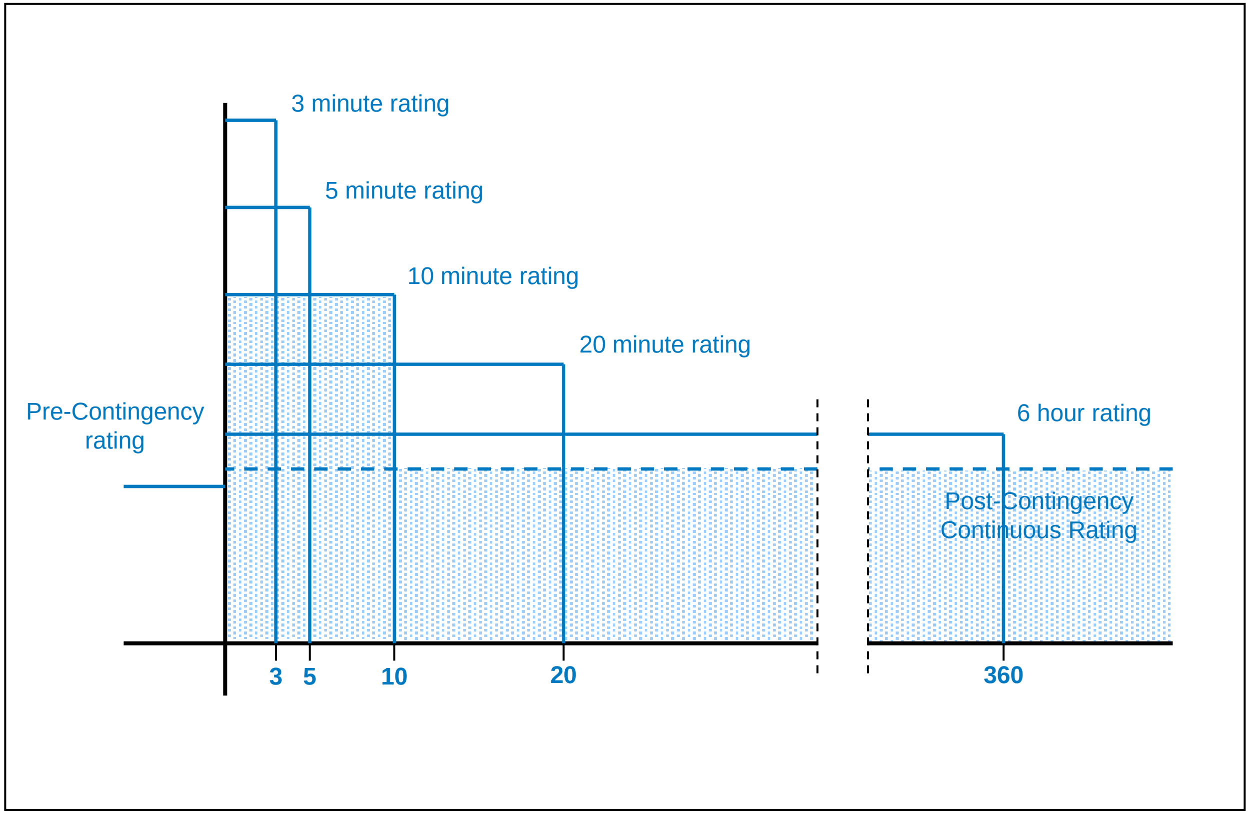
Thermal Security Rating in Practice

- Post-contingency rating is a function of time after contingency occurs

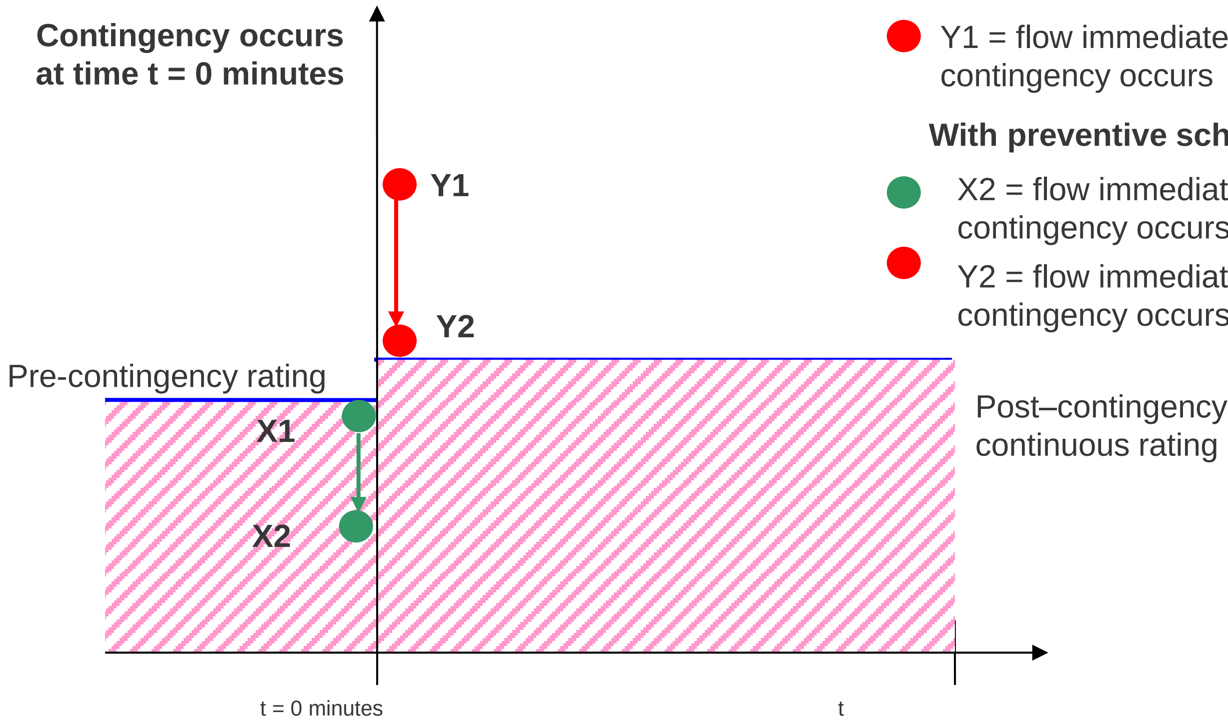


Security Constrained Scheduling – Preventive Scheduling

- Preventive scheduling determines the optimal schedules of market resources to satisfy thermal security criteria including:
  - Pre-contingency rating and
  - Post-contingency continuous rating

- Preventive Actions (Market Model):
  - MW output from market resources:
    - Generators
    - Demand resources
    - Interconnectors
  - Flow and Tap setting from Phase Shifters
  - Flow from HVDC links

Security Constrained Scheduling – Preventive Scheduling



Without preventive action:
Y1 > Post-contingency continuous rating.

- X1 = flow immediately before contingency occurs
- Y1 = flow immediately after contingency occurs

With preventive scheduling

- X2 = flow immediately before contingency occurs
- Y2 = flow immediately after contingency occurs

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

- Pre-defined Corrective Actions (Physical Model):
  - Special Protection Scheme (SPS)/Remedial Action Plan (RAP): Executed automatically by inter-trip schemes when triggering conditions are met or manually by control room staff
  - Actions are on physical devices

- An SPS/RAP can change:
  - a physical generating unit's status / MW output
  - a physical load's status / MW output
  - an interconnector's status / MW flow
  - a phase shifter's status / Tap position / MW flow
  - an internal HVDC link's status / MW flow
  - a switch's status
  - any network element's status (e.g., a line going from in service to out of service)

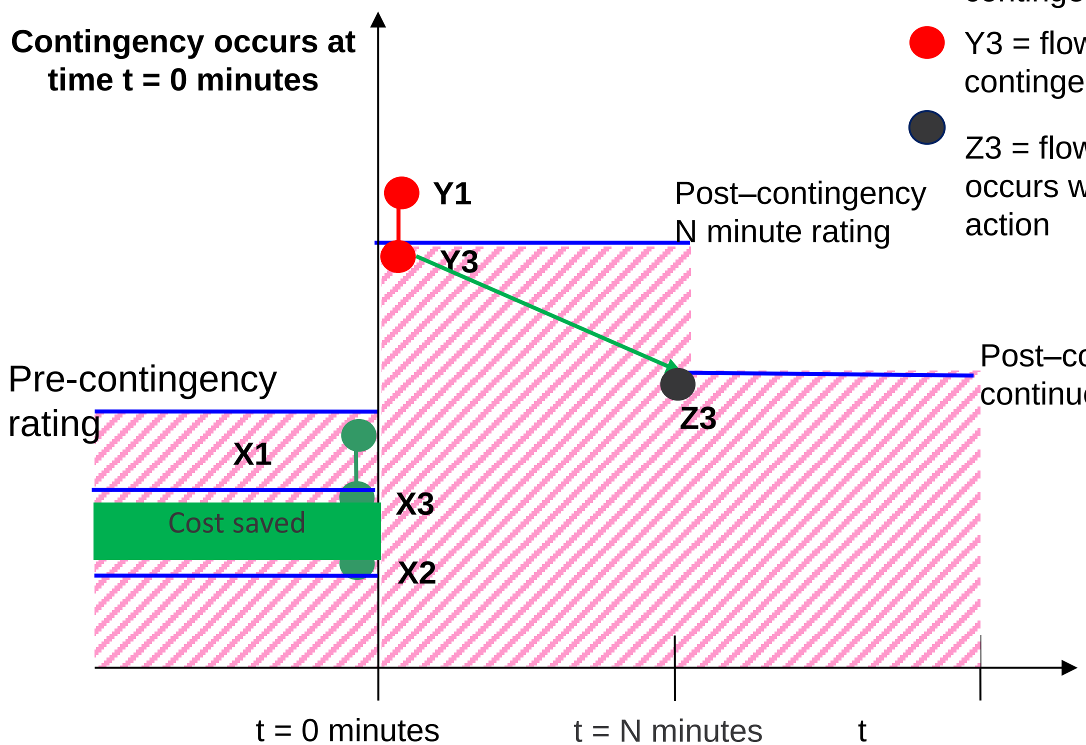
Security Constrained Scheduling – Preventive/Corrective Scheduling with Auto Corrective Actions

- 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
- Benefit:
  - Achieve the same level of transmission security
  - High market efficiency / more economic benefits
- Auto Corrective actions from (market 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 Scheduling with Auto Post-Contingency Corrective Actions

With preventive/corrective action:

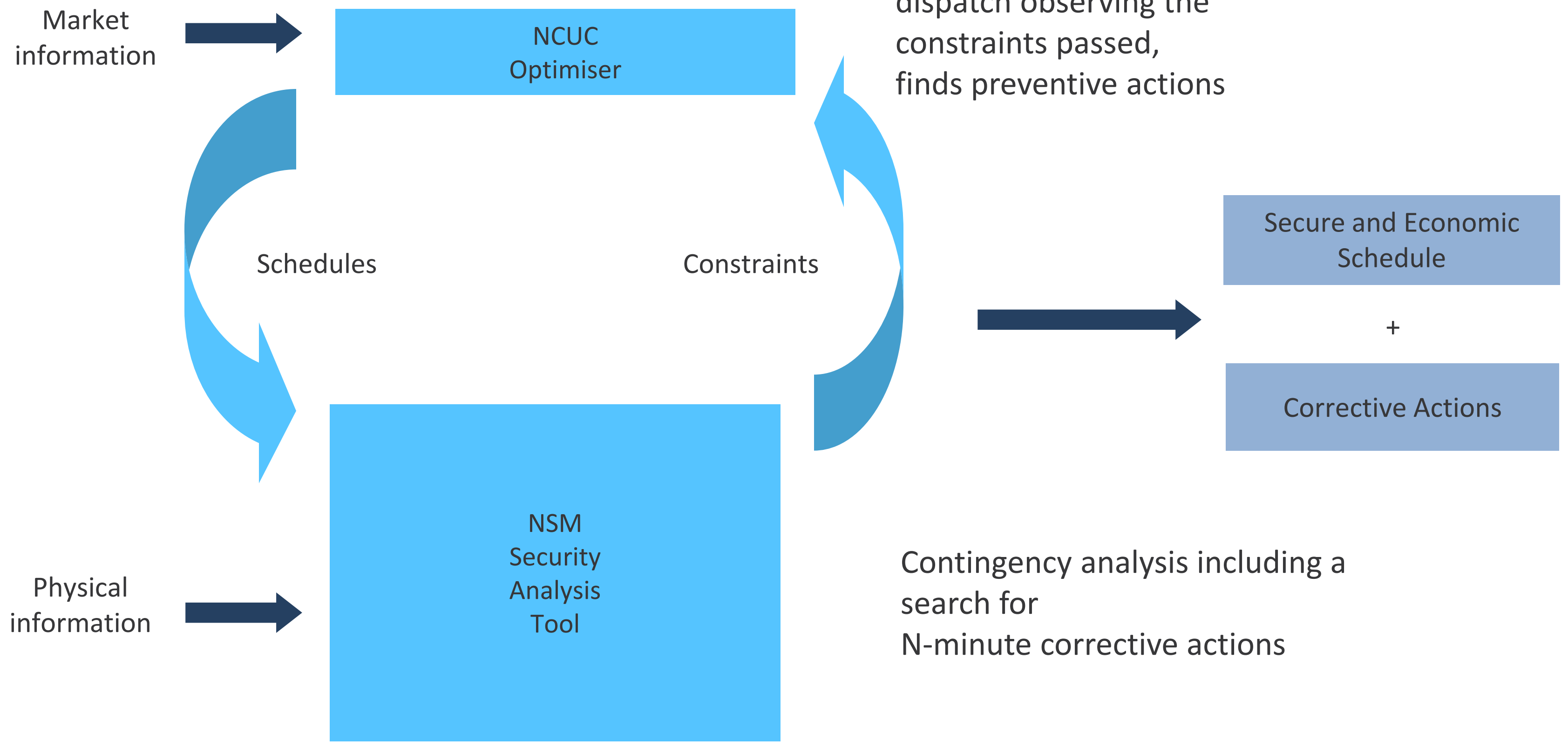
- X3 = flow immediately before contingency occurs
- Y3 = flow immediately after contingency occurs
- Z3 = flow N-minute after contingency occurs with access of corrective action



SCUC Engine

- Security Constrained Unit Commitment (SCUC) market clearing engine utilizing:
  - Network Security Monitor (NSM): performs security monitor and determines limiting constraints
  - Network Constrained Unit Commitment (NCUC): scheduler solves the master problem
- Two modules iterate until the optimal solution is reached

SCUC Engine



Economic scheduling and dispatch observing the constraints passed, finds preventive actions

Contingency analysis including a search for N-minute corrective actions

An integrated process of applying Preventive/Corrective scheduling

Network Security Monitor

Generates constraints for use in the scheduler:

- Preventive constraints for N minute short-term rating
- Benders' Cut

CONTINGENCY ANALYSIS

For each contingency:

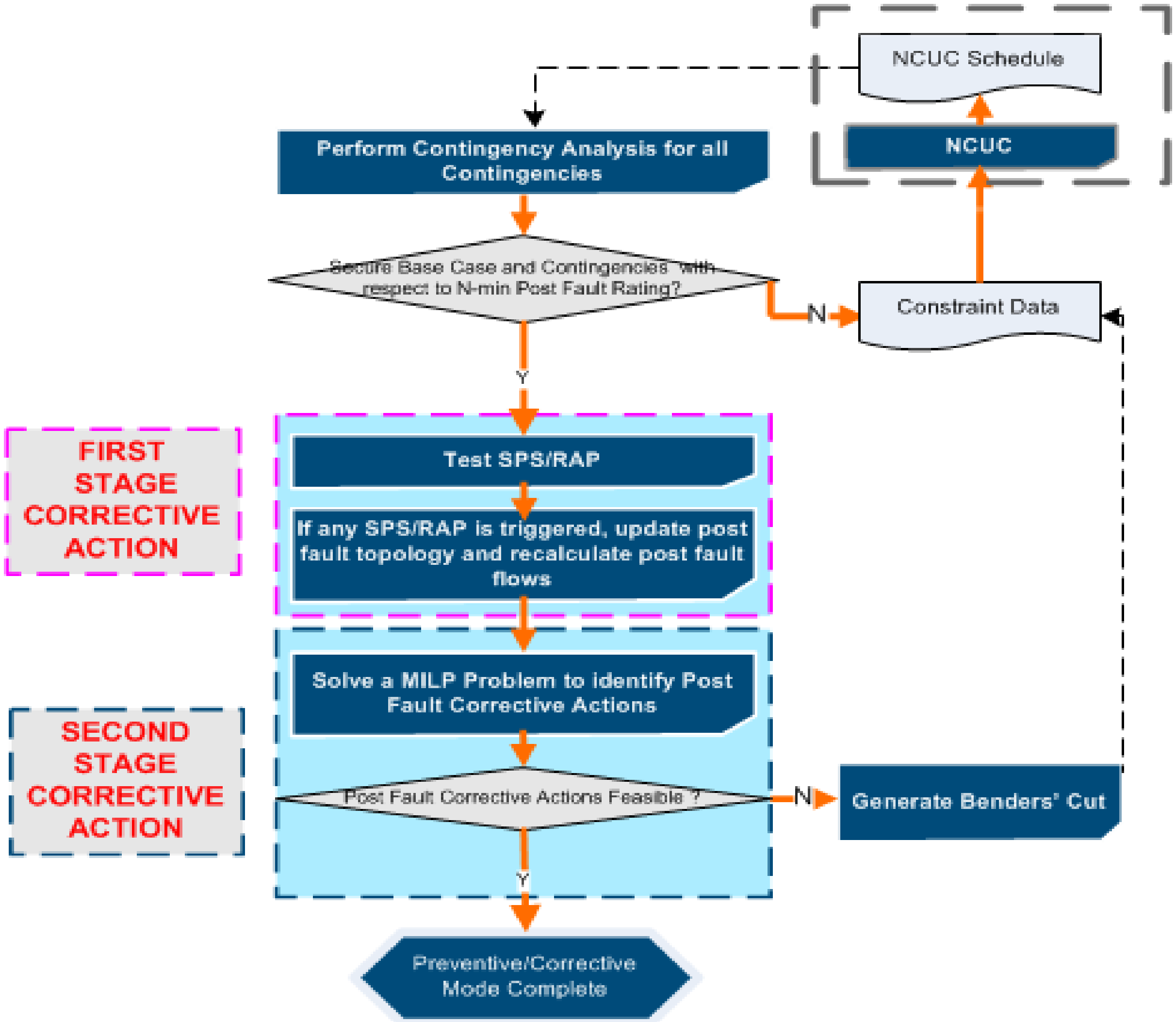
- Analyses the effect on each network element
- Takes into account any pre-defined corrective actions
- Solves a power flow problem
- Produces preventive constraints

SEARCH FOR CORRECTIVE ACTIONS

During the analysis of a contingency:

- Solves a MILP problem to identify a feasible set of N minute corrective actions.
- Produces Benders' Cut constraints if violations cannot be removed.

Process flow of applying preventive/corrective scheduling



Formulation of Identifying Auto Post-Contingency Corrective Actions

- Objective: Minimize (Feasibility Violation)
- Subject to:
  - Power balance
    - Zero balance
    - Maximum generation loss
    - Maximum demand loss
  - Network flow constraint (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
- Solve a MILP problem

Control Options in Preventive/Corrective Scheduling

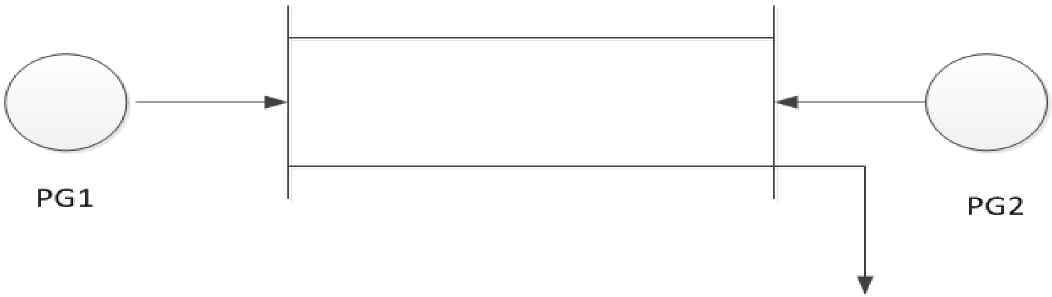
- Global and per Contingency
- Control Options:
  - Preventive Scheduling
  - Pre-defined Corrective Scheduling
    - Immediate Action
    - Manual Action
  - Auto Corrective Scheduling

Choice of N-minute in Preventive/Corrective Scheduling

- Multiple short-term rating allowed in the operation
- N represents the type of short-term rating
  - N between 10 and 30
  - Smaller values of N are impractical with the consideration of operator’s thinking time
  - Limited to two values (N1 and N2 with N2 > N1)

Illustration of post-contingency corrective actions

- A Two-bus system

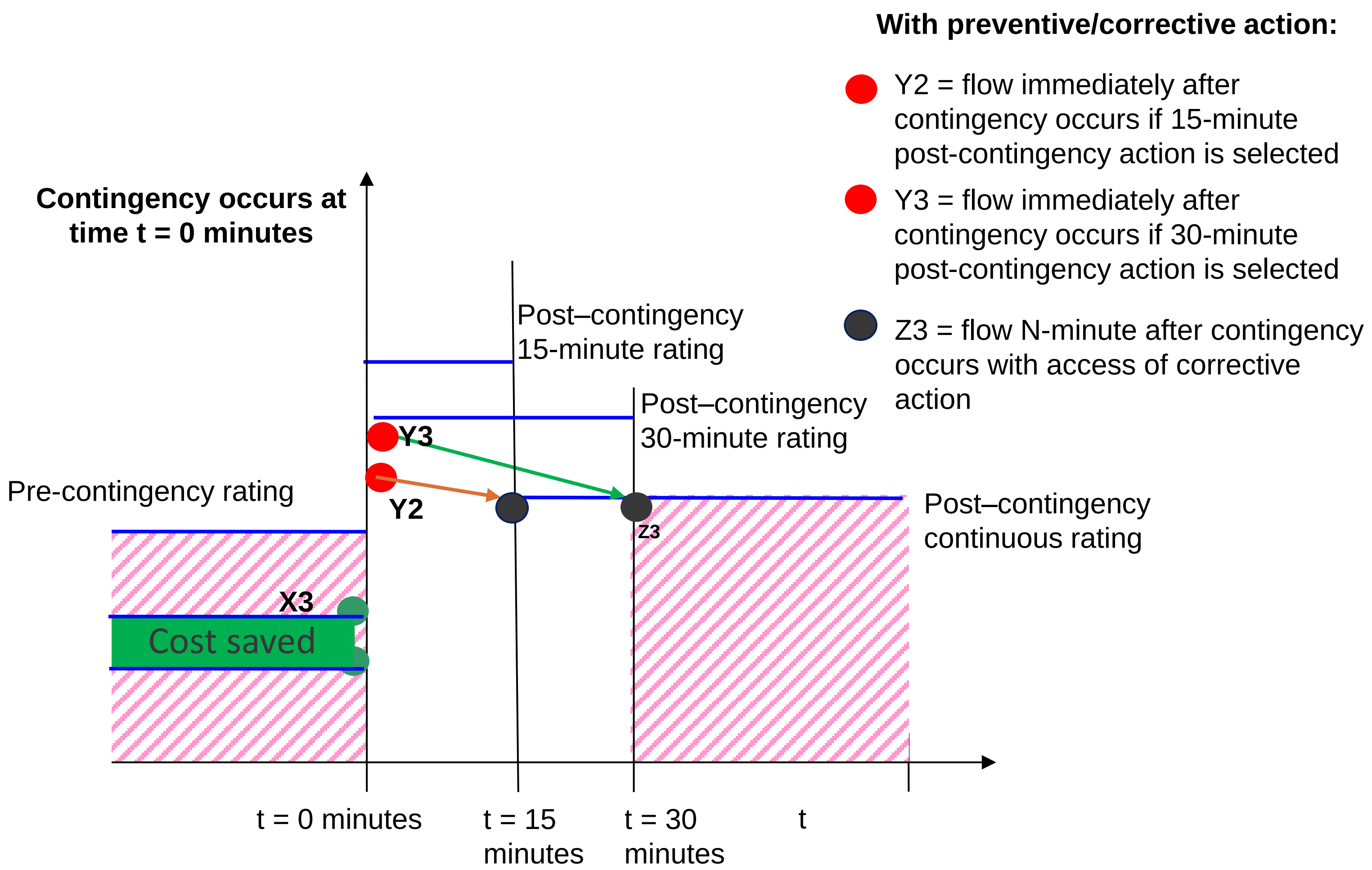


Generators	Max MW	Min MW	Cost ($/MW)	15-min Ramp	30-min Ramp
PG1	200	50	1	20	40
PG2	120	0	2	10	20

Line	Pre-Contingency	15-min Post-Contingency	30-min Post-Contingency	Post-Contingency Continuous
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

Illustration of post-contingency corrective action (Comparison between 15-minute and 30-minute)



Challenges

- Optimal Selection of Corrective Actions between N1 and N2 minute
- Computational Performance
- Practical Operational Implementation of Corrective Actions
  - Consider operator thinking time
  - Consider limits on # of controls from both pre-defined corrective actions and auto corrective actions
- What's next?
  - Integration of automated corrective actions in the real-time operation

Thank You

