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Cascading Outage Prevention in ISO New England

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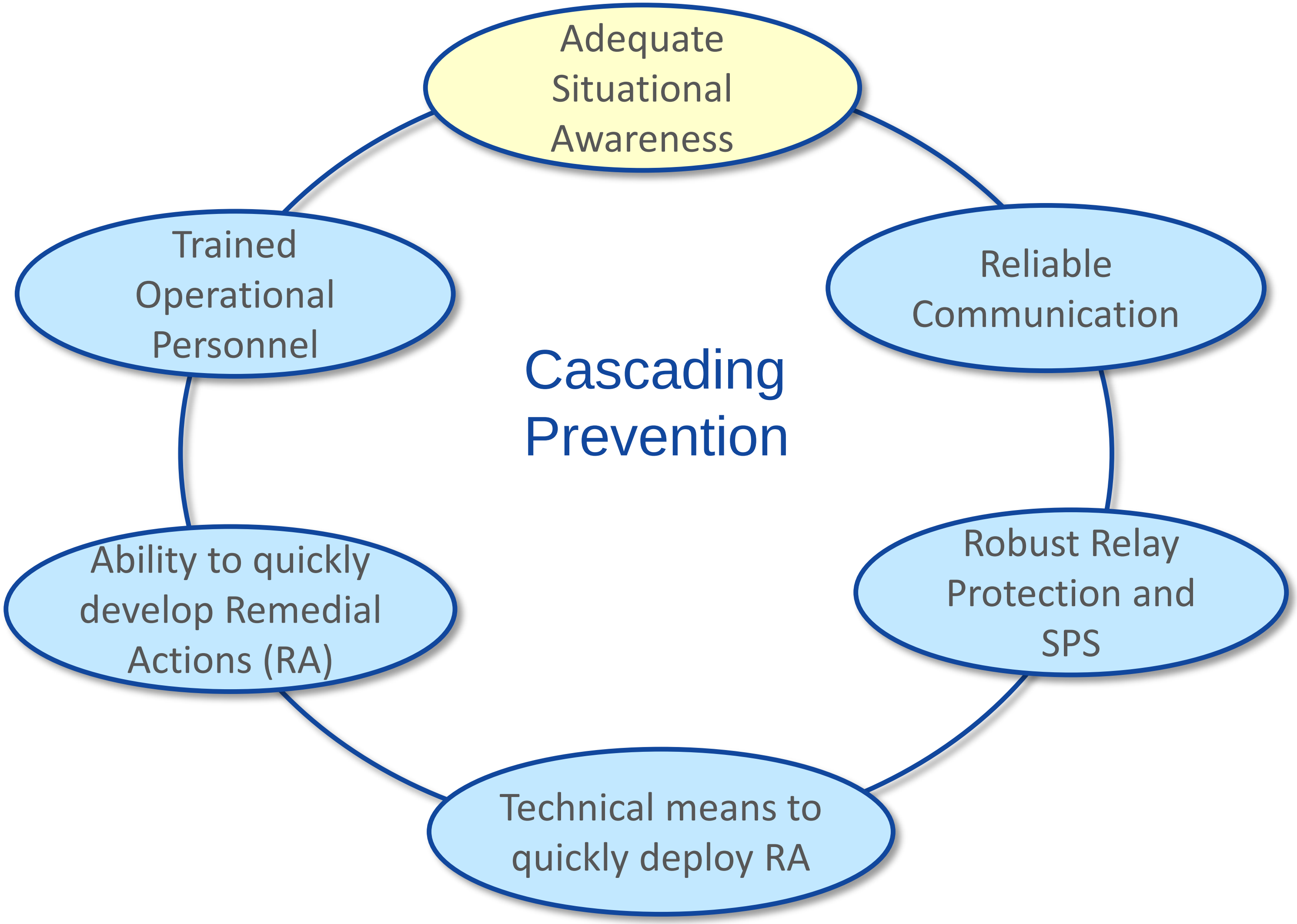
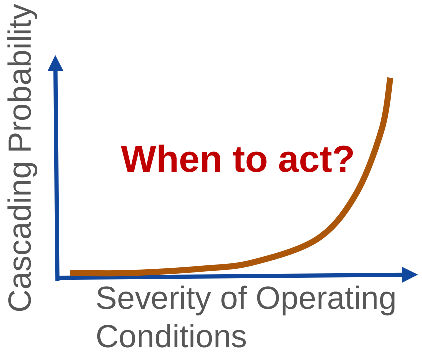
Ingredients of Success



Adequate Situational Awareness

- Is the system state secure against uncontrolled cascading outages?

- Research community proposes variety of indices indicating "Probability of uncontrollable cascading"
  - No indication on when to start mitigation measures



- Base-lining studies to identify "Abnormal" operating conditions
  - "Abnormal" conditions are suitable to trigger Alerts
  - "Abnormal" state does not mean "Insecure"

- Security Analysis is intended to evaluate the system security.

  Is traditional security analysis adequate for preventing of uncontrolled outages?

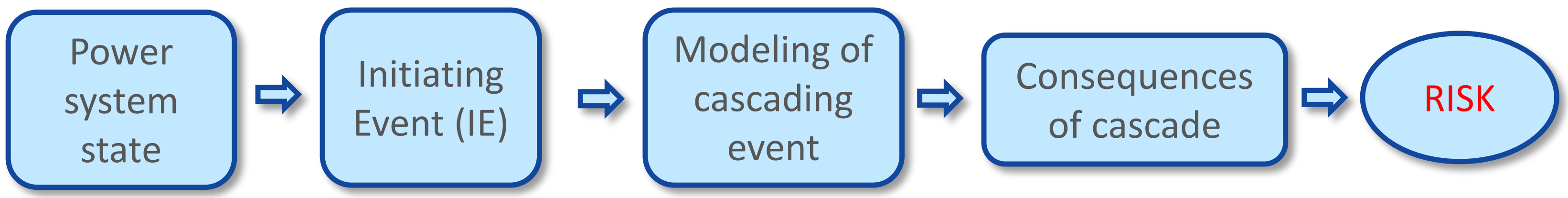
Traditional Security Analysis (SA)

- Objective of SA is to identify and remove violations
- Commonly used N-1 SA could be insufficient to prevent cascading
  - Could be too late to develop and implement Remedial Actions (RA) in the fast developing situation
  - NERC allows up to 30 min post N-1 recovery period to prepare for next contingency. Contingencies can occur with faster pace.
- N-2 SA provides better solution but could be very expensive
  - Pros: N-2 security greatly reduces the risk of uncontrolled outages
  - Cons: Hundreds of N-2 violations to be additionally mitigated. Not all these violations are important to cause uncontrolled outages.

Traditional SA ⇨ **Violations:** Voltage, Thermal, Transient, Voltage stability ⇨ ? What is the impact on cascading?

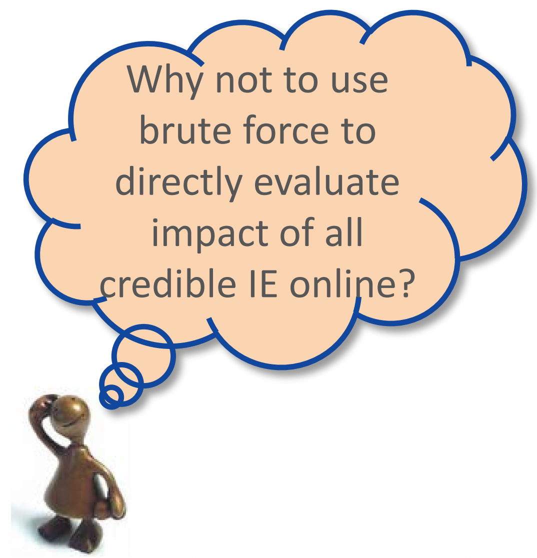
- Traditional SA does not provide adequacy of Remedial Actions to the risk of cascading and could be prohibit able expensive

Risk based approach



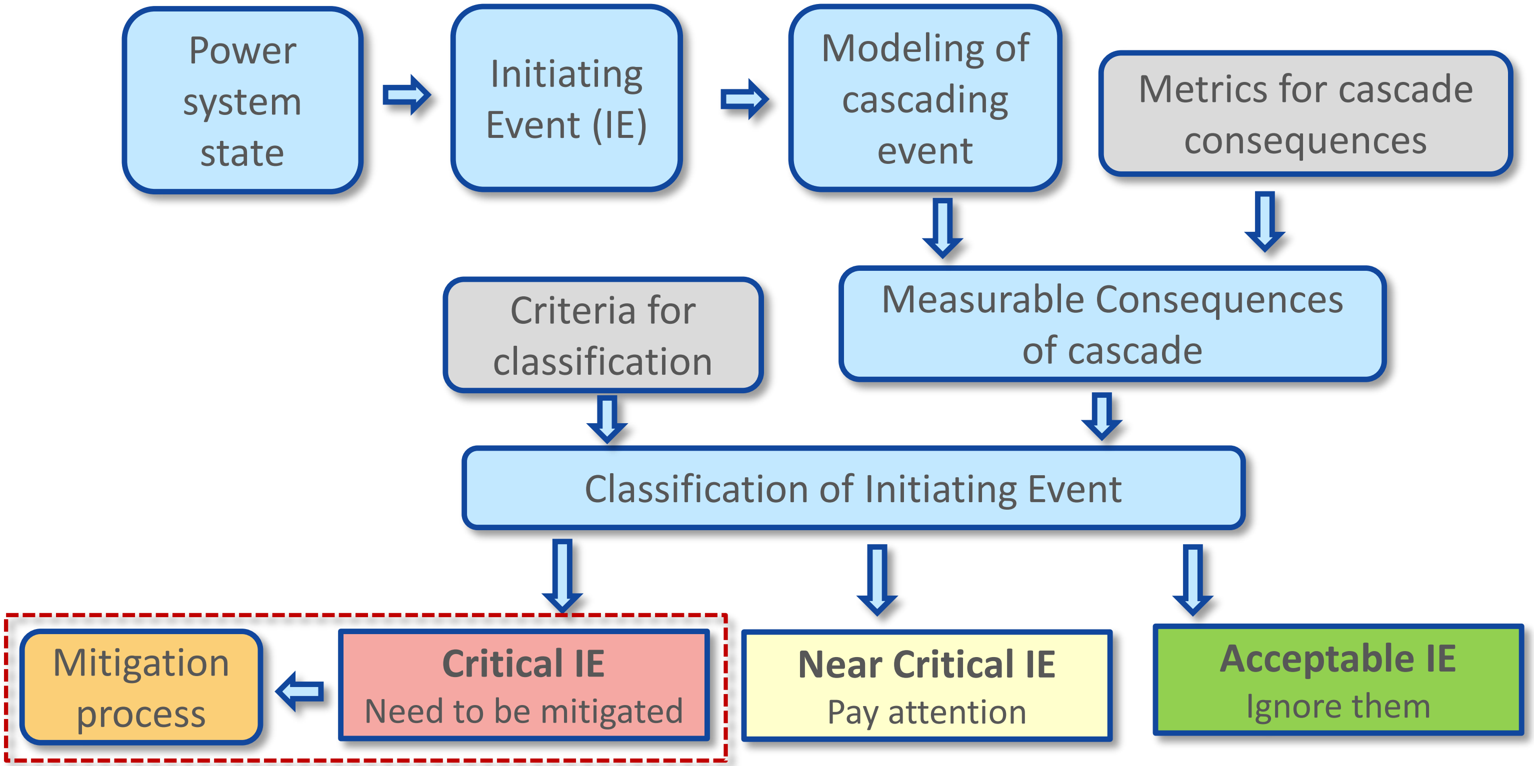
$$RISK_{of\_IE} = PROBABILITY_{of\_IE} \times COST_{of\_consequences}$$

- Make decision on Remedial Actions based on RISK value
- Conceptually right approach
- Difficult to implement in practice due to
  - Unknown probability of Initiating Event
  - Unknown cost of consequence of cascade
  - Uncertain value of acceptable RISK



Proposed practical approach

- Security against uncontrolled cascading outages
- Identify and mitigate Critical Initiating Events only. Criticality is classified based on well understood operational reliability criteria applied to consequences of potential cascade



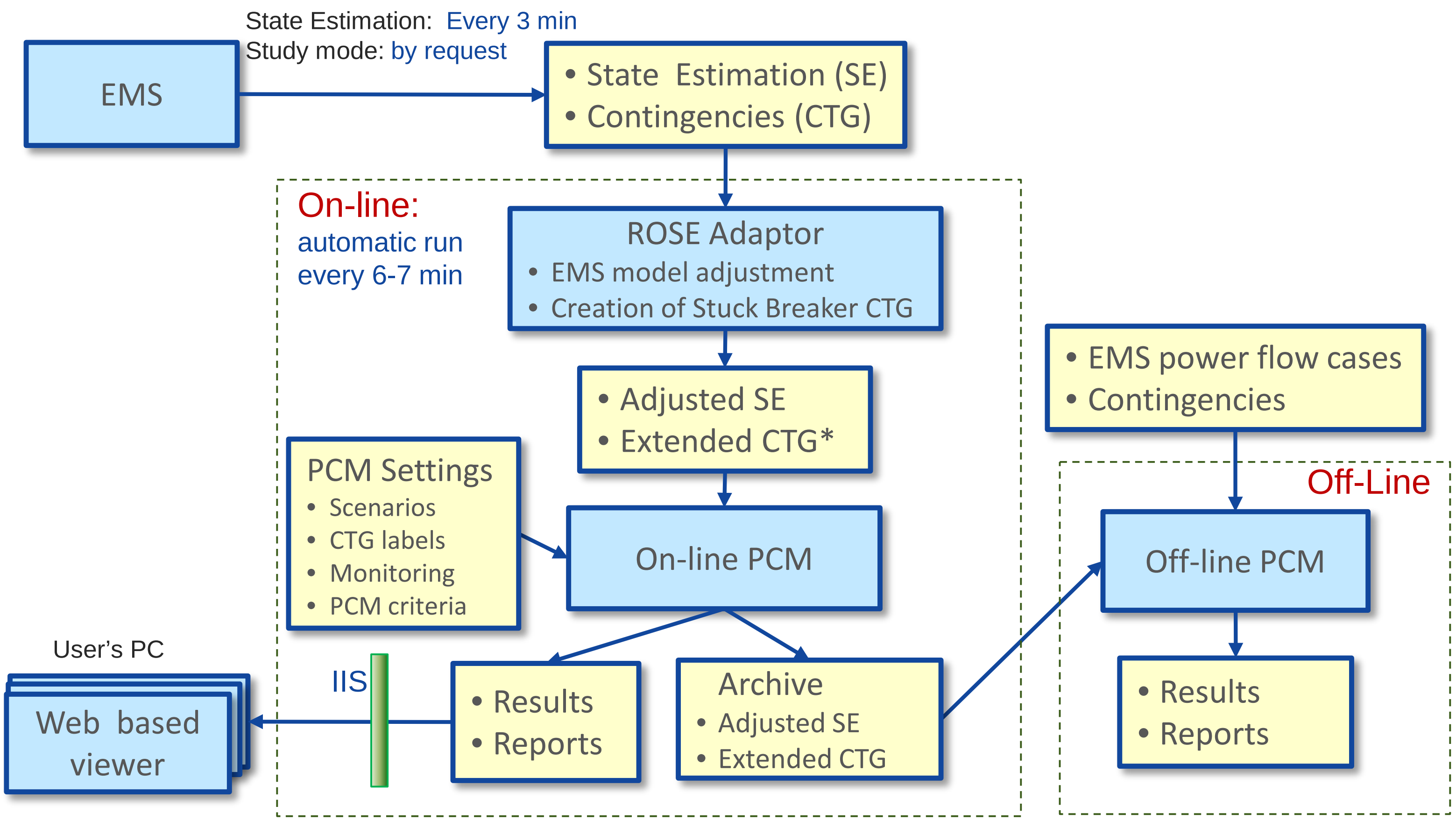
Cascading Analysis

- Objective: for any given state of power system, on-line or off-line, classify severity of initiating contingencies in terms of consequences of uncontrolled cascading outages
- Study conditions
  - Study only a fast developing cascade with no time for Operator to react
  - Initiating Events are complex contingencies (N-2, stuck breaker) beyond N-1 which are addressed in regular dispatch
  - Pre-defined tripping criteria for system elements
- Outcome
  - Measurable cascading consequences for every Initiating Event
  - Classification of every Initiating Event as Critical, Near critical or Acceptable
- On-line Cascading Analysis is a key component of advanced situational awareness and for prevention of uncontrolled cascading outages

Potential Cascading Mode (PCM) tool

- PCM is a module of the V&R Energy's POM/ROSE suite customized per ISO-NE requirements during 2014-2016
- Steady-state analysis of fast developing cascading events when Operator has no time to react
- Comprehensive modeling capability to handle real-life size EMS node-breaker model
  - Topology Processing
  - Multi-threaded calculations
  - Satisfies Cyber Security requirements
- Integrated with ISO-NE EMS
- Runs 24/7 as a pilot project

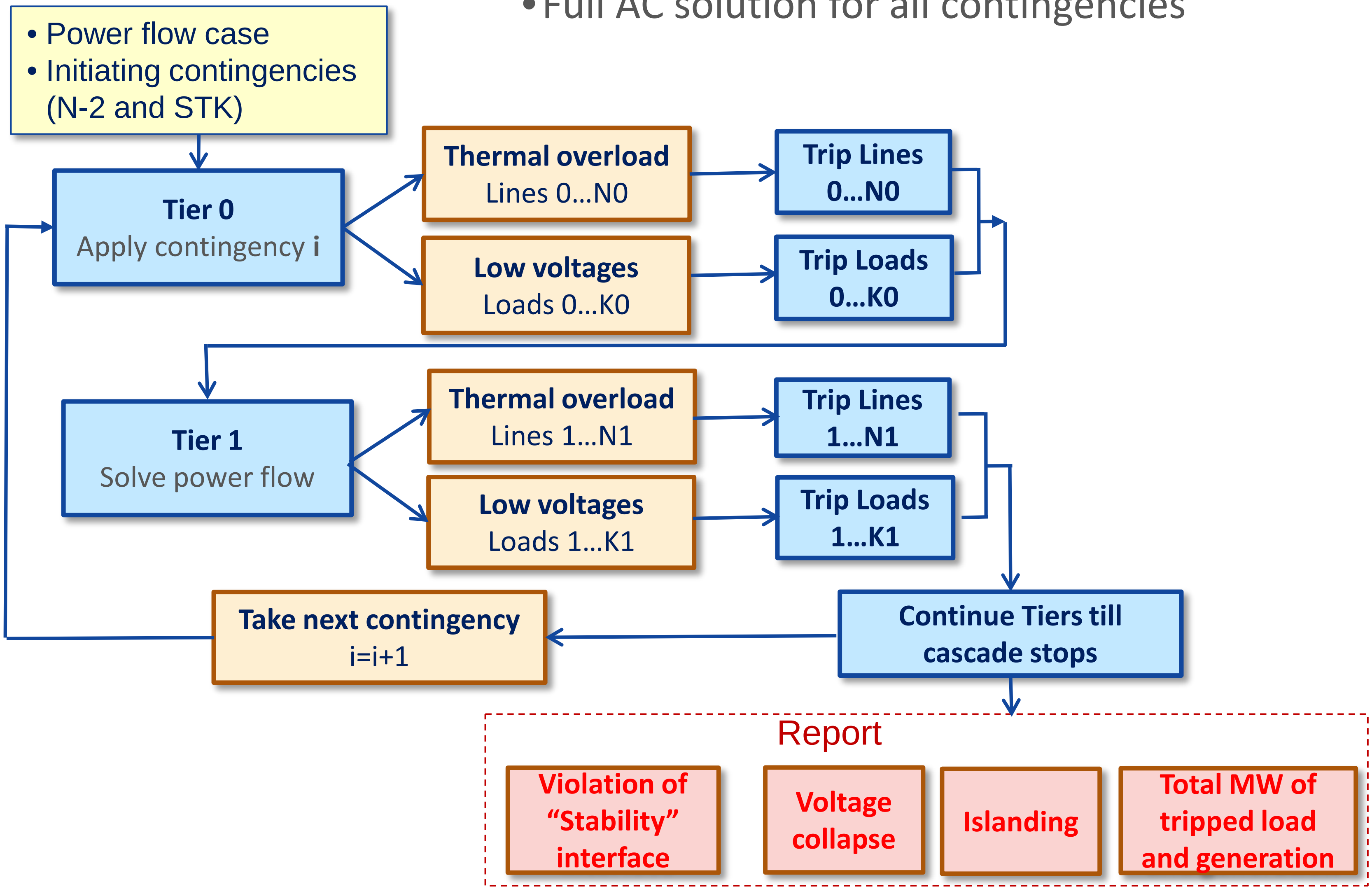
PCM process – data flow



* Extended CTG include selected N-2 used in Day-Ahead processes and all Stuck Breaker. Total ~6,000 x 3 = 18,000 CTGs

Modeling of Cascading Process

- Full AC solution for all contingencies



Classification of Critical Cascade in PCM

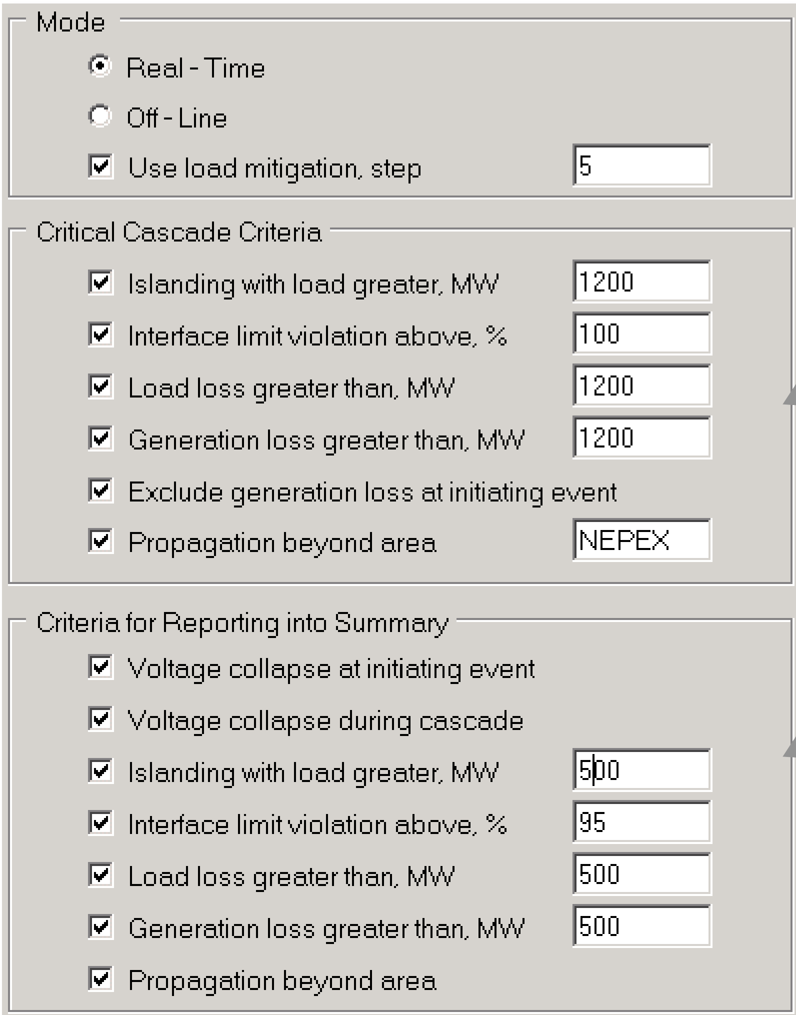
- Classification of cascade as Critical based of severity of consequences means the identification of initiating contingency as Critical

  Critical contingency creates insecurity in terms of cascading

- Criteria of Critical cascade
  - System wide voltage collapse occurs upon applying initiating contingency or as the result of cascading outages
  - Islanding with the total MW of load in island greater than pre-defined threshold
  - Interface MW flow during cascade exceeds “stability” interface limit by pre-defined % level
  - Total MW loss of load exceeds pre-defined threshold
  - Total MW loss of generation exceeds pre-defined threshold
  - Cascade propagates beyond Balancing Area footprint

- Above criteria are consistent with Operational practices evaluating severity of cascading

Settings of PCM



Criteria for identification of "Critical" cascade

Criteria for inclusion of "Critical" and "Near critical" PCMs into Summary Report.

Full report contains ~ 6,000 x 3=18,000 CTGs

Summary Report contains ~ 100 CTGs

Critical Cascade and IROL compliance

- Can be used as a basis for IROL (Inter-Regional Operational Limit) violation analysis and compliance
- Can be a basis of consistent, quantifiable and auditable process of IROL violation analysis
- Is a practical instrument to satisfy generic NERC requirements of IROL compliance
- Current industry practice based on classification of IROL interfaces can be dramatically improved by using cascading analysis
- ISO-NE is targeting two goals by creating online Cascading Analysis
  - Preventing the risk of uncontrolled outages and blackouts
  - Dramatically improve IROL compliance

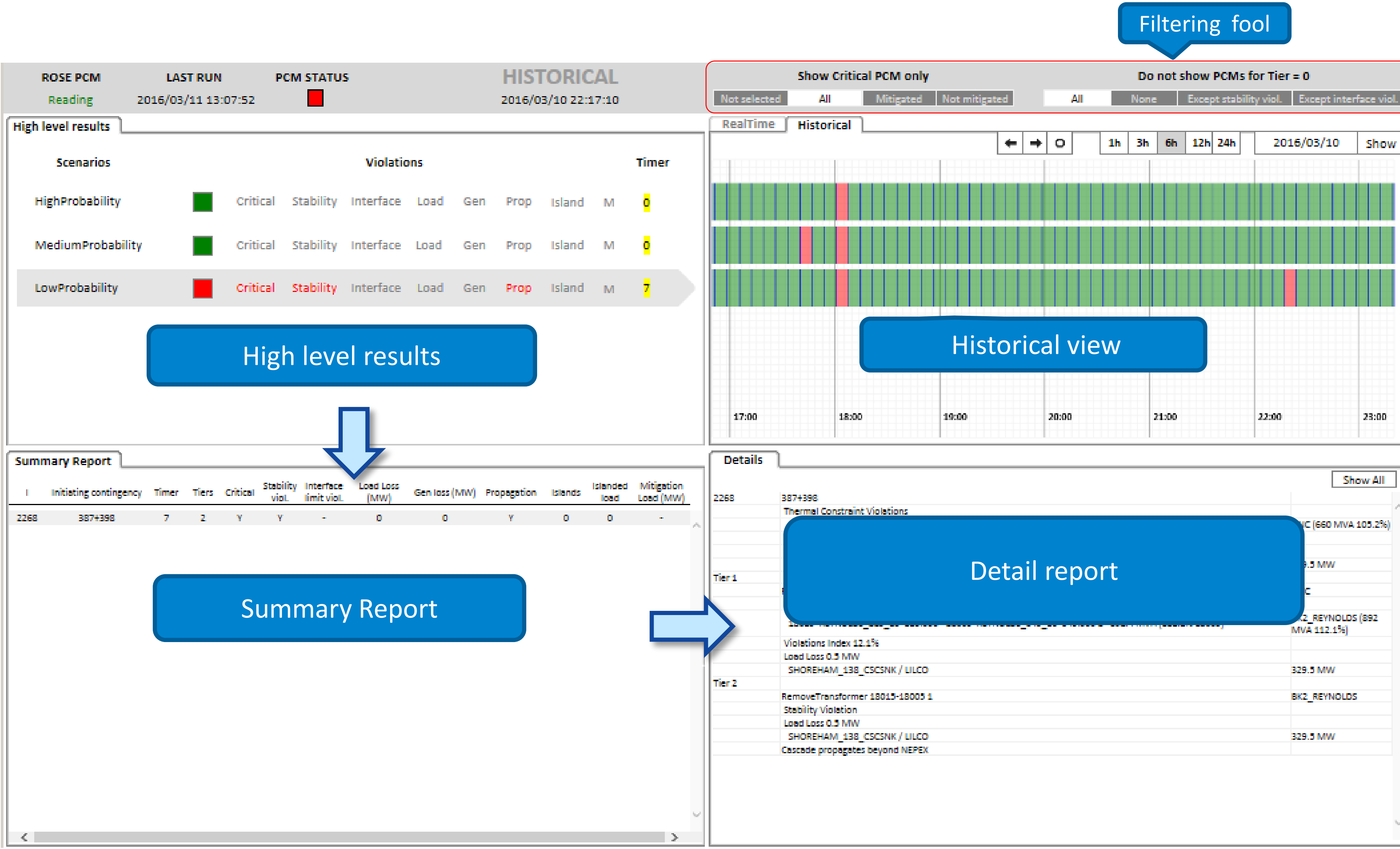
Scenarios in Cascading Analysis

- Cascading study is deterministic per defined tripping criteria
- Tripping criteria can be defined only approximately due to lack of information on relay settings, load composition, operator actions
- Risk of cascading can be evaluated by running several cascading Scenarios for the same initiating contingencies with different tripping criteria

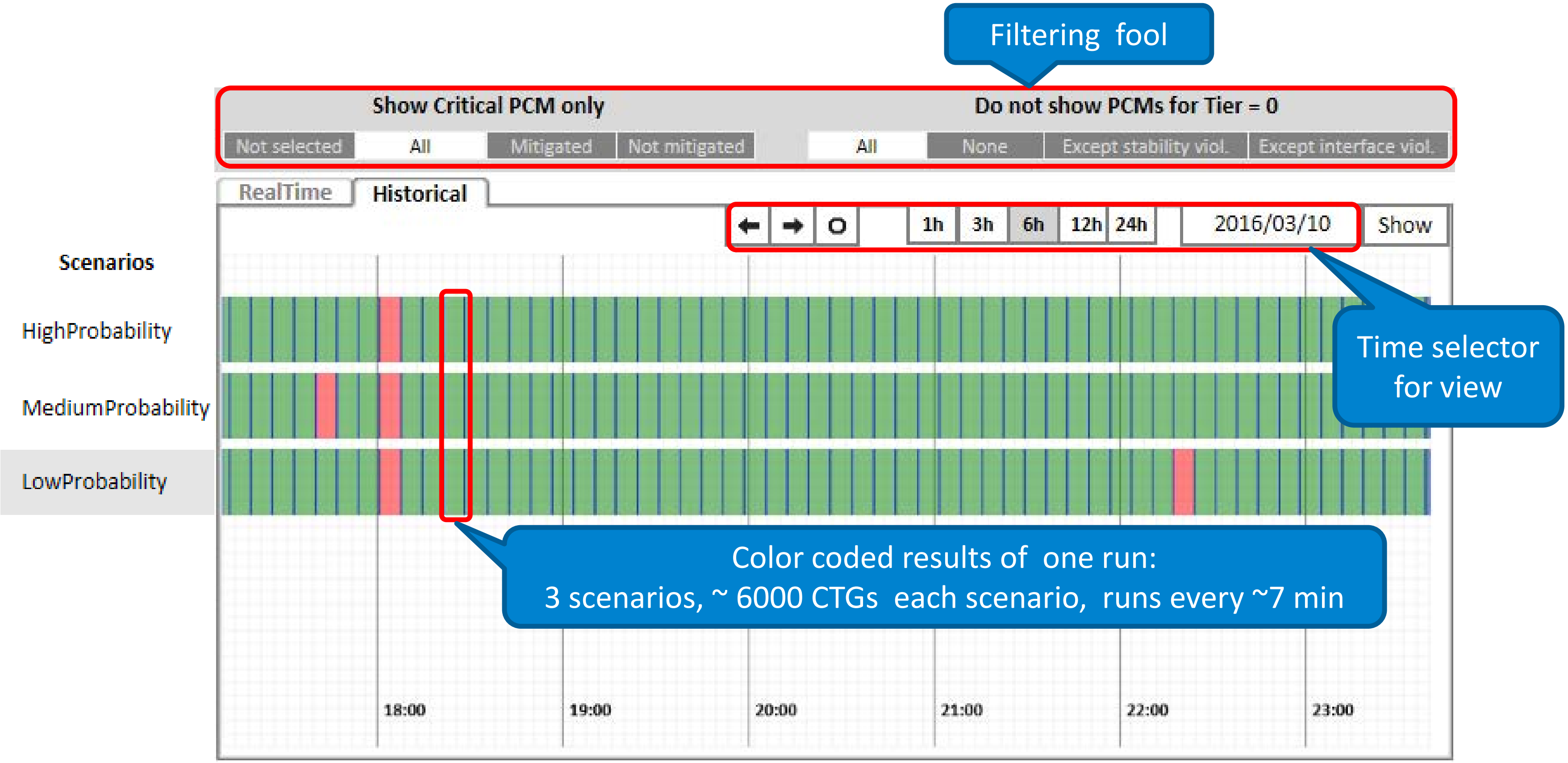
Tripping criteria for Scenarios

Scenario	Line % of rate C	Transformer % of rate C	Load voltage p.u.	Load % tripped
HighProbability	130%	130%	0.85	50%
MediumProbability	115%	115%	0.85	40%
LowProbability	101%	101%	0.85	30%

On-line PCM GUI to view results



Historical view



Color coding of PCMs: Acceptable; Near critical; Critical; Voltage collapse which could be mitigated by load shedding

Metrics for "locality" of voltage collapse

- Too many Critical contingencies are based on local voltage collapse. That creates misleading targets.
- Non-convergence of power flow is reported as "voltage instability".
  - Detailed analysis shows that majority (>90%) of "voltage instability" has local impact and affects quite limited MW of loads
  - Typical power flow solution cannot distinguish "local" from "wide spread" voltage instability
- Added a capability to quantify "locality" of voltage collapse by measuring the minimal MW of load shedding necessary to prevent voltage collapse

Voltage collapse is mitigated by load shedding

MW of load shed

Summary Report

I	Initiating contingency	Timer	Tiers	Critical	Stability viol.	Interface limit viol.	Load Loss (MW)	Gen loss (MW)	Propagation	Islands	Islanded load	Mitigation Load (MW)
3756	1732_14R-4T-2_stk	0	0	-	M	-	21	0	-	0	0	10
4090	266_K266-6_stk	0	0	-	M	-	2	0	-	0	0	18
5379	MADA_300-8_stk	0	0	-	M	-	0	785	-	0	0	79

Mitigation of Critical contingencies

- Two ways are available

1. Add Critical contingency constraint to regular Security Constrained Economic Dispatch. Regular generation re-dispatch provides mitigation
   - Use cascading tripping thresholds as constraint limits
   - Increased electricity production cost is the price for reduction of probability of blackout
2. Do not change dispatch but develop a plan of remedial actions and be ready to implement it upon occurrence of any part of complex critical contingency

Role of PMU in cascading prevention

- PMU measurements cannot be directly used to evaluate post-contingency security or for prediction of developing of uncontrolled outages
- PMU can be used for the following
  - Trending of power system states and alarming
    - “Abnormal” conditions
    - Proximity to a limit calculated on-line per N-k criteria
  - For a fast developing event, monitor the distance to voltage instability in the base case (N-0).
    - Voltage stability limit here can be calculated by using PMU measurements only

Questions

Backup slides

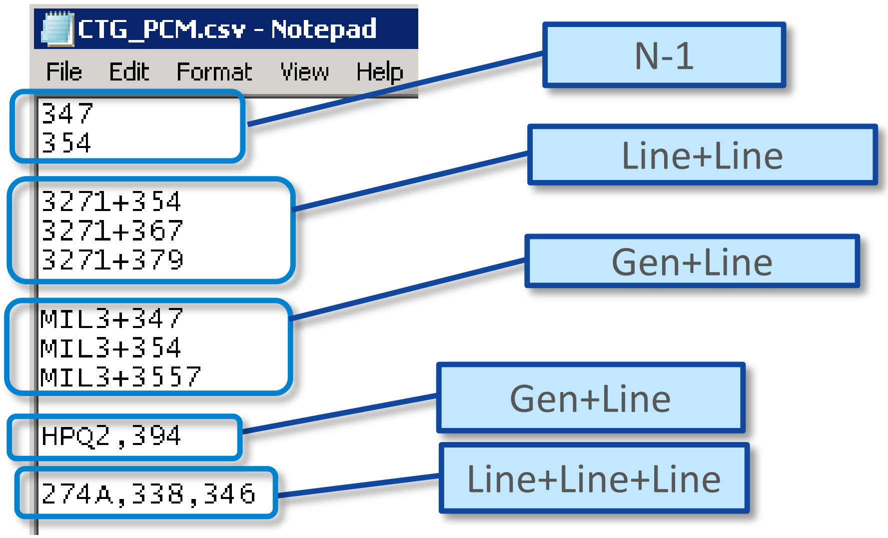
ROSE Adaptor

- Adjusts EMS model
  - Corrects deficiencies in EMS model to make it suitable for voltage studies
  - Implements actions to increase robustness of power flow solution and efficiency of Cascading Analysis
  - This is a necessary step to have robust and accurate PCM process
- Creates Stuck Breaker Contingency (STK) definitions
  - On the fly, creates STK for each breaker used in regular N-1 active contingencies
  - This is a key enabling process to study STK contingencies
  - Tremendous reduction in maintenance efforts
- In-house developed process

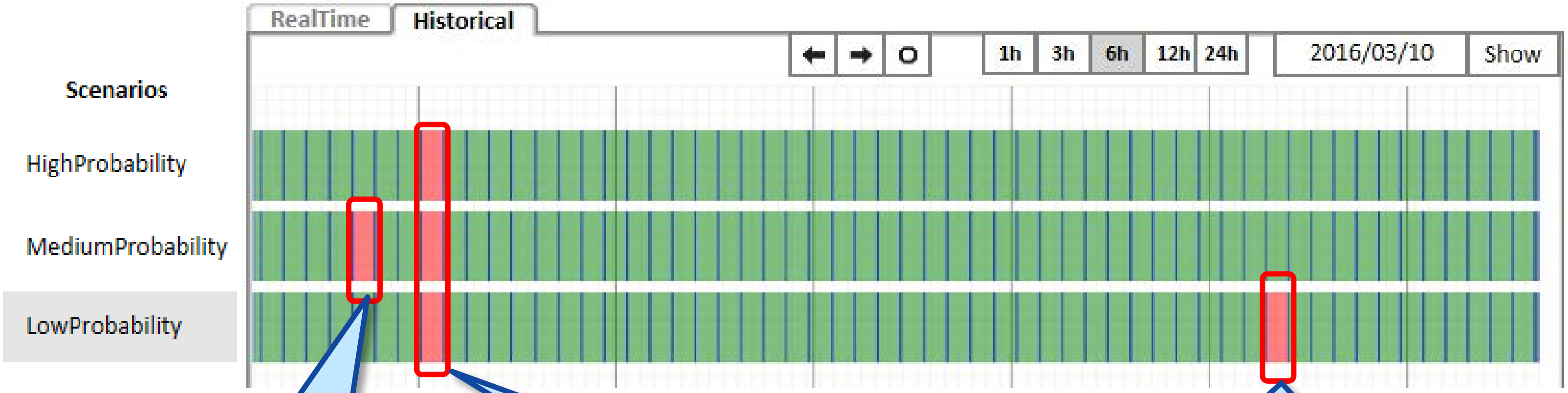
Study contingencies for PCM

- Definition of contingencies and active/disable status are coming from EMS and updated automatically. That is important for accuracy of results and reduction of maintenance efforts.
- PCM uses the list of CTG labels to be studied
- Any N-k can be studied as long as each of k CTG has definition in EMS

Example of study CTGs labels



Understanding of results



- More lines were tripped in LowProbability scenario comparing to other scenarios
- Those extra tripping were serving as remedial actions preventing to develop cascade into critical one

High risk critical cascade. Critical PCM is detected in all three scenarios

Low risk critical cascade. Critical PCM is detected only in LowProbability scenario

Example of results

High level results

Scenarios		Violations								Timer
LowProbability		Critical	Stability	Interface	Load	Gen	Prop	Island	M	7

Timer of Critical PCM in Scenario

Summary Report

I	Initiating contingency	Timer	Tiers	Critical	Stability viol.	Interface limit viol.	Load Loss (MW)	Gen loss (MW)	Propagation	Islands	Islanded load	Mitigation Load (MW)
2268	387+398	7	2	Y	Y	-	0	0	Y	0	0	-

Critical Reasons

Details

Show All

2268 387+398
Thermal Constraint Violations
13777 'N 1 659.7 MVA (105.2% 13777) 660 MVA 105.2%)
Violations Index 5.2%
Load Loss 0.5 MW
S O 329.5 MW
Tier 1
RemoveBranch 13777-15994 1 NNC
Thermal Constraint Violations
18015 'R 1 892.4 MVA (112.1% 18005) B DS (892 MVA 112.1%)
Violations Index 12.1%
Load Loss 0.5 MW
S CO 329.5 MW
Tier 2
RemoveTransformer 18015-18005 1 B DS
Stability Violation
Load Loss 0.5 MW
S CO 329.5 MW
Cascade propagates beyond NEPEX

Detail report of uncontrolled outages in cascade