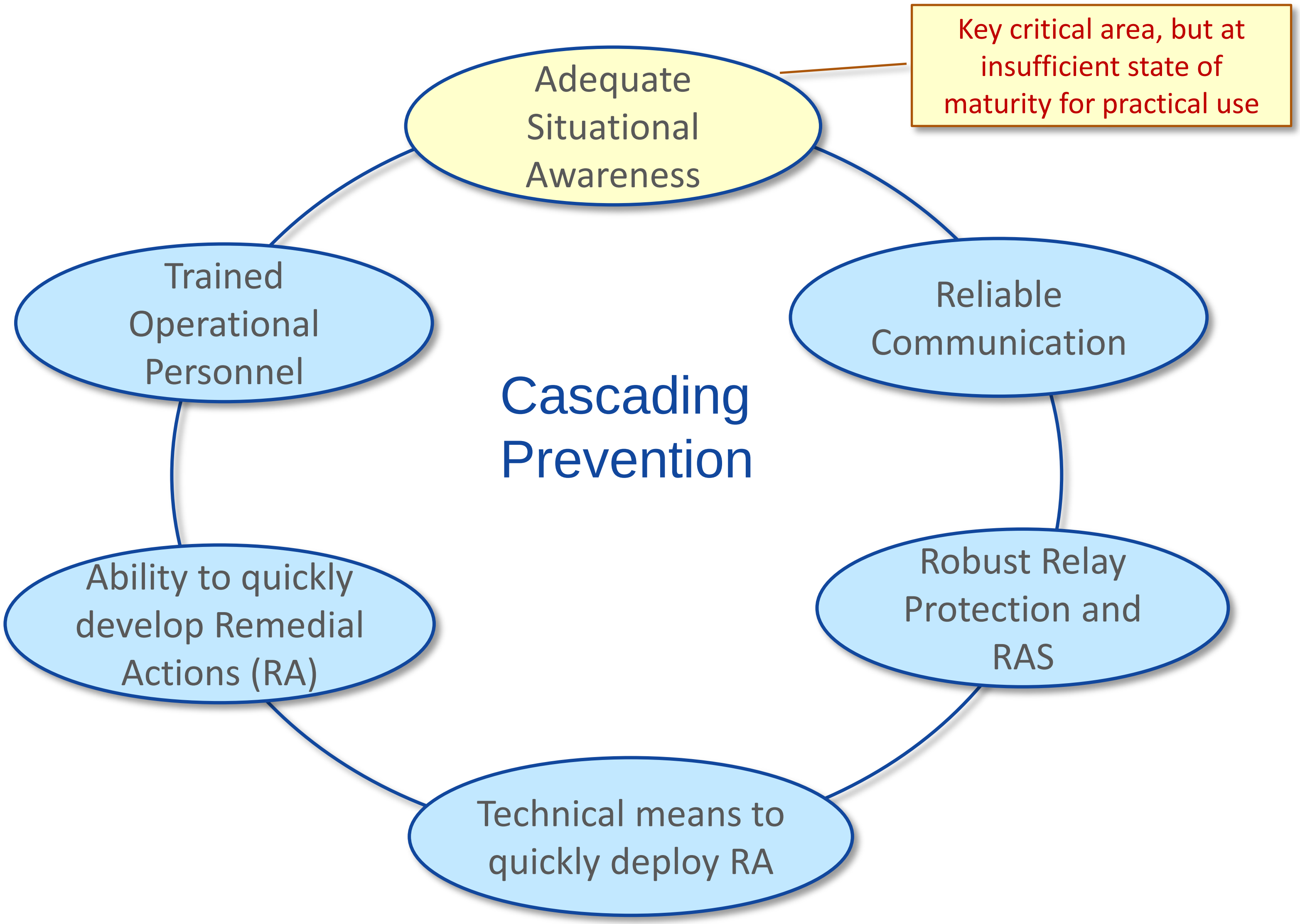
FERC. JUNE 27, 2016

Use of Online Cascading Analysis for Reducing the Risk of Blackouts

SLAVA MASLENNIKOV
XIAOCHUAN LUO
EUGENE LITVINOV

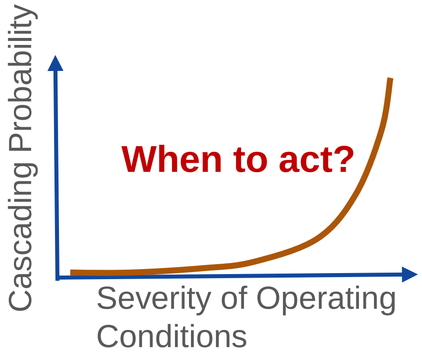
Ingredients of Success



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
  - No indication what exactly causing the danger



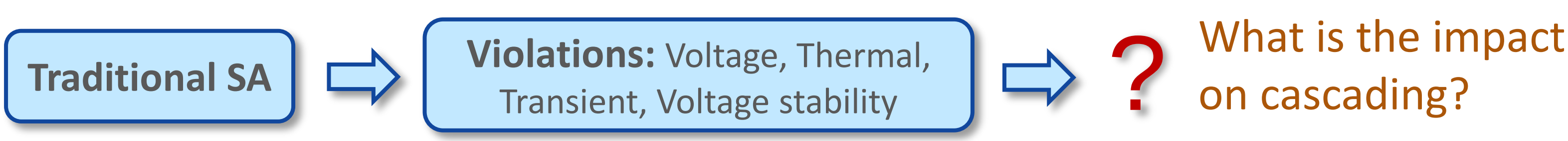
- Base-lining studies to identify “Abnormal” operating conditions
  - “Abnormal” conditions are suitable to trigger Alerts
  - “Abnormal” state does not mean “Insecure”

- Security Analysis is intended to evaluate the system security.

  Is traditional security analysis adequate for preventing uncontrolled outages?

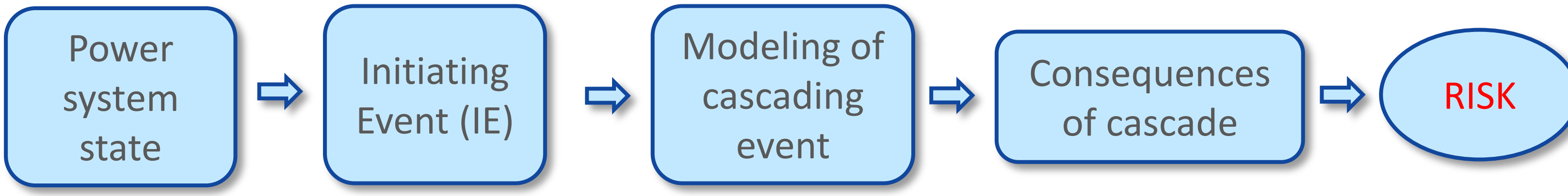
Traditional Security Analysis (SA)

- 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 does not provide adequacy of Remedial Actions to the risk of cascading and could be prohibitively expensive

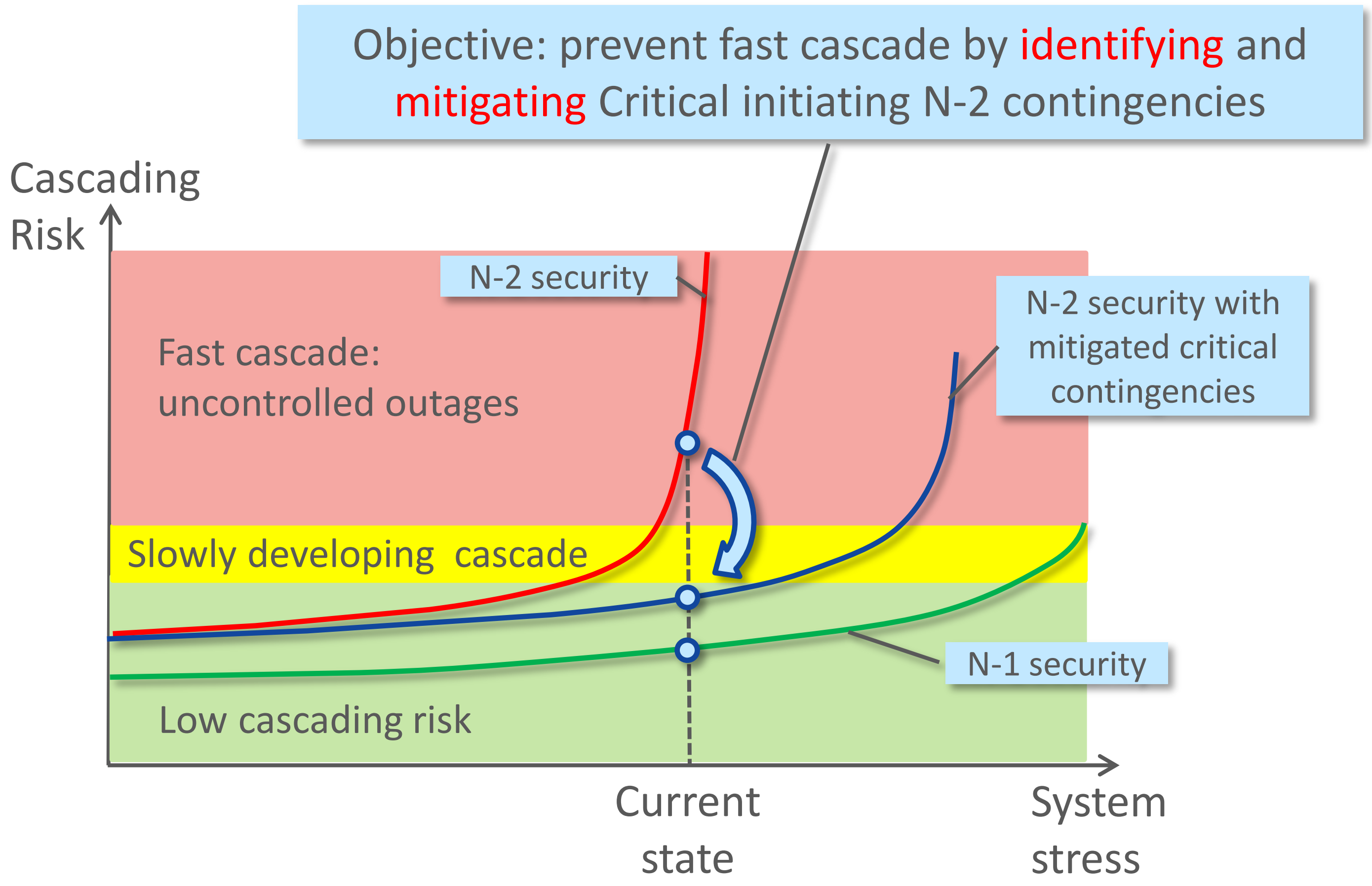
Risk Based Approach



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

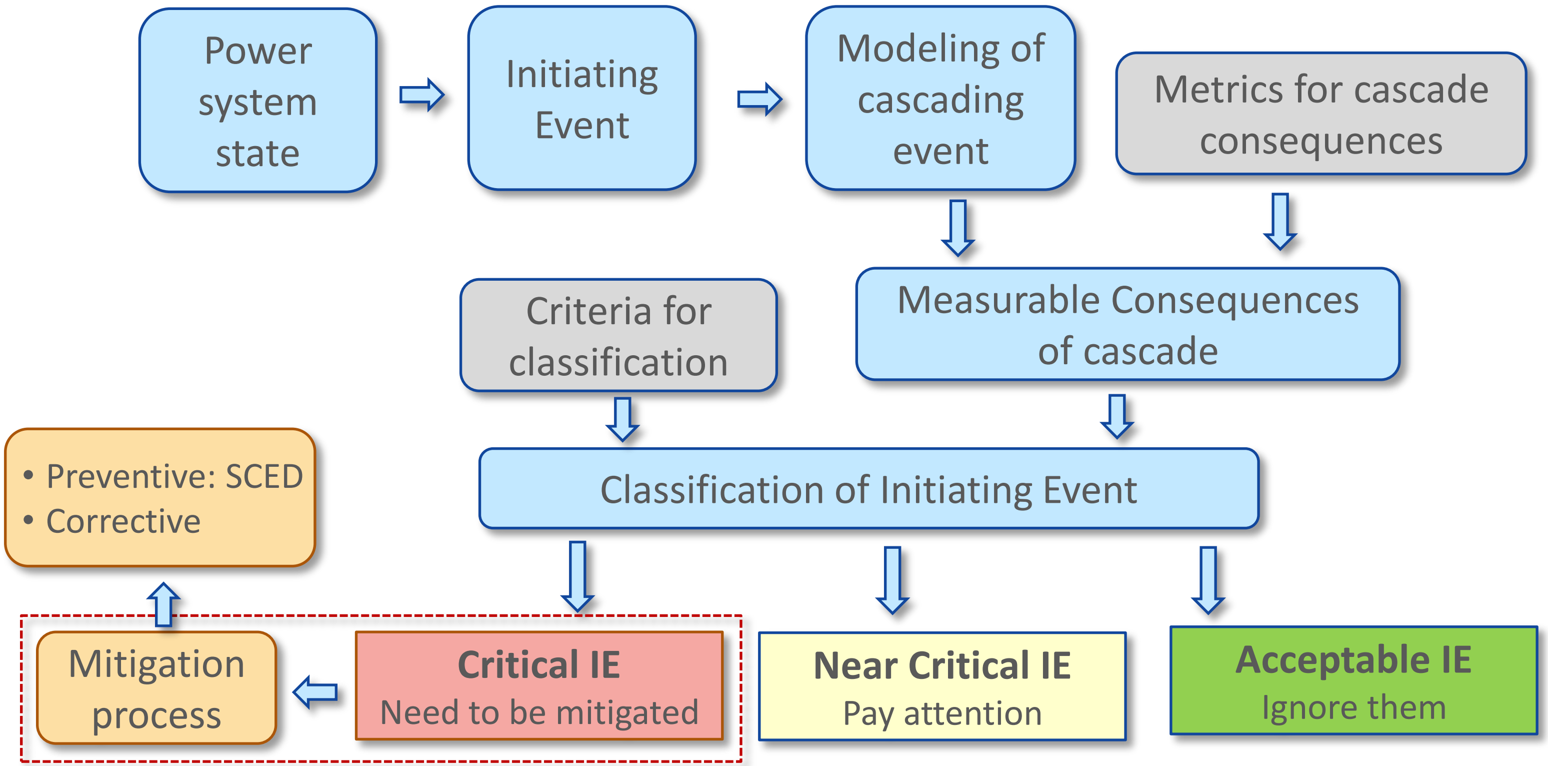
- Make decision on Remedial Actions based on RISK value
- Conceptually right approach but difficult to implement in practice due to
  - Unknown probability of Initiating Event
  - Unknown cost of consequence of cascade
  - Uncertain value of acceptable RISK

Security Against Uncontrolled Cascading Outages



Proposed Practical Approach

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



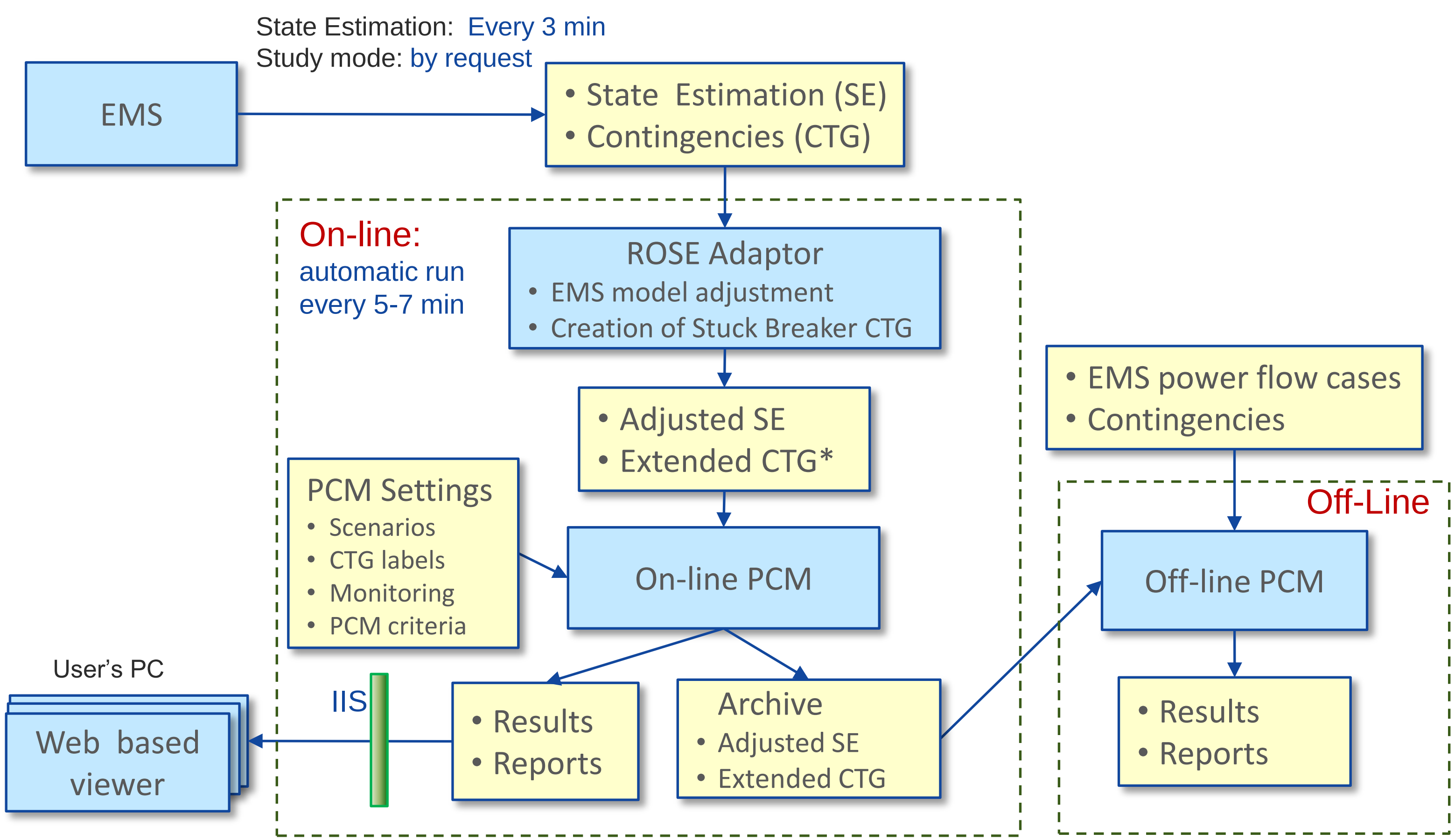
Cascading Analysis

- Objective: 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

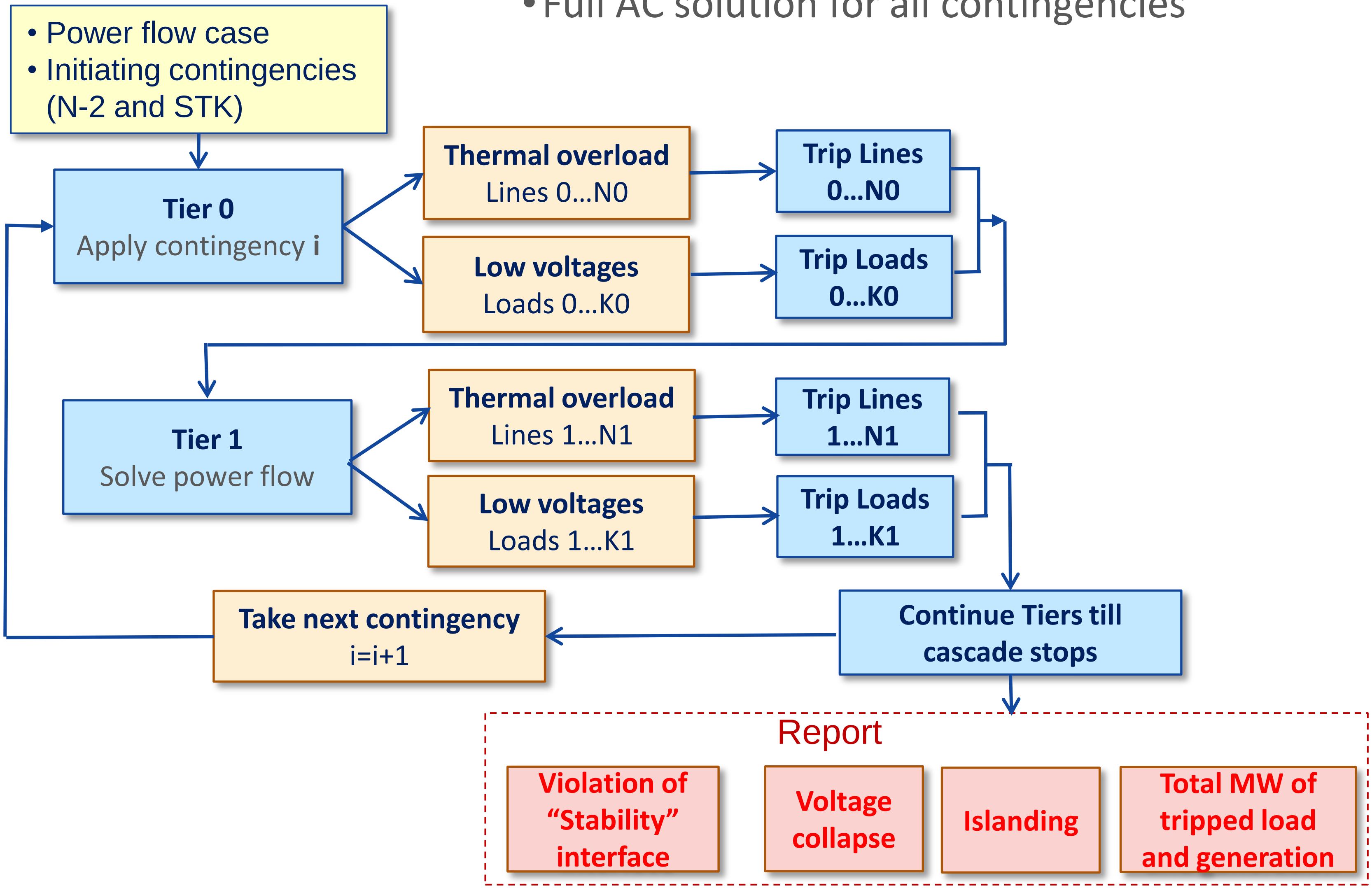
PCM Process – Data Flow



* 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



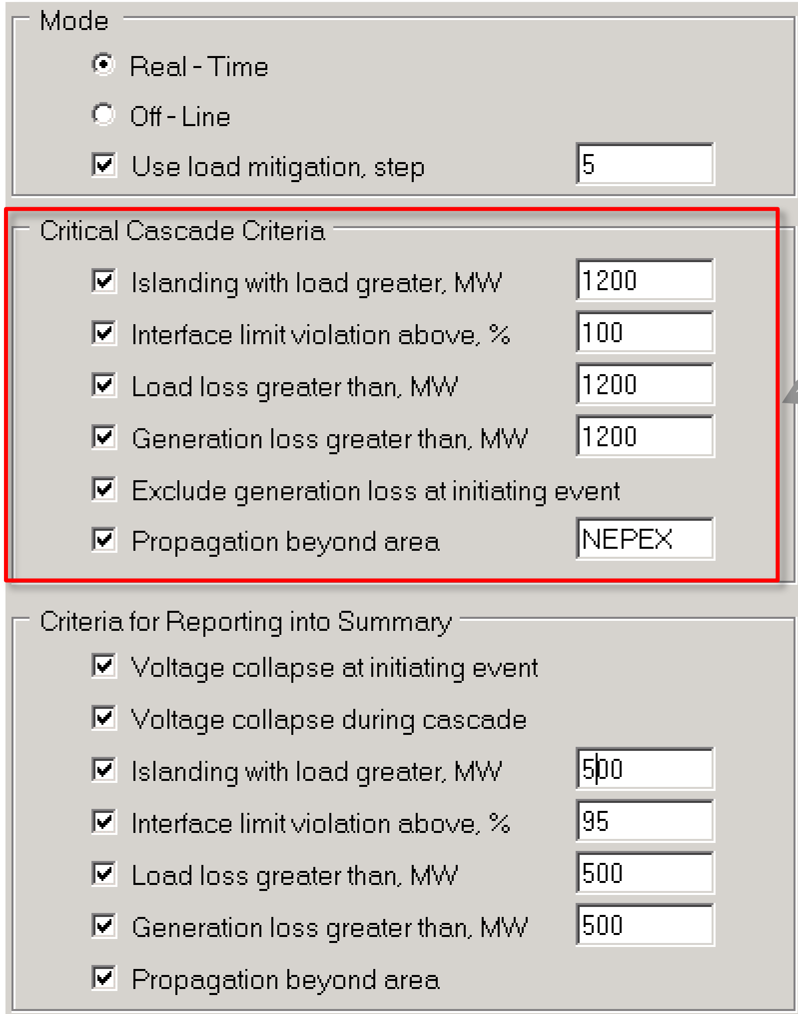
Transient Stability in Cascading Analysis

- Transient stability interface limits are used in PCM as monitored constraints
- Stability-based interface limits are calculated off-line or on-line
- Violation of stability-based interface limit at any stage of cascade in steady-state analysis is an indicator to initiate transient study of this specific cascade
- Dramatic reduction in the need to do transient studies in cascading analysis. Do it only for contingencies resulting in "stability-based" interface limit violation

Classification of Critical Cascade in PCM

- Critical contingency creates insecurity in terms of cascading – triggers fast developing, uncontrolled cascade
- 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 Software



Criteria for identification of "Critical" cascade

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%

Cascading Analysis and Inter Regional Operating Limit (IROL) compliance

Current industry practice based on classification of IROL interfaces can be dramatically improved by using Cascading Analysis

Existing IROL compliance

Pre-defined set of monitored IROL interfaces

- Subjective
- Difficult to audit process
- Inconsistent across industry
- Could be unreasonably expensive
- Does not guarantee reliability
- Simple to implement

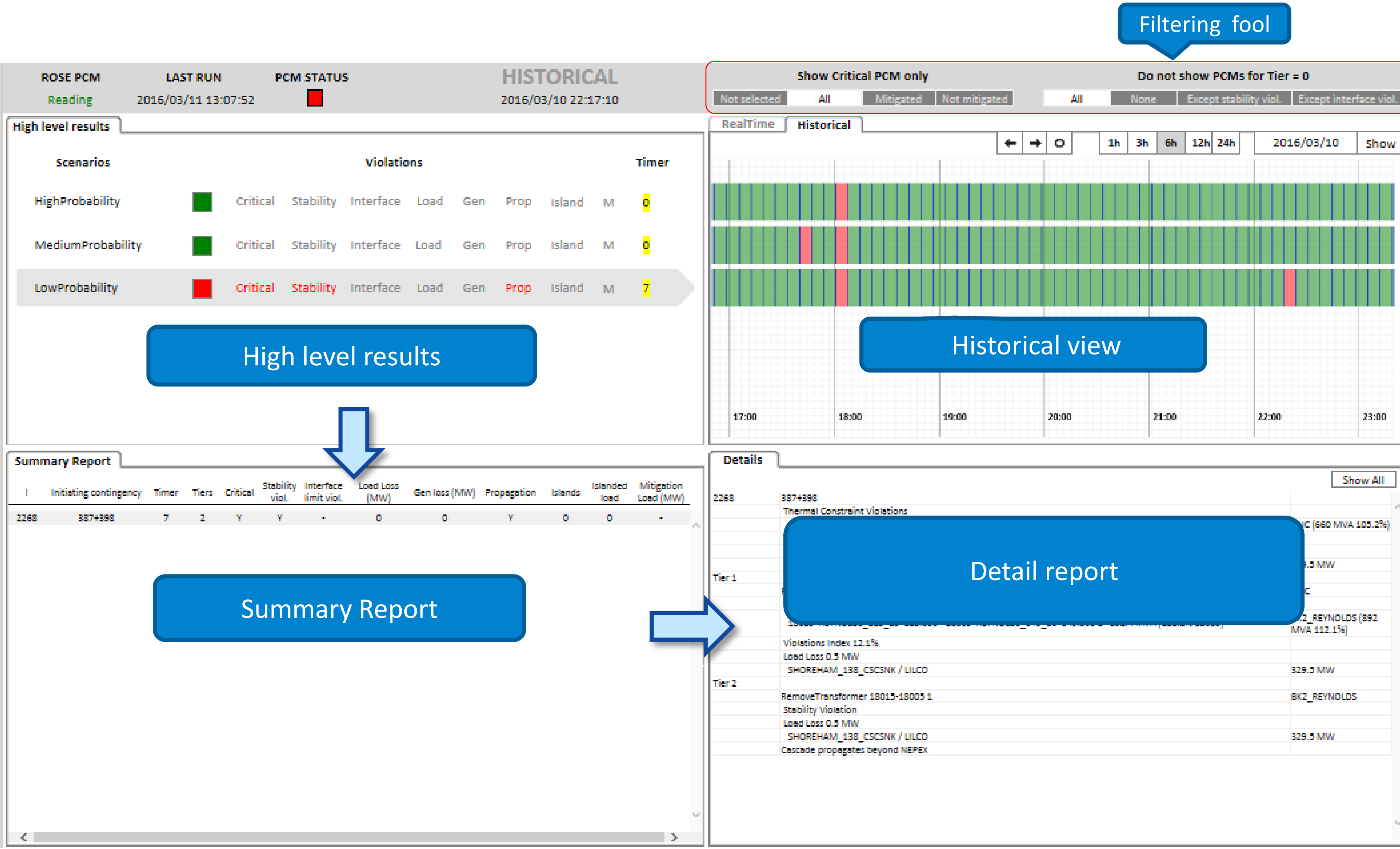
Advanced IROL compliance

Cascading analysis

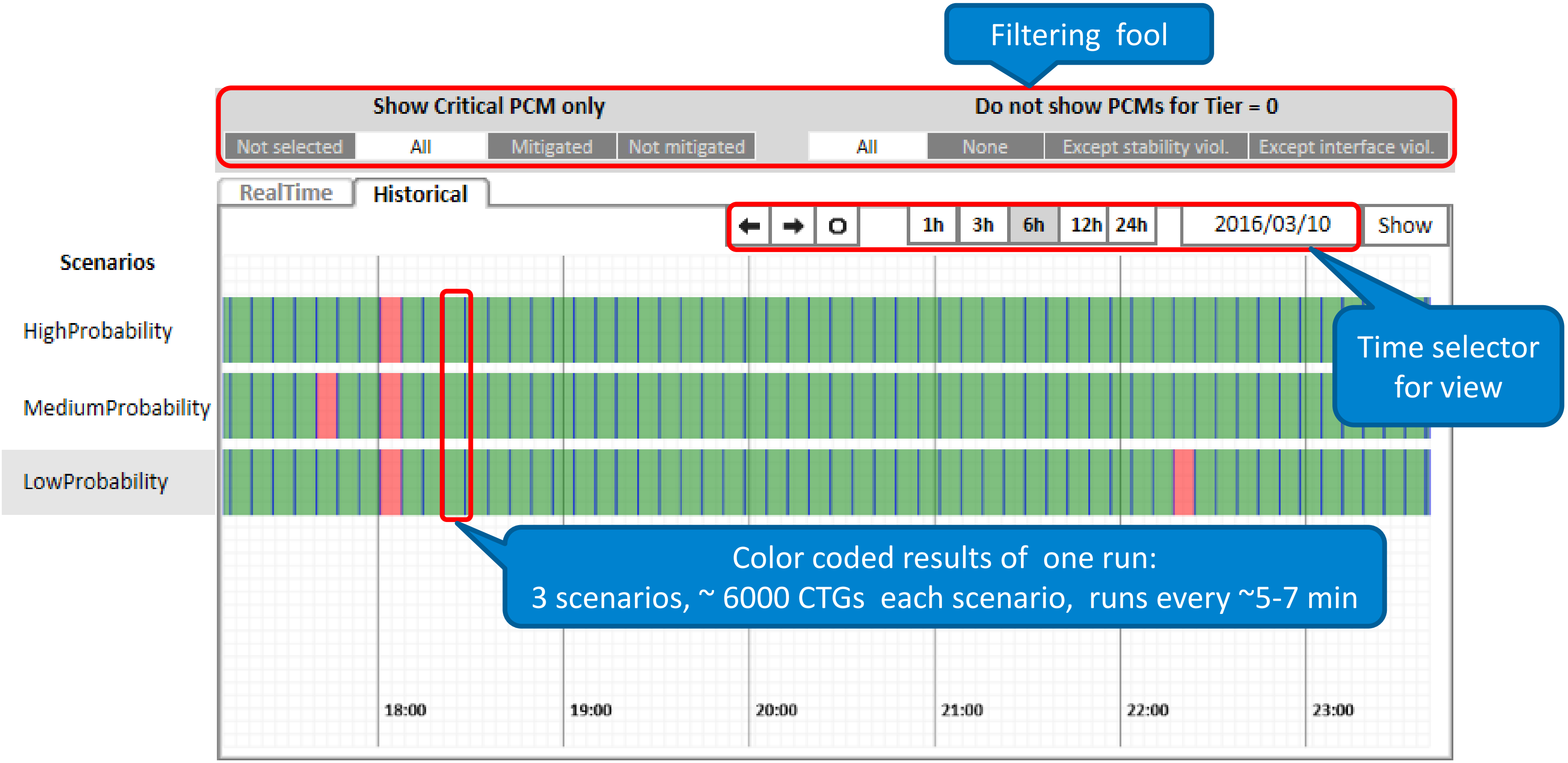
Measurable consequences of cascade

- Just and objective criteria
- Auditable process
- Consistent across industry
- Requires Cascading Analysis

On-line PCM GUI to View Results



Historical View



Color coding: 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".
  - 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

Identified Critical contingency

Preventive

Add Critical contingency constraint to regular SCED

- Increased electricity production cost is the price for reduction of blackout risk
- Use cascading tripping thresholds as constraint limits
- Need an ability to activate a constraint related to Critical contingency

Corrective

Develop a remedial actions plan and be ready to implement it upon occurrence of any part of complex critical contingency

- No increase in production cost
- Applicable only when time allows to apply Remedial Actions upon N-1

Mitigation of Critical Contingencies, cont.

- In normal operating conditions typically, not more than 1-2 critical complex CTGs (from ~ 6,000 N-2 and stuck breaker) is detected
- Increase of production cost in Preventive mode should be reasonable
  - Numerical $$ value to be evaluated
- Developing of Remedial Action plan in Corrective mode even manually is manageable and also could be automated

Benefits of Using Cascading Analysis

- Advanced situational awareness. Ability to identify exact Critical complex contingencies (beyond N-1) triggering fast developing uncontrolled cascading
  - In Real-Time operation
  - At any stage of Operational Planning horizon
- Practical way to reduce risk of blackouts. Systematic approach to constantly mitigate the risk of contingencies triggering uncontrolled cascading
- Possibility to dramatically improve IROL analysis and compliance

Questions

Backup slides

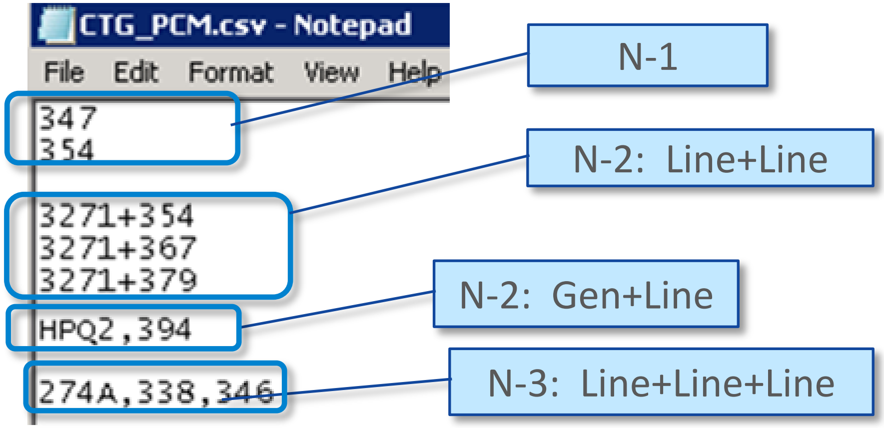
ROSE Adaptor

- 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

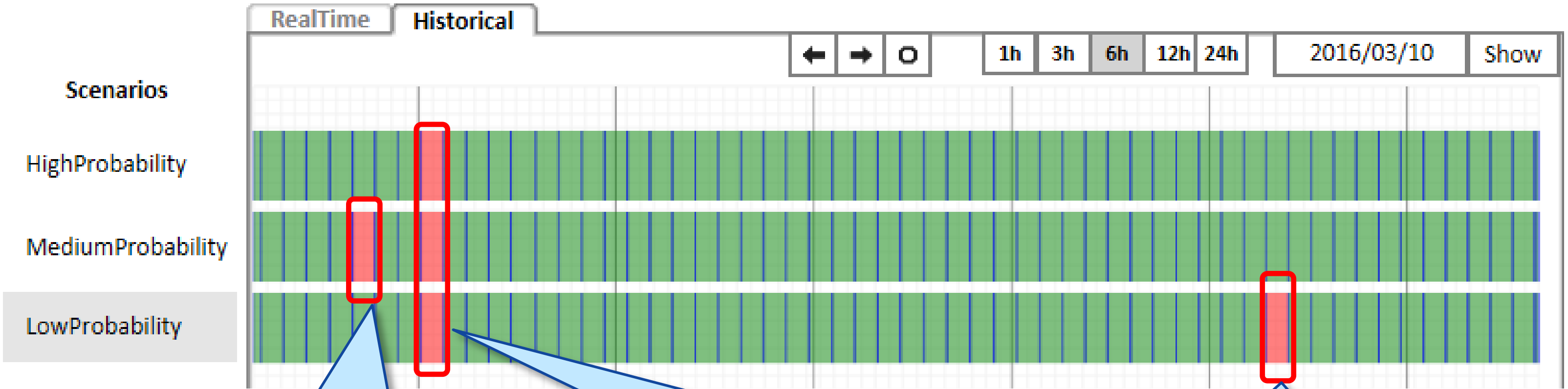
Study Contingencies for PCM

- Do not need to modify existing EMS to study complex contingencies
- Definition of N-1 contingencies and active/disable status are coming from EMS and updated automatically.
- PCM software requires labels of N-k CTGs only but not definitions
- 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



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

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

- More lines were tripped in LowProbability scenario
- Those extra tripping were serving as remedial actions preventing to develop cascade into critical one
- “Accidental” discovery of “line switching” as remedial action

Example of Results

High level results

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

Timer of Critical PCM

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 S (892 MVA 112.1%)
	Violations Index 12.1%	
	Load Loss 0.5 MW	
	S O	329.5 MW
Tier 2		
	RemoveTransformer 18015-18005 1	B S
	Stability Violation	
	Load Loss 0.5 MW	
	S CO	329.5 MW
	Cascade propagates beyond NEPEX	

Detail report of outages in cascade