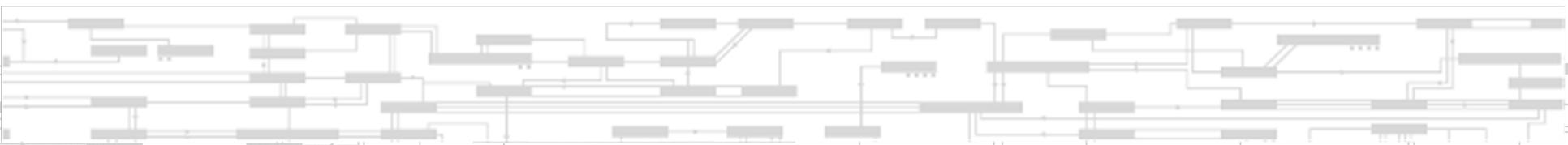


# Voltage Control and Coordination at ISO New England



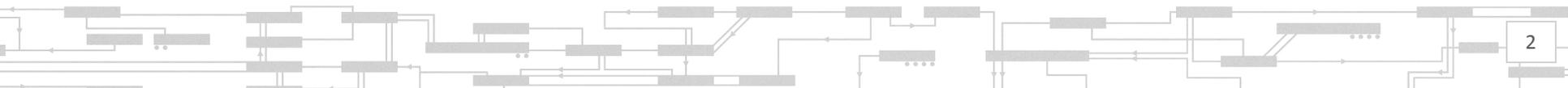
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*Second Annual Meeting of the ISOs on Future  
Market Design and Software Enhancements*



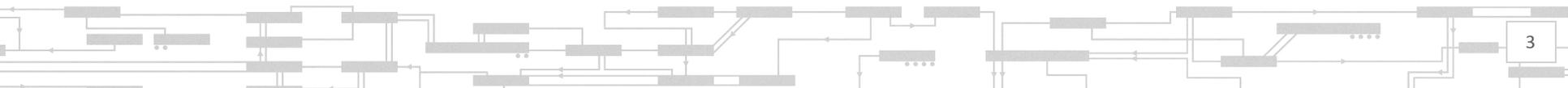
# Outline

- Overview of New England's electric power system
- Responsibilities of voltage control
- ISO New England's operation practice in voltage control
- Var service payment
- Application of AC OPF and challenges
- Future plans and summary



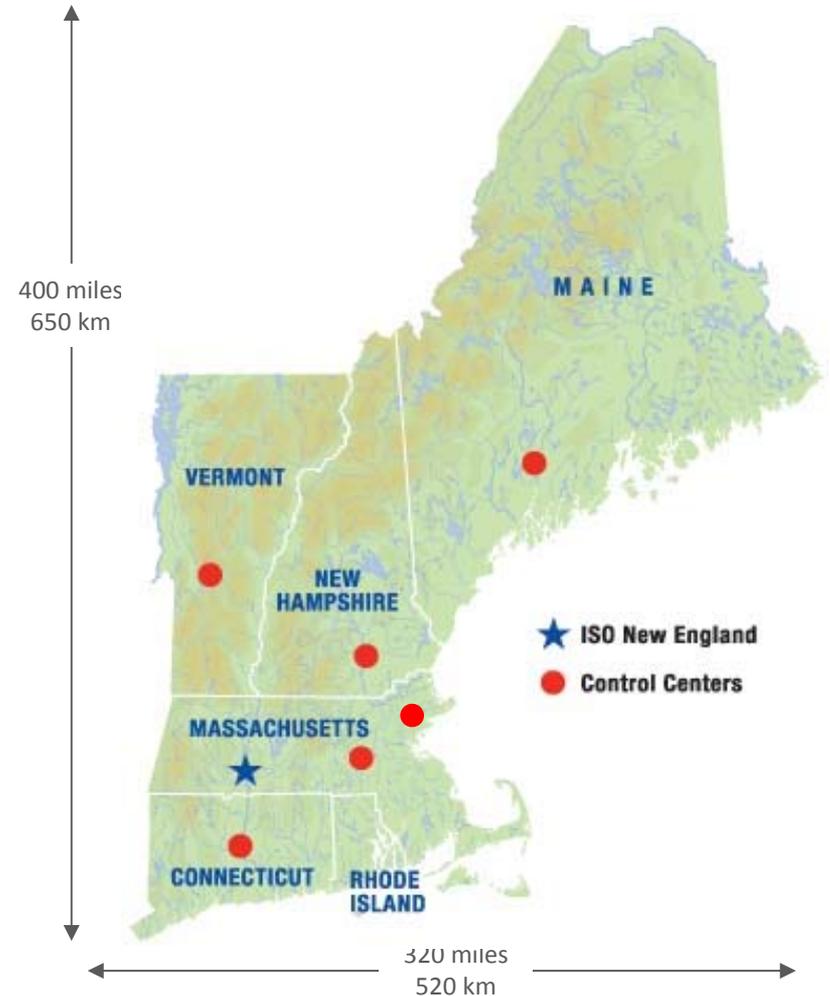
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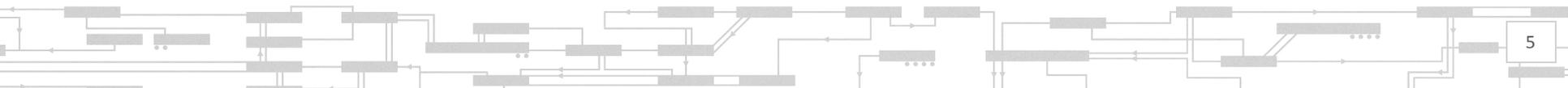
# New England's Electric Power System

- 6.5 million electricity customers; population 14 million
- 350+ generators, 400+ Participants
- 8,000+ miles of high-voltage transmission lines
- 13 interconnections with systems in New York and Canada
- 32,000 MW of installed generation capacity
- Peak demand: 28,130 MW on August 2, 2006 (after approximately 640 MW of load reduction from DR programs and other actions)



# New England's Electric Power System (Cont.)

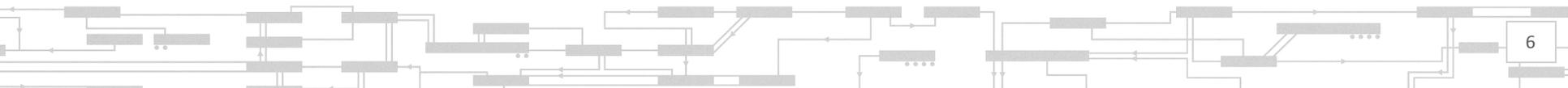
- HVDC Facilities
  - Three Conventional HVDC Facilities
    - Highgate
    - Comerford Phase I (retired)
    - Sandy Pond Phase II
  - One Voltage Source Converter HVDC Facility
    - Cross Sound Cable
- FACTS Controllers
  - Two Static VAR Compensator (SVC): Chester, Barnstable
  - Three STATCOMs: Essex, 2 at Glenbrook
  - Three DVAR: 2 at Stony Hill, 1 at Bates Rock
- Synchronous Condenser
  - Four at Granite



# New England's Electric Power System (Cont.)

## Low Voltage and voltage collapse concerns:

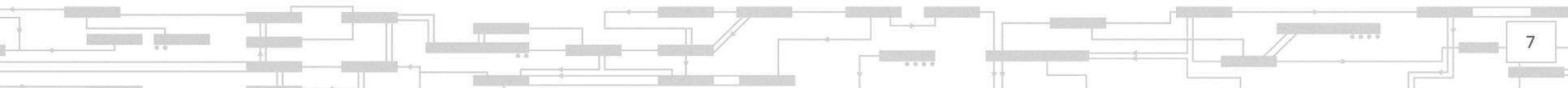
- Heavy power transfers within New England and with neighboring systems
- Transmission line outages and unavailability of some units during heavy load conditions
- Certain areas in New England are highly compensated; the critical voltage at voltage collapse point is relatively high which could put the system at risk even when the voltages are within the normal ranges.



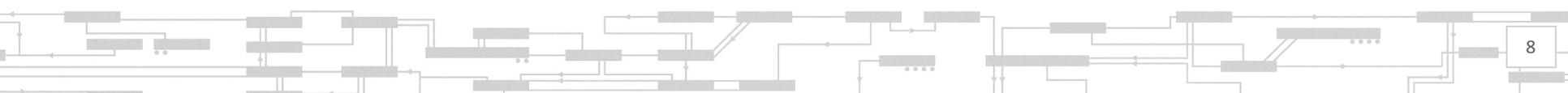
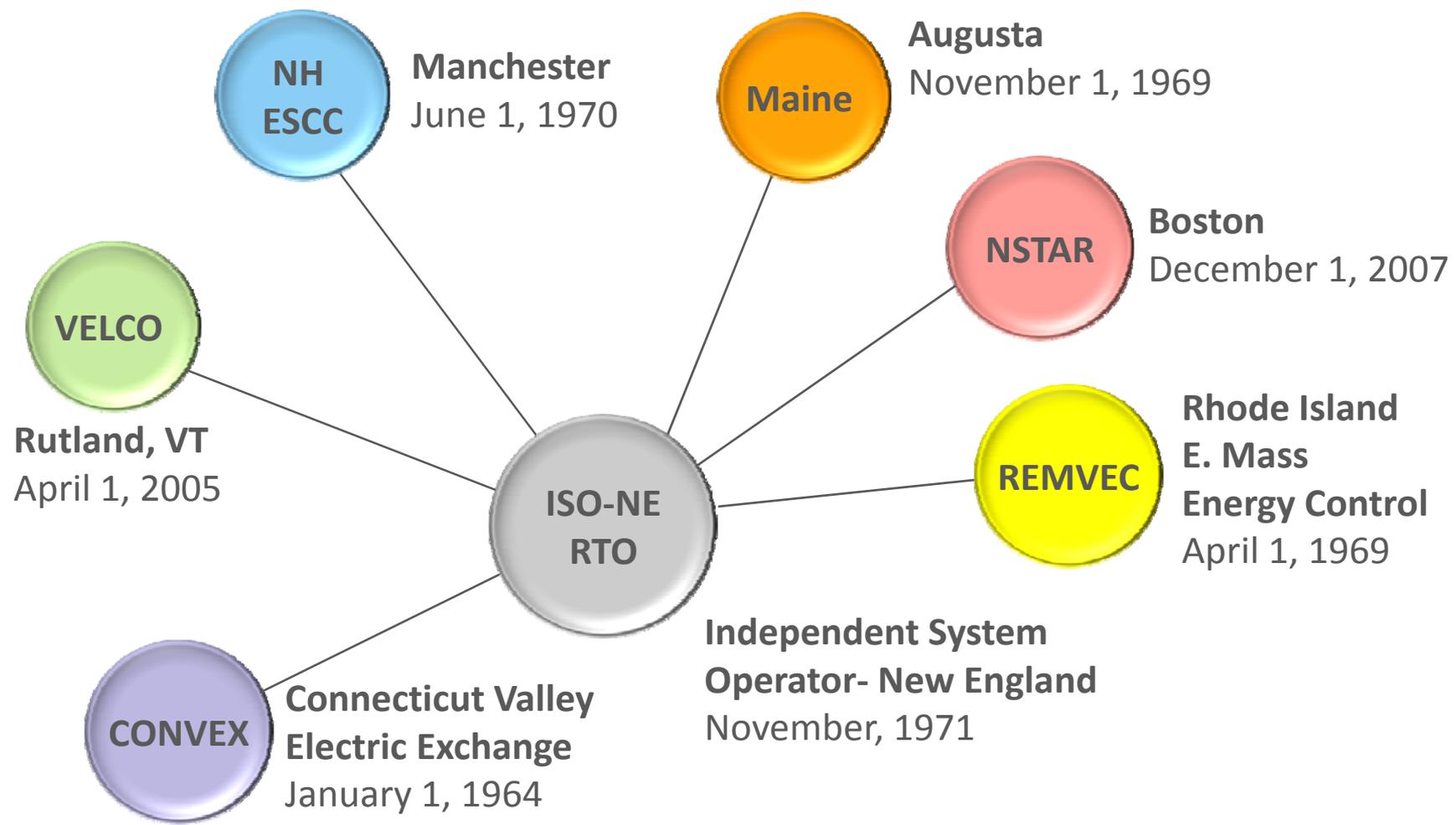
# New England's Electric Power System (Cont.)

## High Voltage Concerns:

- Added new transmission lines for peak load needs is adding capacitive charging
  - Underground cables in Boston and Southwest Connecticut
  - High pressure, fluid filled cables (i.e. HPFF) have approximately 20 MVAR / mile of charging
- Added capacitors (distribution and transmission) for peak load; high voltage concerns need to be managed during lighter load periods
  - Transmission level capacitors are normally switchable
  - Sub-transmission and distribution capacitors may or may not be switchable
  - Many areas do not remove all lower voltage capacitors during the light load seasons (spring and fall)
- Reductions in light load levels
- Lengthy generator outages

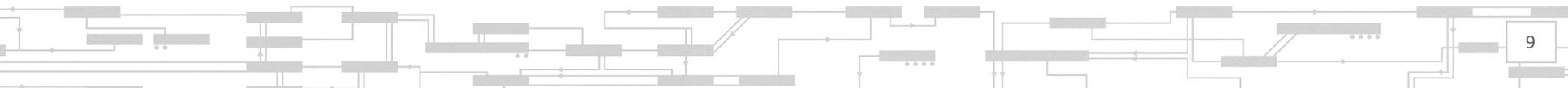


# ISO – Local Control Center (LCC)



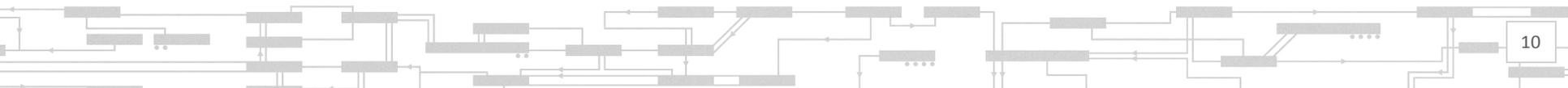
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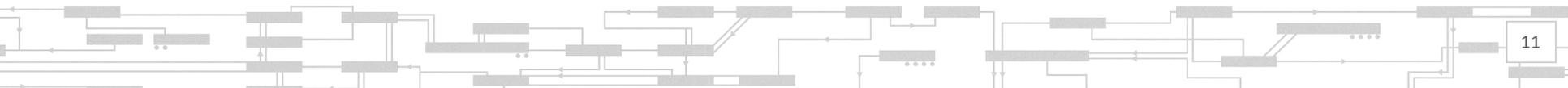
# Responsibilities of Voltage Control

- Generator and Transmission substations are responsible for:
  - Maintaining station services and other local voltage requirements and scheduled voltages.
  - Maintaining voltage schedules set at the high side of the generator step up transformer.
  - When unable to maintain scheduled voltages the generating or transmission station operators must notify their respective LCC operator.
- Local Control Centers are responsible for :
  - Detecting and correcting deviations from normal scheduled voltage/reactive operations.
  - Responding to notifications by station operators of difficulty in maintaining station or other local voltage or reactive schedules.
  - Responding to ISO requests to assist with inter-LCC or inter-Area problems.



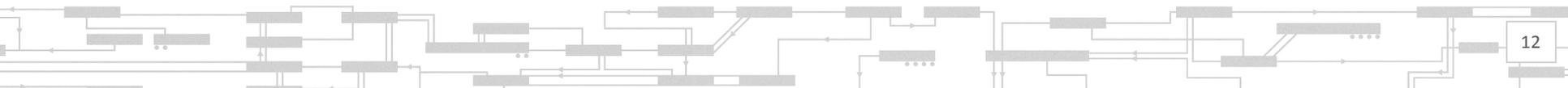
# Responsibilities (cont'd)

- Local Control Centers also monitor and supervise the following within their territories:
  - Voltage schedules and limits
  - Unit MVAR loadings, capabilities and reserves
  - Shunt capacitor and reactor dispatches
  - Transformer voltage schedules or fixed tap settings
  - MVAR flows between the AC and HVDC facilities
  - Static VAR Compensator operation (must be coordinated with ISO)
  - Line switching for voltage /reactive control (must be coordinated with ISO and other LCCs)
  - Load management (must be coordinated with ISO)



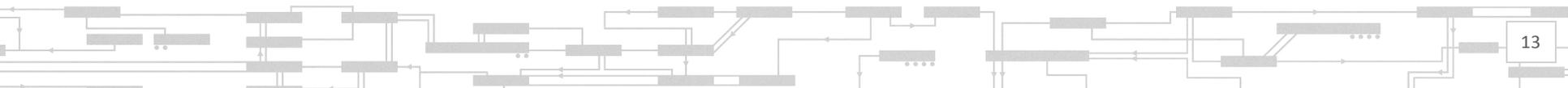
# Responsibilities (cont'd)

- ISO-NE is responsible for:
  - General monitoring and supervision of voltage/reactive conditions in the New England area (115KV and above)
  - When a LCC reports to the ISO that it is not possible to correct a problem at a station or LCC level, the ISO will assume direct responsibility for alleviating the problem
  - Monitoring and supervising voltage/reactive operations of inter-Area ties
- ISO-NE is authorized to work with/through the LCCs to eliminate voltage problem using:
  - All actions of LCC, and
  - Unit MW re-dispatching



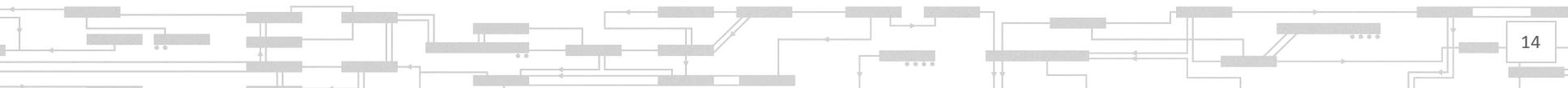
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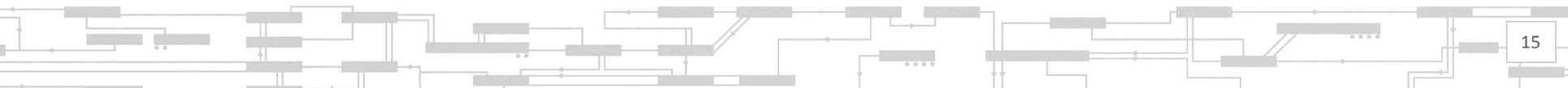
# Bulk Power Substation

- Minimum and Maximum voltage limits are established based on substation equipment ratings and customer voltage requirements
- The limits provide adequate distribution bus voltages during various system loading conditions and potential contingencies using the full capabilities of the transmission network reactive resources:
  - load tap changing equipment
  - shunt devices (capacitors / reactors)
  - dynamic devices (SVCs, STATCOMs, synchronous condensers)



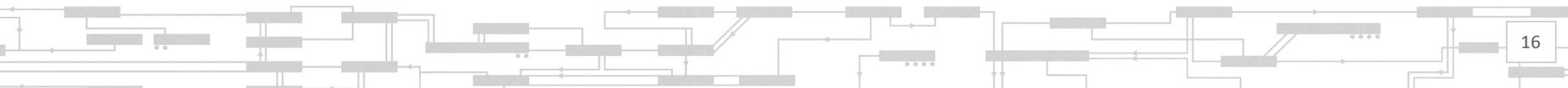
# Voltage Profiles

- ISO New England Operating Procedure No. 12
  - Voltage schedule, maximum and minimum voltage
  - Heavy load period & light load period
- Coordinated studies through Voltage Task Force (VTF) among ISO, LCC and Transmission Owners
  - Power flow (contingency analysis) and stability study
  - Different system topologies
  - Different system transfers
  - Different generation dispatches
  - Different load levels



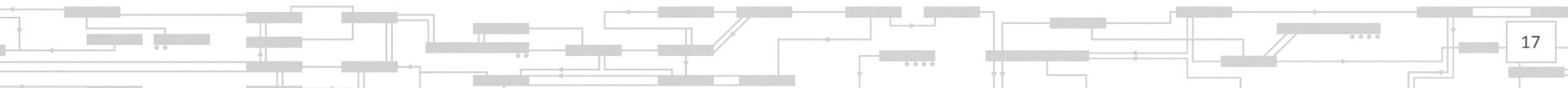
# Voltage Profiles (Cont.)

- Once voltage schedules are determined by VTF, all the planning studies use them as given inputs
- Thus when planned projects move into operations, the voltage profiles will be maintained
- All short-term operational studies and real time EMS power flow analysis use the voltage schedules as inputs as well
- In real time operations, generator needs to adhere to its voltage schedule at all times, unless instructed to do otherwise by an LCC or the ISO



# Operations Planning

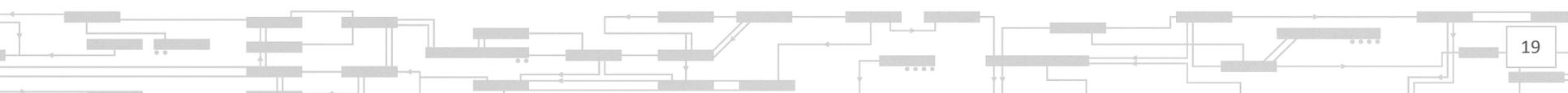
- Perform seasonal and line outage power flow and stability analysis to establish operating guides (many of them are voltage related)
- Calculate transmission interface transfer limits to avoid low voltages
- Establish operating Nomogram to ensure no violation of established thermal, voltage and stability limits
- Verification of generation reactive capability



## Voltage/Reactive Documents in the ISO New England Transmission Operating Guides

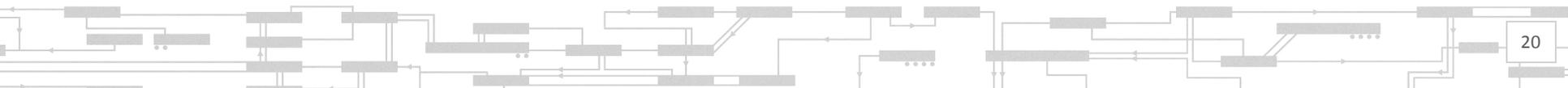
Voltage/Reactive Document	1	2	3	4	5	6	7
	Voltage Limits	Units Critical to Voltage Control	Required Reactive Reserves	Shunt Information	Interface Voltage Transfer Limits	Line Switching for High Voltage	Load Management Actions
Eastern Massachusetts and Rhode Island Low Voltage Guide	X		X	X			X
Northern New England Transmission Corridor-Low Voltage Guide	X	X		X			X
Northern New England Transmission Corridor-High Voltage Guide	X	X		X			X
Orrington Capacitor Bank Control Operating Guide	X			X			
Boston Import Area Operations Planning Guide and Operations Guide	X			X		X	X
Northern Vermont Interface (NVI) Limit Guide	X	X	X		X		
M/LCC 9 - Operation of the Chester SVC	X		X	X			
M/LCC 1 - Nuclear Plant Transmission Operations, Atts A, B, C, & D	X						
Procedure to Protect for Loss of Single Source Contingency Guide					X		
Southwest Connecticut Import Voltage/Reactive Limit Guide	X	X			X		
Tremont-East Area Operations Guide	X	X	X	X	X		X
Connecticut Import Voltage/Reactive Limit Guide	X	X			X		
New England to New Brunswick Voltage/Reactive (V/R) Limit Calculator Guide	X	X	X	X	X		
VELCO Highgate Converter Export Guidelines	X		X	X	X		

Voltage/Reactive Document	1	2	3	4	5	6	7
	Voltage Limits	Units Critical to Voltage Control	Required Reactive Reserves	Shunt Information	Interface Voltage Transfer Limits	Line Switching for High Voltage	Load Management Actions
Voltage Reactive Coordination of New England-New Brunswick Interface Guide	X	X	X	X	X		
Western Maine Area Voltage Support Requirements Guide		X	X	X			X
Southwest Connecticut Unit Commitment Requirements		X	X	X			
Pittsfield Area Operating Guide	X	X		X			
Connecticut Operating Guide	X		X		X		X
Halvarsson-Tomson 481 Line Guide	X						
Norwalk Harbor-Northport 601, 602 & 603 Cables Operating Guide	X						
388 Line Out Guide		X					X
ISO-NE – NBSO CDI-001 Operating Guide			X	X	X		
NewPage Plant Load Shedding Scheme Description Guide	X						X
C-040 Common Dispatch Instructions for HQ & ISONE for ± 450 kV DC Line					X		
Gen-C-042 Common Operating Instruction for the Phase II Facilities	X			X	X		
M/LCC 5 Att B - Procedure for Millstone Point Station Generation Reduction		X			X		
Northwest New England 345 kV High Voltage Guide	X	X	X	X		X	



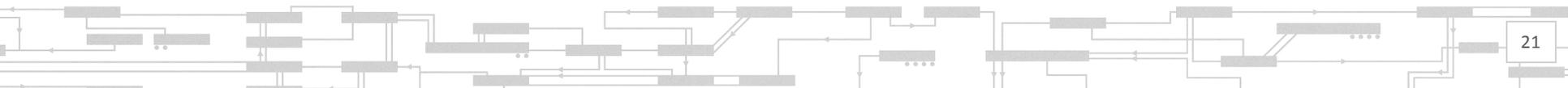
# Day Ahead

- Transmission interface limits (MW) are used as a surrogate for the voltage limits
- Double contingency proxy limits are enforced for pre-defined areas in clearing the day-ahead market
  - “Line – Line” contingency
  - “Line – Generation” contingency
  - Consider 30 minutes system responses
- System reactive resources and/or must run units are committed per system operating guides to control high / low voltage conditions



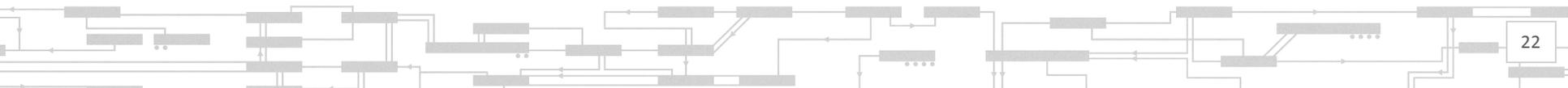
# Real Time

- Local Reserve Requirements (LRR) are enforced during real time dispatch
  - Difference between 1st contingency and double contingency interface limits
  - Double contingency limits: minimum of thermal and voltage limits
- Adherence to voltage / reactive schedules for generators and transmission devices
- Unit MW redispatch (down) to provide VAR support when needed
- Transmission network adjustments, potentially including line switching, to control high voltages in certain areas



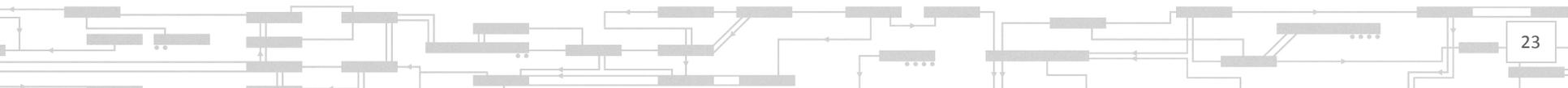
# Applications or Tools

- EMS environment:
  - Alstom's PWRFLOW and RTCA
  - In-house developed ILC and DOUBLEC
- Operations Planning and Day Ahead
  - PSSE (Power flow and stability analyses)
  - In-house developed TTC Calculator based on Power World (interface limits)

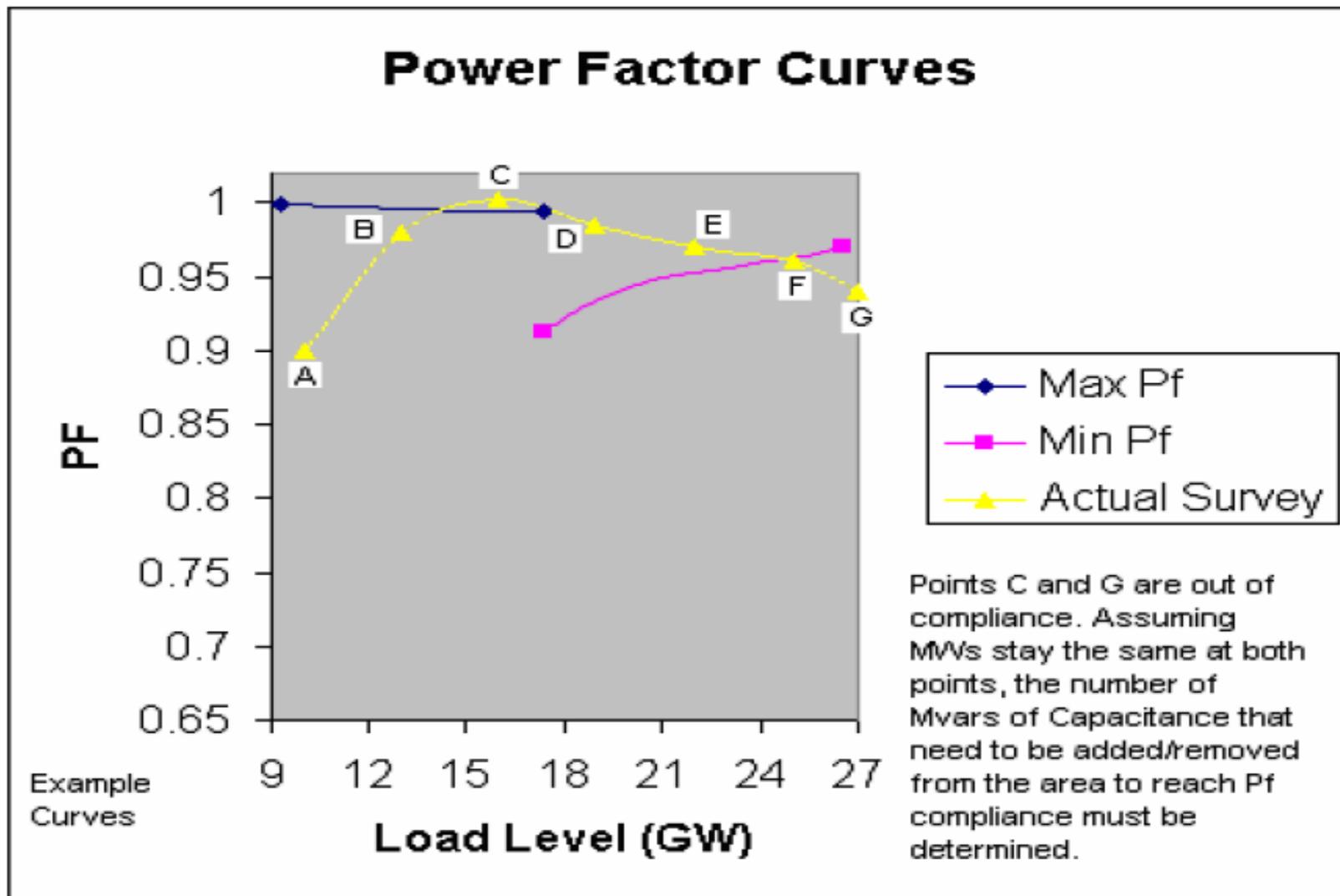


# Load Power Factor Requirements

- Ranges of acceptable load power factors for various zones within the New England Control Area
  - Determined through load flow simulation at three load levels
  - Reviewed by ISO and Voltage Task Force annually
- Transmission Owners monitor the load power factor of all connected distribution loads
- ISO conducts power factor survey on an annual basis and evaluates the audit results
- If non-compliant, shunt capacitors or reactors need to be added on the distribution system to achieve compliance

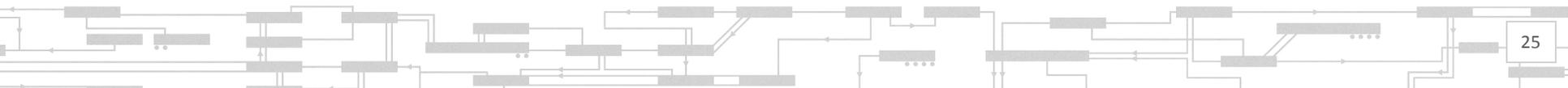


**Figure 1: Sample Power Factor Curve and Survey**



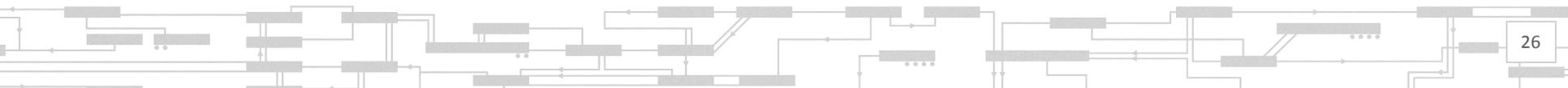
# Load Power Factor Use

- Survey data utilized to create accurate models of system performance for off-line analysis
- Used in operating studies
  - Accurate load power factors are often critical for optimization of reactive resource and system voltage control
- Used to develop region-wide assumptions for load power factor for system planning work



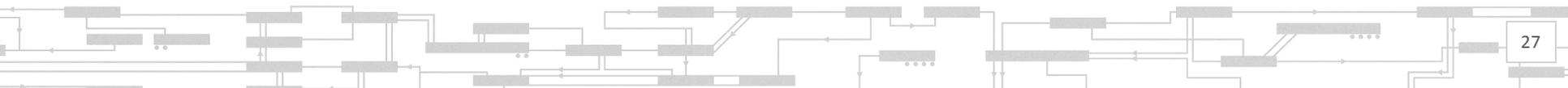
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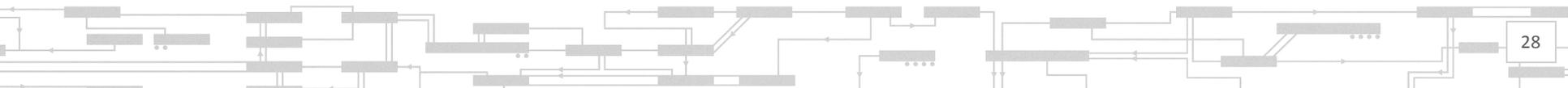
# VAR Service Payment

- Qualified Reactive Resources (QRR) are compensated for reactive supply and voltage control service under Schedule 2 of the Open Access Transmission Tariff
- Schedule 2 compensates for four components:
  - Capacity Cost
  - Lost Opportunity Cost
  - Cost of Energy Consumed
  - Cost of Energy Produced



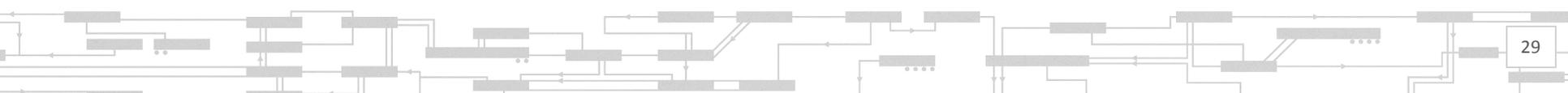
# VAR Service Payment – Fixed payment

- Capacity Cost
  - $Mvar \times \text{Schedule 2 VAR Rate } (\$/Mvar\text{-year})$
  - Include both leading and lagging VAR capability
  - Must perform leading and lagging reactive capability tests at least once every five-years
- Lagging reactive capability tests
  - Generate MWs within 95-105% of its S-SCC for at least 60 consecutive minutes
  - The average of the 5-minute interval MVAR values achieved over the course of the test will be utilized to determine the Qualified VARs
- Leading reactive capability tests
  - Generate MWs within 95-105% of its EcoMin for at least 60 consecutive minutes
  - The average of the 5-minute interval MVAR values achieved over the course of the test will be utilized to determine the Qualified VARs



# VAR Service Payment – Variable Payment

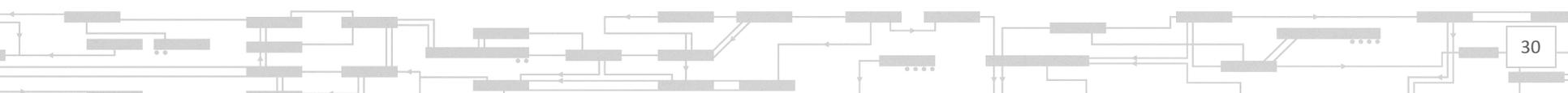
- Lost Opportunity Cost
  - Payment for generators that are dispatched down by the ISO for the purpose of providing VAR Service
- Cost of Energy Consumed
  - Payment associated with hydro and pumped storage generating units that are motoring at the request of the ISO or a LCC for the purpose of providing VAR Service.
- Cost of Energy Produced
  - Payment that compensates a generating unit if the ISO or LCC brings the unit on line (and the unit produces real power) for the purpose of providing VAR Service.



# VAR Service Payment (Cont.)

- Each Qualifies Reactive Resource (QRR) must have its AVR data, including operating mode and set-point, telemetered (ICCP) to the ISO and LCC as a condition for receiving Capacity Cost compensation.
- Unless directed by the ISO or the LCC, each QRR must have its AVR turned on and in terminal voltage control mode at all times.

AVR Voltage Control Mode	Telemeter Code
Fixed excitation (AVR Off)	0
Automatic, Controlling voltage	1
Automatic, controlling Vars	0
Automatic, controlling power factor	0

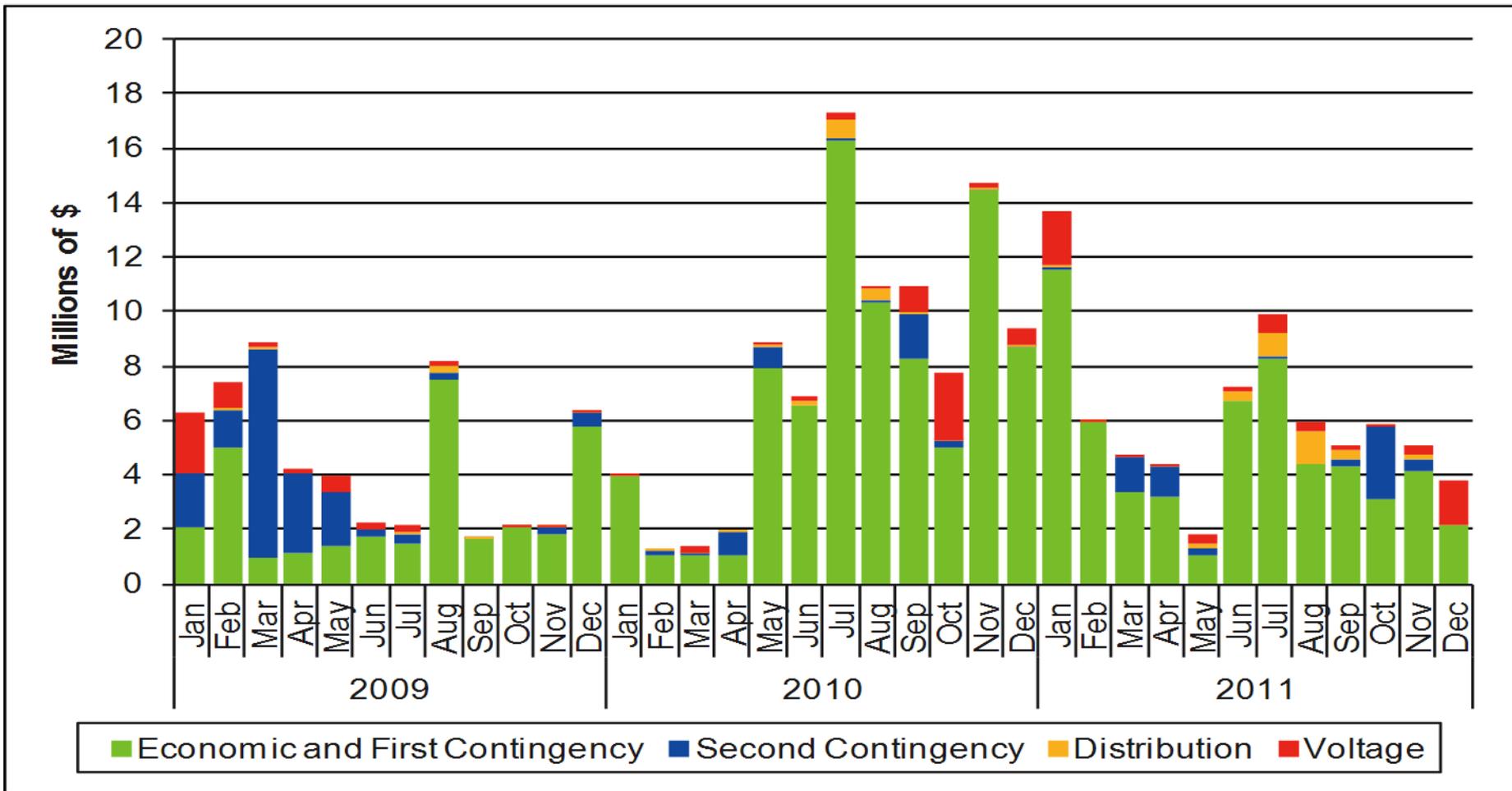


# Total Daily Reliability Payment

Payment Type	2009	2010	2011
Economic and first-contingency payments	32,556,784	84,719,772	58,137,524
Second-contingency reliability payments	17,527,919	3,898,515	6,150,674
Distribution	586,034	1,635,375	3,358,238
Voltage	5,006,698	5,084,097	5,923,494
Total	55,677,435	95,337,758	73,569,931

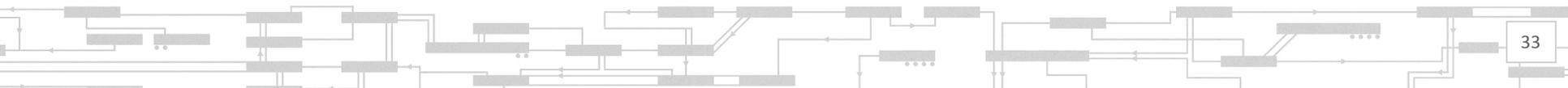
# Daily Reliability Payment by Month

## (January 2009 – December 2011)



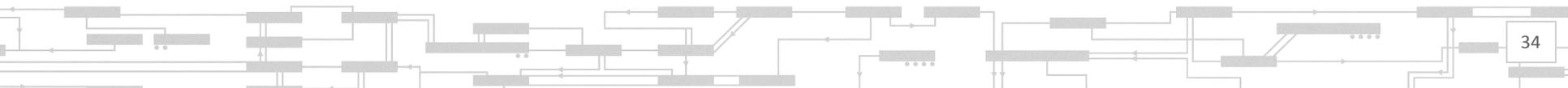
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# AC OPF

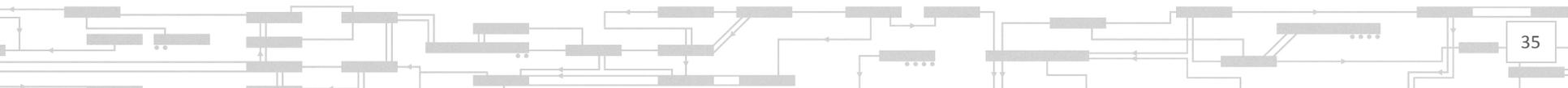
- Current practice in day-ahead and real-time market is using proxy interface limits to represent voltage constraints
  - Manual unit commitment for local voltage constraints
- Theoretically the voltage constraints can be explicitly modeled in AC OPF



# Challenges of AC OPF in Power Market

Software and algorithm:

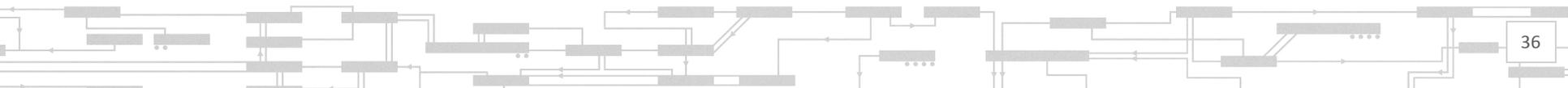
- Non-convexity
- Local optimum; no global optimization algorithm for large scale system
- Robustness (convergence difficulty)
- Solution speed
- Security constrained ACOPF still requires linearization
- Additional complexity:
  - Model voltage stability constraints and N-1-1 contingencies
  - Unit commitment (besides dispatch) for voltage support
  - Commitment and pricing of discrete reactive devices such as shunt and transformers
  - Reactive power assumption for load in DA market (bid-in load and virtual bids)



# Challenges of AC OPF in Power Market (Cont.)

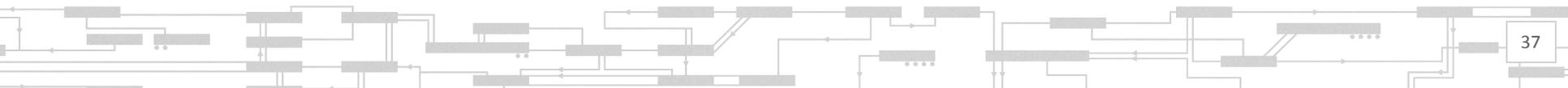
## EMS Models:

- EMS is accurately tuned for real power modeling after years of market operations
- EMS has certain deficiencies in reactive modeling
  - Equivalent of sub-transmission and distribution system
  - Lack of reactive metering and problems with reactive power signs
  - Metering accuracy for voltage
    - Most older potential transformers (PTs) may only have an accuracy of +/- 1.5%, which is an error of +/- 5 kV on 345 kV base
    - Newer PTs can have an accuracy of +/- 0.3%, which is an error of +/- 1 kV on 345 kV base



# ISO-NE's Case Studies using AC OPF

- Voltage profile optimization study
  - Objective was to evaluate the robustness and flexibility of NETSS's Extended OPF (XOPF) program
  - Work was done by NETSS in 2009 ; Joint sponsorship from ISO-NE, NYPA, BCTC and Israel Electric through Center for Energy Advancement Through Technological Innovation (CEATI)
  - Quantify the improvement of voltage dispatch in:
    - Voltage security
    - System loadability
    - Operation efficiency (transmission losses)
    - Reactive reserve
    - Corrective dispatch for non-time critical contingencies



# ISO-NE's Case Studies using AC OPF (Cont.)

## Voltage Security

- Employ an optimization that quadratically penalizes voltages outside the range of 0.95-1.05 pu
- Available controls include generator real power and voltages, and transformer settings

Run #	Solution	Controls	Outliers	Worst-Case Outliers (Min , Max) [puV]
-	Original	Original.	9	0.941 , 1.052
24	NETSS	Fixed except for real power generation.	8	0.944 , 1.052
25	NETSS	Variable.	0	None , None

# ISO-NE's Case Studies using AC OPF (Cont.)

## System Loadability

- Employ an optimization that maximizes load within security limits
- Available controls include generator real power and voltages, and transformer settings

Run #	Solution	Controls	Load Increase
34	NETSS	Fixed except for real-power generation.	0.8 %
35	NETSS	Variable.	3.4 %
36	NETSS	Same as Run 35 except for the placement of a 210 MW real-power generator at Bus 73704.	4.4 %

# ISO-NE's Case Studies using AC OPF (Cont.)

## Operation Efficiency

- Minimize total real power generation
- Essentially the same as loss minimization

Run #	Solution	Controls	Generation [MW]	Losses [MW]
-	Original	Original	30567	777
5	NETSS	Fixed except for real-power generation	30533	743
6	NETSS	Variable	30450	660

# ISO-NE's Case Studies using AC OPF (Cont.)

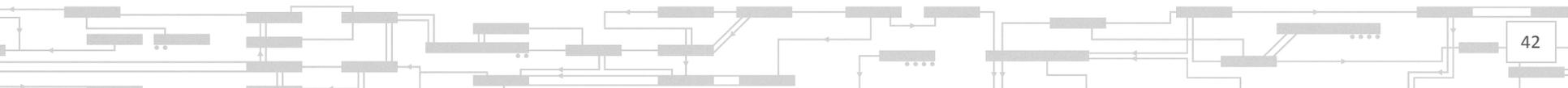
## Reactive Reserve

- Minimize the total of the squared reactive power generated by each generator

Run #	Solution	Controls	RSS Reactive Generation [MVAR]	Real Generation [MW]
-	Original	Original	1492	30567
13	NETSS	Fixed except for real power generation	1418	30500
14	NETSS	Same as Run 13 except for voltage adjustments at buses 72692, 72694, 73110 and 73216	1368	30502
15	NETSS	Same as Run 14 except for additional voltage adjustments at buses 73116 and 73276	1342	30502
16	NETSS	Variable	1152	30492

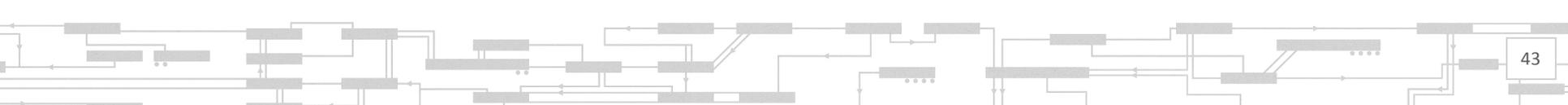
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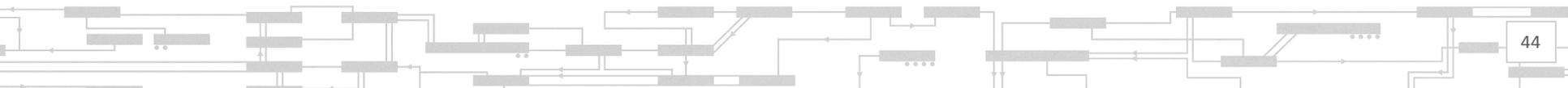
# Future Plans

- EMS model improvement
- On-line voltage stability assessment
- Voltage profile optimization
- EMS/DMS integration



# Summary

- Coordinated hierarchical voltage control is adopted in the New England region
- Dispatch of reactive resources is driven by the system RELIABILITY need
- Proxy interface limits are used to represent voltage violations or voltage stability during commitment and dispatch. They work well to maintain reliable and efficient operations in the market.
- Application of AC OPF in the day-ahead and real-time market is challenging



# Questions

