AC Optimal Power Flow for Day-Ahead Reactive Planning

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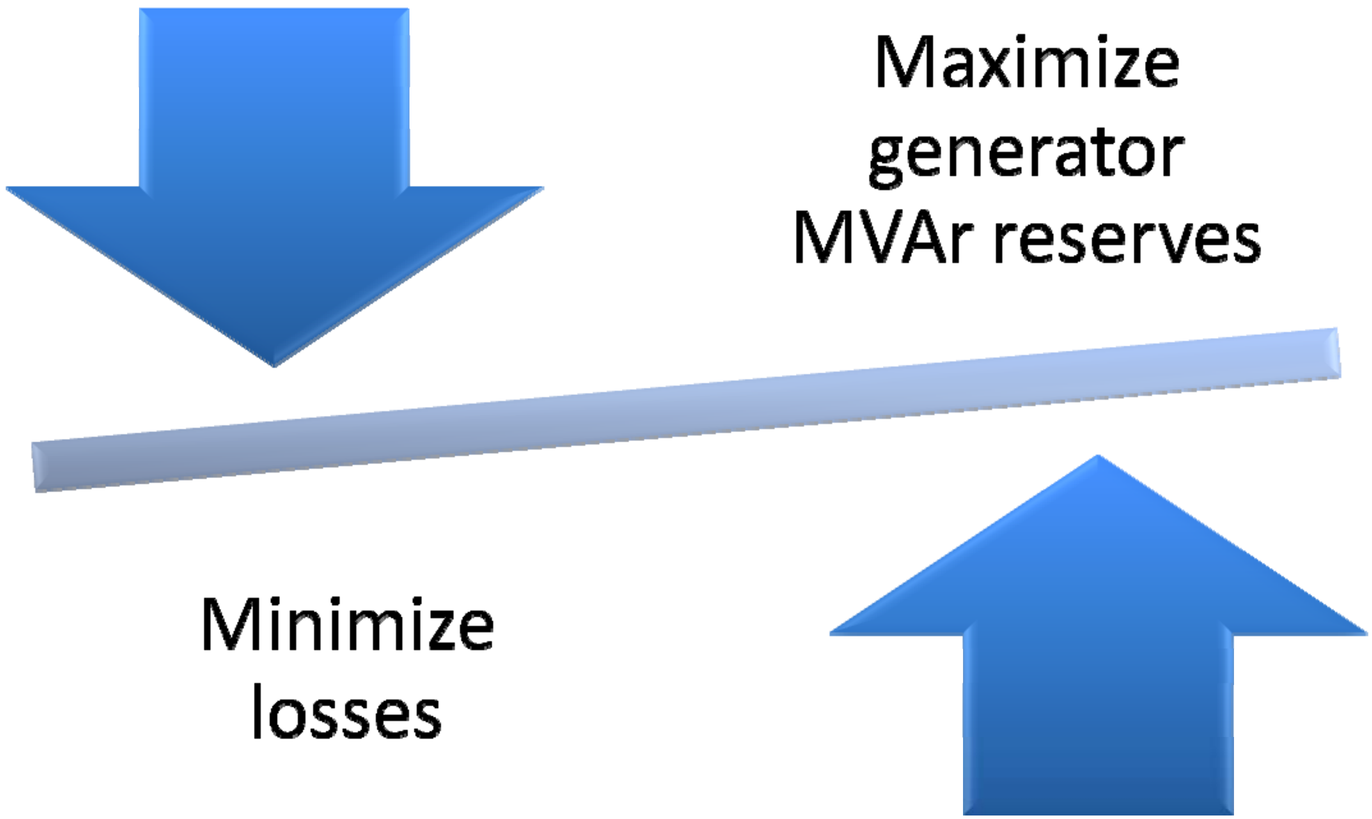
Enhanced real-time optimal power flow market models

Nexant

This Describes an Actual Implementation

- At a major system operator
  - Where MVAr providers generate or absorb within their capabilities, at no incremental cost
  - Voltage regulating devices under the control of the operator are dispatched at no incremental cost
- The result is
  - Hourly voltage/MVAr schedules to support real-time operation, based on the day-ahead MW market (and updated as needed)
  - A practical, tunable, balance between system MVAr-related economy and security

The Operational Objective – A Balance Between:



This is a Specific Application of Reactive SCOPF

- Each reactive SCOPF solution is based on a scheduled MW dispatch from day-ahead SCUC, which is secure in terms of thermal (and some stability) constraints
- An accurate AC model of the network is used
- The OPF produces reactive schedules to support voltage security, without compromising MW security
- Semi-coupled P and Q optimization is an inherent consequence of real-life power system engineering (a) design, (b) operation and (c) control

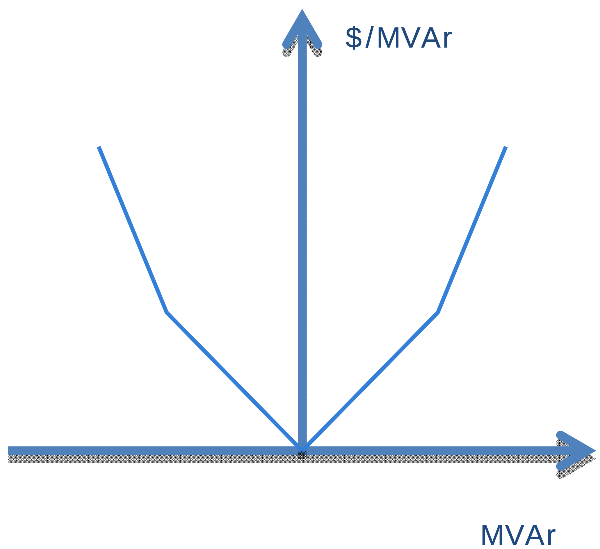
Fully coupled P and Q optimization has mathematical formulations, but it violates (a), (b) and (c) and therefore gives unreliable, often unusable, engineering results

The SCOPF Objective Function

Min: $\omega_1 \Sigma$ MW losses + $\omega_2 \Sigma$ MVAr losses + $\omega_3 \Sigma$ MVArs

- Losses are for designated or all branches and shunts

- Maximizing MVAr reserve ≅ minimizing MVAr generated
  - Therefore, minimize
    - MVArs supplied/absorbed by generating units
    - MVArs through network interfaces
    - By applying "cost curves" to MVArs, discouraging operation near limits



The Hourly Reactive Scheduling Process

Data Preparation

- Merge hourly data
  - Network model, including MW schedule (from EMS)
  - Generator MVAr limits
  - Branch group definition

Reactive Optimization

- Perform reactive SCOPF, computing optimum
  - Settings for regulated voltages, taps and other devices
  - Switching for shunt reactive devices
  - Settings for phase-shifting devices

Output Results

- Voltage settings and profiles
- MVAr dispatches
- Taps (in-phase & out-of-phase) settings

SCOPF Reactive Controls

- Regulated voltage set points
  - Regulated by generators, LTC taps or SVCs
- Directly dispatched transformer taps
- Shunt MVArs
- SVC MVAr set points
- Transformer phase angles
  - For loss and cost minimization objectives
- With multi-level priority activation/deactivation

SCOPF Reactive Constraints

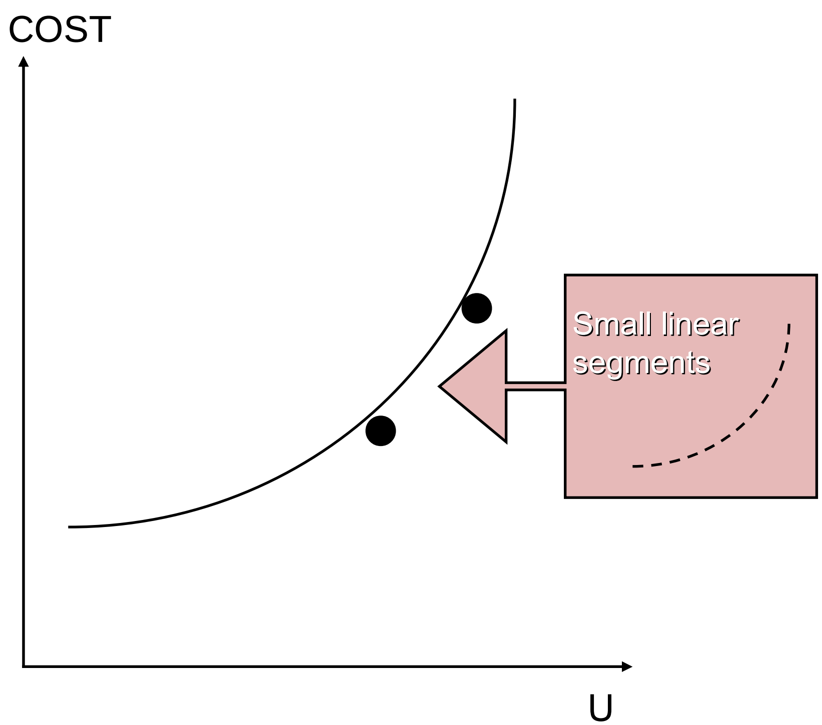
- Full set of pre- & post-contingency constraints (n-1 etc)
  - Branch flows (rated in MVA or amperes)
  - MVAr branch group limits
  - MVAr interchange between zones
  - MVAr generation reserve
  - Generator MVAr limits
  - Voltage high-low limits & rise-drop limits
  - Voltage magnitude differences between assigned pairs of buses
  - Bus voltage post-contingency change
  - Timed response for slow control adjustments
  - Multi-level priority activation/deactivation

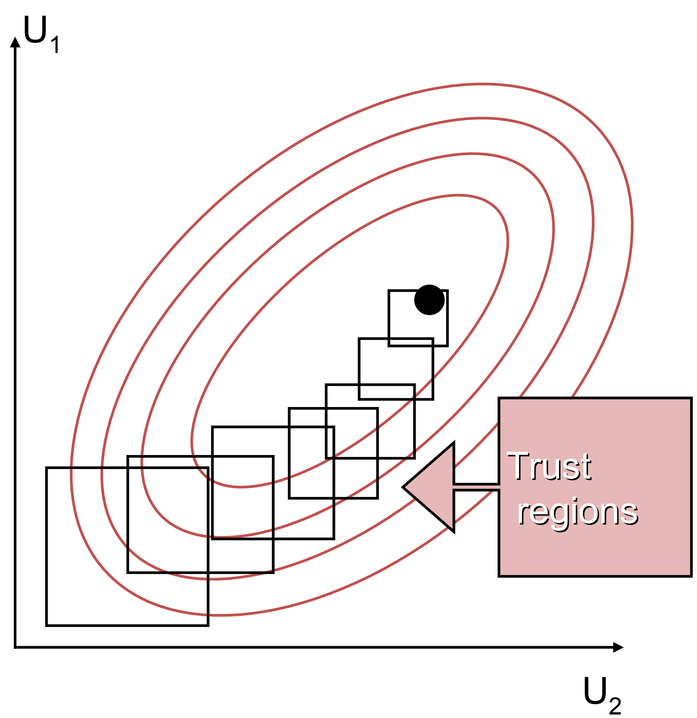
Model/Solution Features

- Inclusion of active power constraints
  - Used when solution is iterated with economic MW dispatch or corrective MW control
- Switching actions
  - Alleviate overloads and voltage problems by reconfiguring the network
- Control ganging
  - Parallel transformer taps
  - Radial transformer taps (load and generator step-up)
- Control discretization
  - Transformer taps
  - Shunts

Algorithms - Handling High Nonlinearity

- MW and MVAr losses are non-separable and quite nonlinear
- We use successive LP with special efficient piecewise-linearization techniques, iterated with accurate AC power flow





Experience and Future Potential

- The power system operators have found the resulting secure voltage/MVAr schedule satisfactory throughout daily operation
  - The mixed objective function has proved to be very practical
  - There is always further scope for refining the trade-off of cost-of-losses against spinning reactive reserve
- A virtually identical approach will support a true MVAr market
  - Where the present semi-arbitrary generator MVAr “cost” curves merely become replaced by actual market MVAr bid curves