Some Key Requirements for Practical OPF Calculations

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Opportunities for Increasing Real-Time & Day-Ahead Market Efficiency Through Improved Software

Nexant

This Presentation Addresses

- People interested in Optimal Power Flow (OPF)
  - Actual or potential engineering users
  - Methods and software developers
  - Researchers, teachers
  - Operations and market designers
  - Regulators, monitors and auditors

This Presentation Outlines

- Some of the key solution requirements and challenges, based on the authors' decades of experience
  - To help evaluate existing and future tools
  - To promote useful directions of further work

OPF Technology

- Has received vast amounts of R&D for 50 years
- In many power systems, OPF is now central to operations, markets & planning, e.g.
  - MW and voltage-VAR dispatch
  - Unit commitment (SCUC)
  - Transmission and generation expansion
  - Corrective and restorative control
  - Transmission congestion rights
- Real-life formulations are much more complicated than in textbooks
- Reliable and practical OPF calculations are still elusive

Extended Formulations

- More advanced OPF problems are continually being formulated, e.g.
  - Topology optimization
  - Stochastic objectives and constraints
  - Stability constraints
  - Time-varying optimization with temporal constraints
  - Multiple objectives
- Solutions increase in difficulty with realistic modeling

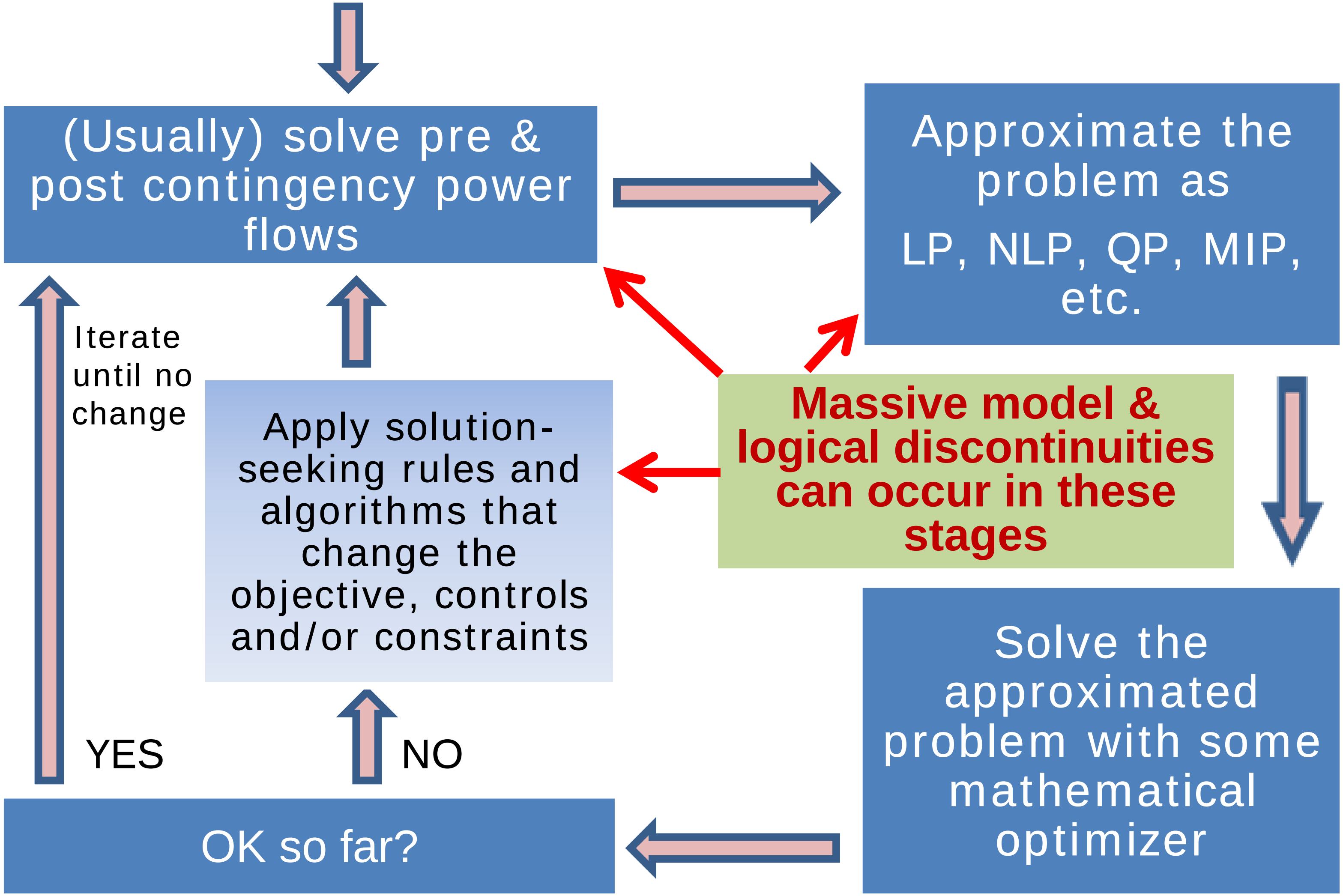
1. OPF is Security Constrained

- Real-life OPF calculations are nearly all security (contingency) constrained
  - Typically with "preventive N-1" security
- But (at a guess) 95% of all OPF R&D has not included security constraints
  - *Methods developed without security constraints tend to be unsuitable for security-constrained OPF*
  - Therefore, any R&D exercise must address this requirement

2. Security Concepts are Changing

- Power systems currently operate "preventively secure" (*no violations following any contingency*)
  - Largely within the scope of current technology
- However, not all constraints are of equal likelihood and have equal operational/economic impact
- "Corrective security" for overload-tolerant constraints is a "hot topic" (*violations following any contingency can be removed by remedial action*)
  - Greater economy
  - More adaptive to uncertainty (e.g. renewables)
  - Synergistic with demand-response technologies
  - Technology is complicated, needs further development

3. OPF Problems are Not At All Smooth



4. Overall OPF Solution

- Most of the efficiency and reliability of an OPF calculation depends on
  - The power-system-specific modeling, techniques and decisions outside the central optimizer
    - Many of which are very heuristic and discontinuous
- A practical AC OPF problem
  - Is not solvable by a general-purpose optimizer alone
  - Has a path-dependent solution
  - Has no known useful convergence theory (including local and global optima)

5. Objective Functions are Composite

- The objective function in almost any practical OPF solution acquires added terms, e.g. for
  - Optimizing “cost-free” controls
  - Discouraging movements
  - Penalizing soft constraint violations
  - Preventing violations (e.g. barriers)
  - Overcoming degeneracy
  - Invoking priorities
  - Suppressing oscillations
  - Promoting discreteness

- What does solution optimality then mean?
- How to price these objective function add-ons?
- How to interpret or remove their influence on marginal costs?

6. The PVQ Optimization Inconsistency

- Simultaneous optimization of active and reactive power controls
  - Deploys all available controls to get “best” solution
  - Mathematically this looks attractive and logical, *but it violates power system design and operation fundamentals and tends to give unusable results*
- To make PVQ optimization practical, non-trivial breakthrough work is required
  - Small or zero V-Q costs tend to push VARs unacceptably around the system
  - Assigning real "costs" to the V-Q controls is arbitrary and difficult

7. Control Discreteness

- Discreteness of optimized and non-optimized controls
  - Is handled only with great approximation, and intricate heuristics
  - Remains a difficult problem
    - Big steps are particularly problematic
- For non-small OPF problems, mixed-integer programming cannot (yet) provide a general solution

8. Locally-Acting Controls

- Locally-acting (non-optimized) controls in OPF
  - Their modeling can almost never be avoided
  - Artificially designating them as optimized and/or constrained brings more problems
    - Post-contingency responses and control "costs"
- When they hit or back off limits
  - They introduce step-changes in the network model and its sensitivities
  - They increase the tendency of the OPF solution to be more oscillatory and more path-dependent

9. Handling Infeasibility

- The OPF calculation should never terminate with "problem infeasible" or "solution not converged"
  - Always give the best possible solution, together with maximum information on the bottlenecks
- Infeasibility behavior is absolutely critical
  - Expand constraint limits (rather arbitrary)
  - Invoke rules (change controls, objective, constraints)
  - Give constraints a softness threshold with WLS or other violation penalties
    - Practical, quantitative identification of bottlenecks
    - Best spread of violations for a "least-emergency" solution

10. Solution Degeneracy

- OPF problems are often degenerate
  - Degeneracy typically arises between controls and/or between constraints
- Markets often require equitable, pro-rata, awards in degenerate situations
  - Optimization packages handle degeneracy arbitrarily (may cause cycling, convergence failure, and different marginal costs)
- OPF needs power-system-specific degeneracy technology

Concluding Remarks

- Text-book OPF formulations do not define, even as simplifications, real-life engineering problems
- Almost all OPF problems are security constrained
- Active and reactive powers cannot usually be optimized simultaneously
- General-purpose optimization packages can form only a small part of any overall OPF solution process

A huge amount of R&D work remains to be done