Transmission Constraint Management at ISO New England

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Introduction

• Existing Transmission Constraint Management has been built incrementally over decades for traditional power systems

• Dramatic changes in operational environment
  – Increasing level of uncertainty and complexity
  – Higher penetration of intermittent resources
  – Fundamental change in generation mix
  – Greater security challenges for the Electric grid that blends physical grid, communication, hardware and software

• Operating uncertainties of the future grid
  – Extended set of contingencies (uncertainties)
  – The increasing probability of cascading events
  – The increasing impact of more frequent extreme weather events

• All these trends require significant changes in the Transmission Constraint Management. This presentation discusses four areas of the improvement
Shifting from Reliability-based to Risk-based dispatch.
Online Cascading Analysis as a practical approach
Need to look beyond N-1 security

• Traditional dispatch is based on N-1 security concept and preventively mitigates thermal, voltage and stability violations assuming 100% probability of contingency

• Applying the same approach for N-k, k>1 is prohibitively expensive

• “Violation” itself does not indicate actual risk to the system, such as MW of lost generation and load

• N-k, k>1 events can be secured by using risk-based approach

\[
\text{Risk} = \text{Impact\_of\_event} \times \text{Probability\_of\_event}
\]

• Impact\_of\_event can be expressed as MW of lost generation and load

• Only high-risk N-k events need to be mitigated

• Online Cascading Analysis is a practical way of estimating Impact\_of\_event and identify high-risk initiating N-k events
Example of a Risk-based dispatch

Risk-based dispatch

Reliability dispatch

EMS → N-1 contingencies → Real-Time Contingency Analysis → N-1 creating violations → Dispatch

~10^3

Resilience dispatch

Contingency Screening → Credible N-2 → Online Cascading Analysis → Critical N-k, k>1

~10^3

Credible N-k, k>2 → Steady-state simulation → Dynamic simulation

~10^3-10^4

<10-20
Online Cascading Analysis (OCA)

- OCA is used to *dynamically* identify high-risk N-k contingencies
  - Need to mitigate only these contingencies in addition to N-1
  - Integrated with the ISO-NE EMS and runs 24/7

- Identified by the OCA high-risk contingencies are mitigated via regular dispatch*
  - “N-1 stuck breaker” and N-2
  - N-k with elevated probabilities related to weather conditions

* Mitigation is not implemented yet in the existing pilot OCA process
OCA Data Flow

Every 3 min

EMS
- State Estimation
- EMS N-1 CTGs

N-2 Contingency Screening
- Assign probabilities
- Select N-k with elevated probability

Every 7-9 min

Online PCM
- Steady-state cascading analysis

Every 3 min

Online TSAT
- Time-domain cascading analysis

Every 3-5 min

Web based viewer for both PCM and TSAT results

Other processes including risk calculation

User’s PC

IIS

Full OCA cycle: 3-5 min

NOAA Weather data

Every hour

Screening reduces initial set of ~6,000,000 to ~500-2,500

PCM run ~1,500-7,500 dynamically screened CTGs (three scenarios)

TSAT run < 100 dynamically screened CTGs

* CTG: Contingency
PCM: Potential Cascading Mode
OCA Display

High level results

Historical view

Summary Report

Detail report

Filtering fool

Color coded results of ~6000 contingencies
OCA Statistics on MW Outages

- Estimated MW impact of critical N-2 and Stuck Breaker initiating events
- Statistics for July 18-24, 2019
Extreme Weather Impact Monitoring
Extreme Weather Impact (EWI) Monitoring

• The tool performs real-time weather impact assessment, including predicting future equipment outage probabilities due to severe weather conditions, using:
  – Weather data on wind, ice-rain, lightning, etc.
  – ISO operational data, including network topology, load flow, etc.
  – Fragility curves of transmission structures (towers and conductors)
  – Machine learning models to account for uncertain impact factors.

• The tool calculates the probabilities of
  – N-2 and “Stuck breaker” contingencies
  – Identifies N-k, k>2 with elevated probabilities

• The calculated contingency probabilities and identified N-k are fed into the OCA process
Main Methodologies for Computing Failure Probabilities – Structural Failures

• Conditional failure probabilities of the power transmission equipment subject to weather conditions
  – Develop fragility curves based on the finite element models of transmission structures (towers and conductors)
  – Train deep learning models with utility outage data to study other factors such as tree trimming schedules.
  – Collaboration with university civil engineering experts.
9-Hour Look-Ahead EWI Assessment (Hurricane Sandy, 12/29/2012)
Online Calculation of Interface Limits
Objective

• Interface limits are used as a proxy transmission constraint to enforce the stability-, voltage- and N-1-1 thermal-based limitations

• Majority of stability- and voltage-based limits are calculated offline (months before the real-time)
  – Thermal limits are typically calculated once a day

• Issues
  – Potential inconsistency in modeled and actual real-time system state creates inaccuracy in limits
  – Offline calculated limits are typically conservative
  – A lot of effort to account for uncertainties in offline studies

• Solution: online calculation of as many as possible interface limits
Challenges

• Deficiencies of Real-Time EMS model for voltage and stability studies
  – Lack of modeling of sub-transmission and distribution parts
  – Lack of dynamic data (available in planning model)
  – Lack of modeling of external areas for dynamic studies

• Software tools
  – Multiple commercial tools can be used for online studies
  – Powertech Labs VSAT and TSAT are the ISO-NE tools of choice
  – “Black box” dynamic models from the PSSE planning model should be converted to standard models for the use in TSAT

• Operators’ Concern of being overly-dependent on the automated tools for the limit calculation and losing the skills doing it manually when the software is unavailable
VSAT Implementation: steady-state limits

• Online calculation of voltage-based N-2 limit for Connecticut interface was implemented in 2016.
  – Complex design with five scenarios including 2D nomograms
  – Accumulated experience and lesson learned

• Future plans
  – Extend for other voltage-limited interfaces
  – Add calculation of thermal N-1-1 limits
  – Optimize EMS – VSAT interaction to make the setup flexible and scalable to serve ISO-NE needs
**TSAT Implementation: stability limits**

- The framework to use TSAT with EMS model has been established.

- The framework is used for:
  - Pilot calculation of stability interface limits; run cycle 15 min
  - Online Cascading Analysis; run cycle 3-5 min

- Future plans:
  - Staged implementation of online calculation of stability limits. Easy to implement limits come first.
  - Systematic identification and elimination of obstacles for online calculation of stability limits
  - Development of adaptive, PMU-based dynamic equivalent for the external system
Existing Dynamic Equivalent

- Number of generators in the Eastern Interconnection (EI) model > 8,000
- DYNRED software was used to create equivalent of EI beyond NYISO
  - Equivalent preserves modal structure of inter-area oscillations
  - Modal structure changes over time and a static equivalent is not always accurate to model inter-area oscillations for Study Area (ISO-NE)

Diagram:
- Equivalent ~1000 generators
  - External area
- NYISO Relatively detail model
  - ~400 generators
  - Buffer area
- ISO-NE Detail model
  - ~600 generators
  - Study area
- New Brunswick ~40 generators

Connectors:
- 17 AC tie-lines
- 8 AC and 1 DC tie-lines
- 2 AC tie-lines
**Desired Dynamic Equivalent**

- Each of 17 tie-lines between NYISO and EI is replaced by a Transfer Function (TF)
  - Input for TF: measurements from ISO-NE or NYISO
  - Output of TF: MW and Mvar flow in tie-line

- TF is periodically updated online by using PMU measurements

- TF can be modeled as User Defined Model in TSAT
Transmission Operating Guide Formalization
Transmission Operating Guide (TOG)

- TOG is a paper document defining a process (type of lookup table) to select stability-based interface limit value as a function of power system state.
  - Number of stability TOGs ~200

- TOG is created offline by converting results of stability studies into a type of lookup table

- TOG limit is used as a transmission constraint

Deficiency: TOGs are paper documents not allowing automated translation of limits into other processes using TOGs
  - Significant manual efforts to use TOG’s limits in other processes
  - A possibility of different interpretation of TOG by different people
Formalized Description of Limits in TOG

• A developed structure allows representing any existing paper TOG in a digital format, including data and logical conditions

![Diagram of M, L, A, B matrices and conditions]

- **Any** $c_j$ is a real number: any system parameter or logical conditions (0-false, 1-true)

- Each $m_{ij}$ element is a pair of real numbers defining lower and upper bound for $c_j$

1. Each row $m_i$ is a filter to select a system state in TOG by using $c_j$.
2. Matrix $M$ is created in a way that not more than one filter is TRUE for any given system state.
Calculation of Limit

For any power system state:

Step 1: Calculate values of Conditions \( c_j, j = 1, \ldots, n \)

Step 2: Find the row \( i \) which has \( \sum_{j=1}^{n} c_{ij} \cdot a_{ij} \leq b_i \). Set \( i = 0 \) if all \( \sum_{j=1}^{n} c_{ij} \cdot a_{ij} = b_i \).

Step 3: Calculate limit value

\[
Lim = \begin{cases} 
\min\{(l_i + \sum_{j=1}^{n} c_{ij} \cdot a_{ij}), b_i\} & \text{for } i \neq 0 \\
99999 & \text{for } i = 0 
\end{cases}
\]

Fully formalized process allowing automated calculation
Use of TOGs

Old process

- EMS
  - EMS Modeling Group
    - TOG in paper format
    - Engineers
    - Tedious, manual
  - Other processes

New process

- EMS
  - EMS Modeling Group
    - TOG structure
    - Engineers
    - Automated
  - Other processes
  - TOG in paper format

- Other processes

• Drastic improvement efficiency of the TOG utilization.

• Automated conversion of TOG-related study results (hundreds) into TOG structure by using the Decision Tree technology.
Conclusion

• Future Electric Grid with an increasing level of uncertainty and complexity calls for significant changes in the Transmission Constraint Management

• The Risk-based operations provide a unified framework for reliability and resilience metrics

• Online Cascading Analysis is a practical approach to measure the impact of initiating events including the events caused by severe weather conditions

• Moving offline calculation of interface limits online is an efficient way to manage uncertainties
Questions