State of the automation
&
Closed loop contingency alleviation

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State of the automation

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What do operators do?

- Operational planning
- Operation under forecast conditions
- Operation under contingency conditions
- Operation under emergency conditions
- Restoration after a blackout

Operational planning

- Purpose:
  - Are enough resources available?
  - Under all credible operating conditions
  - Day-ahead, week(s) ahead
- At the root of all further automation
- Challenges:
  - Stochastic renewable generation
  - Electricity markets

Operational planning

- Can this be automated?
  - Involves a lot of data gathering
    - Forecasts: load, markets, renewable generation
    - Maintenance plans: generation, transmission
  - Simulation tools are increasingly sophisticated
  - Fairly routine work
    - Well-established criteria and procedures
  - Except in unusual circumstances
    - Severe weather, eclipses, unanticipated outages

Operation under forecast conditions

- Normal operation is quite boring…
- Substantially automated:
  - Automatic Generation Control (AGC)
  - Real-time balancing markets (5 minutes)
  - EMS real-time sequence
- Issues:
  - Safety clearances for maintenance operations
  - Nuisance alarms
  - Interactions with neighboring systems

Operation under contingency conditions

- Contingency condition = anticipated credible deviation from forecast conditions
  - N-1 conditions:
    - Generation outage
    - Transmission outage
  - Large deviation from net load forecast
- Preventive vs. corrective security

Preventive security

- System remains stable after the contingency
- System is typically no longer N-1 secure
- Must be returned to a N-1 secure state
- Must determine that state by solving a Security Constrained Optimal Power Flow (SCOPF)
- Must drive the system towards that state
- May have implications for later operations
- Could probably be automated

Corrective security

- Post-contingency corrective actions are required to maintain stability
- System operators prefer preventive security because an immediate response is not needed
- Manual vs. automatic corrective actions

Automated corrective actions

- Also known as Remedial Action Schemes (RAS)
- Fast action often involving load shedding
- Usually event-driven rather than state-driven
  - Difficult to define states where scheme should/should not trigger
  - Leads to a multiplication of these schemes
  - Interactions between schemes not well-understood
- Schemes are often armed only under certain conditions to avoid spurious operation

Manual corrective actions

- Generation redispatch, line switching, reactive device switching, fast starting generation
- Take advantage of slower system time constants
- Some work has been done on automating these actions
  - e.g. Almassalkhi & Hiskens

Operation under emergency conditions

- Emergency conditions = beyond what is considered credible
- Leads to blackouts
- Space is vast
- Operators:
  - Lack situation awareness
  - Hesitate to take drastic actions

Automation under emergency conditions

- EDF developed a network splitting scheme to deal with emergencies
  - Goal: save parts of the system from collapsing
- Operated the scheme in open loop
- Generated several false alarms
- Scheme was discontinued

Why do we get blackouts?

- Typical large scale blackout:
  - Trigger in the heavy electrical infrastructure
  - Compounded by problems in the information infrastructure
- Don't have models that link the two
- Don't know when the information is wrong
- Automation can and does make matters worse
- Out-of-the-loop syndrome

Restoration after a blackout

- Unknown territory
- No two blackouts are the same
- Lots of unexpected problems crop up
- Requires communication with many actors
  - Field crews, power plants, ..
- Requires specialist knowledge in a variety of areas

Closed loop contingency alleviation

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Baosen Zhang
Nicolò Mazzi (University of Padova, Italy)

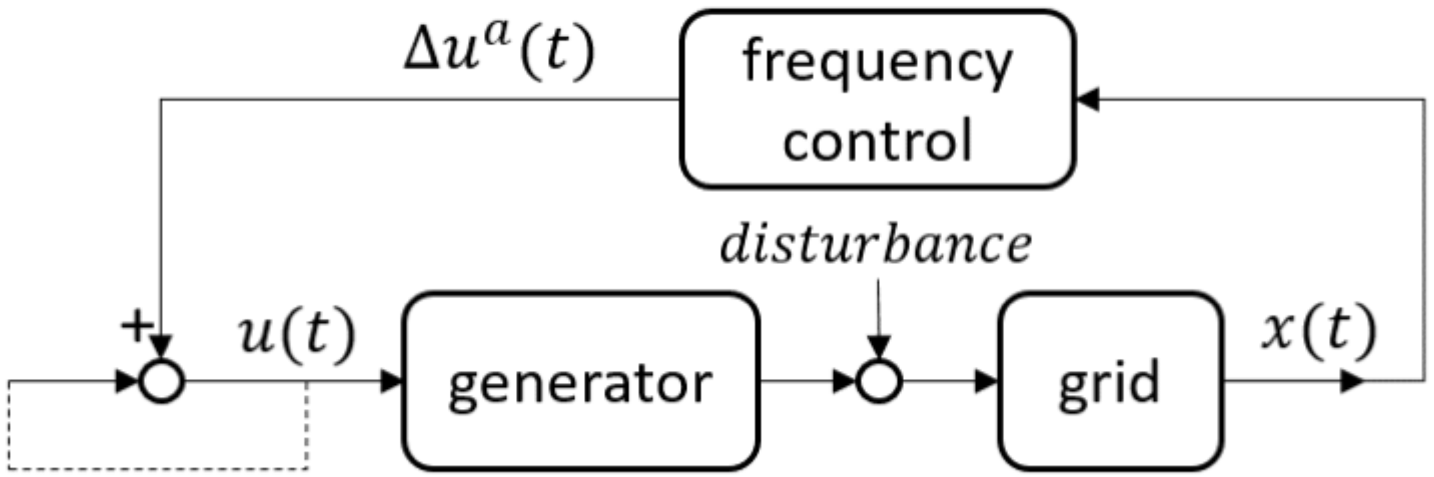
Context

- Power system under a contingency condition
- Operating constraints are violated:
  - Line flow limit
  - Voltage limit
- Corrective actions are required:
  - Generation redispatch
  - Voltage set-point adjustment
- Can we automate the process?

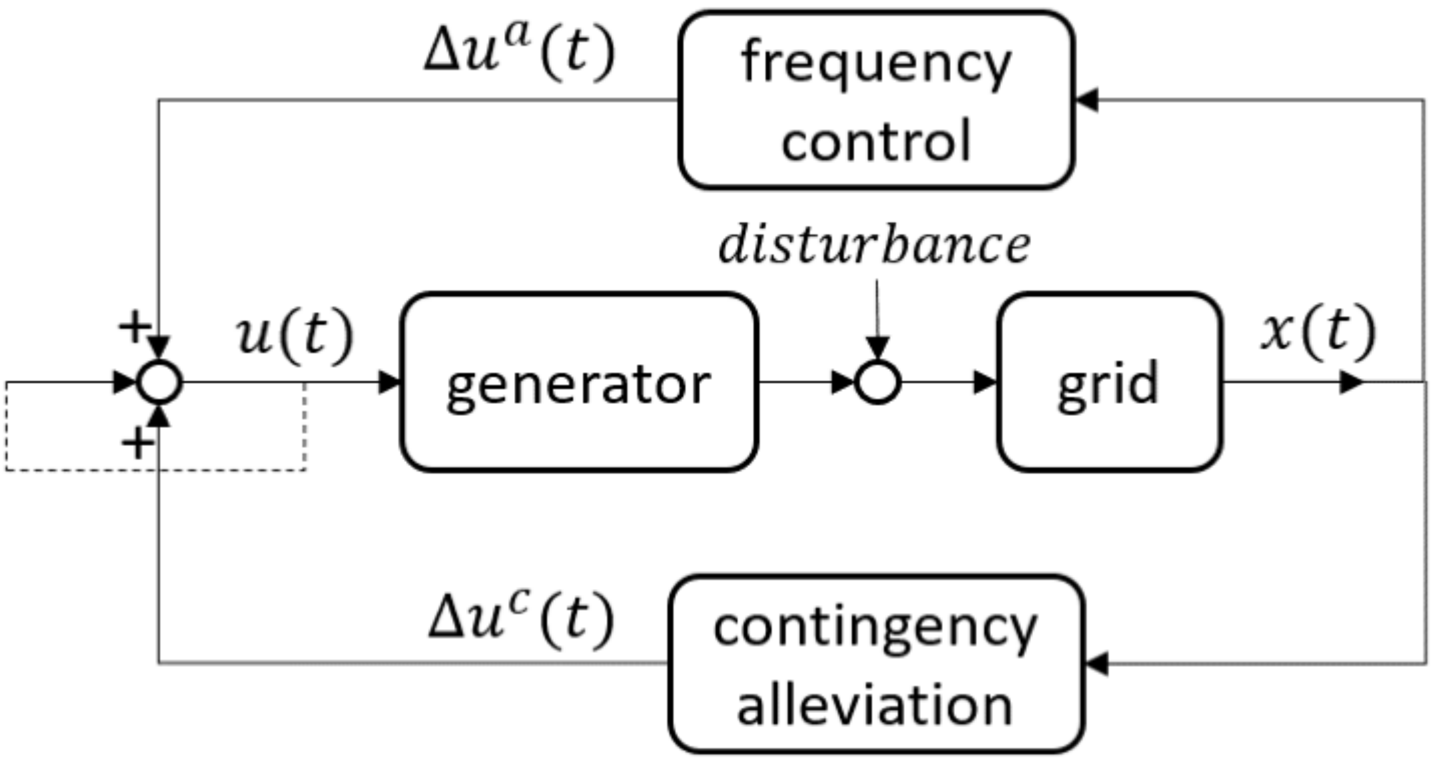
Concept

- Standard approach:
  - Determine a new operating point using an OPF
  - Drive the system towards that operating point
- Problems:
  - Full OPF solution takes time
  - Models are inaccurate
  - Trajectory may be problematic
- Work by Steve Low and his students on online algorithm for OPF
- Can we just do that using closed loop control?

Automatic Generation Control (AGC)



Contingency alleviation concept

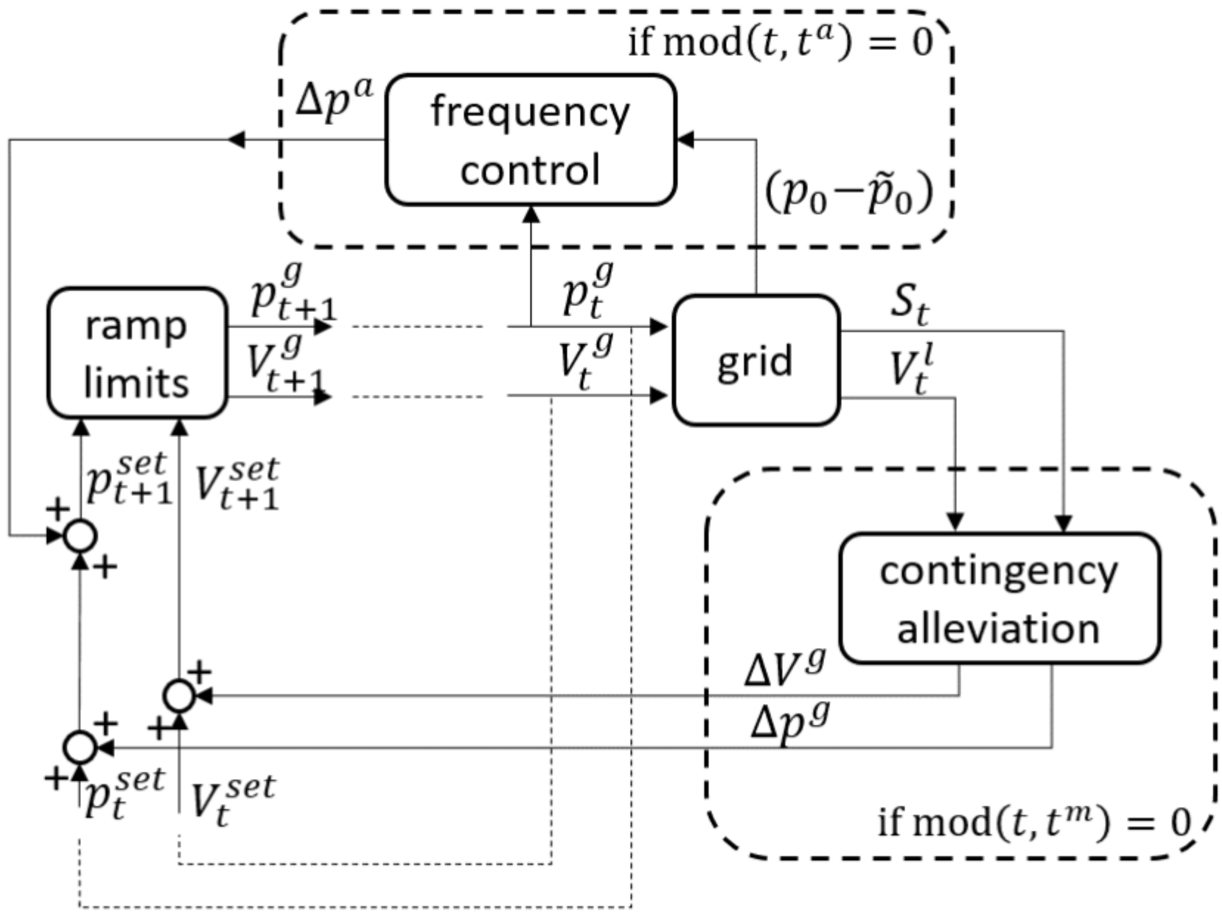


Basic algorithm

- Detect operating constraint violation(s) from network measurements
- Determine optimal control actions that can be implemented considering ramp rate limits and update rate of AGC
- Wait for next measurement

→ Start moving the system immediately towards a better, more stable operating point

Schematic representation



Objective function

Basic objective function:

$$\mathcal{L} = \mu \sum_{l \in N^l} \max(|V_l - 1| - \overline{v}, 0) + \frac{1}{k} \sum_{(ij) \in E} \max(|S_{ij}| - \overline{S}_{ij}, 0)$$

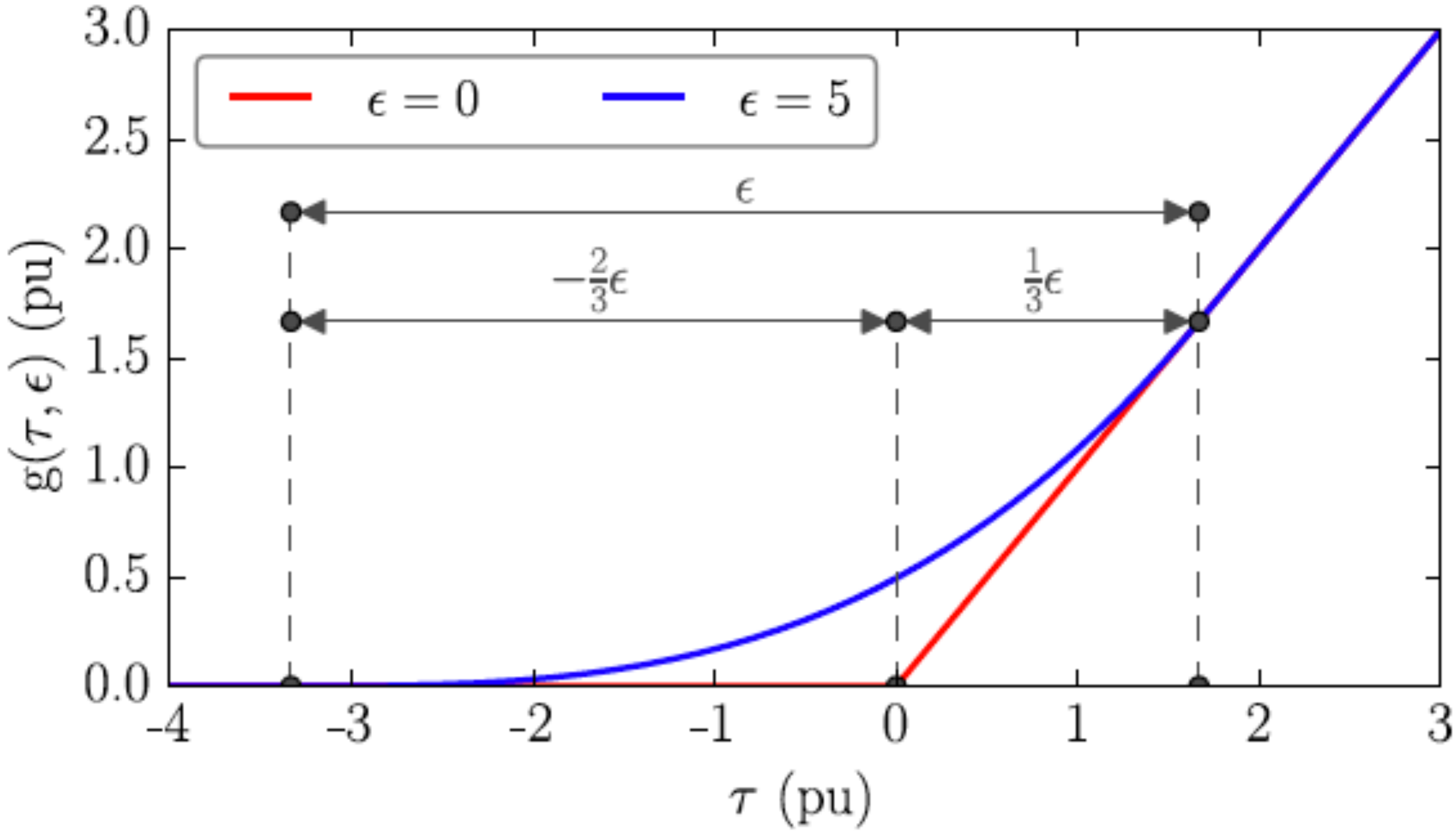
- Not smooth
- Not sensitive to variables close to their limit

Penalized objective function:

$$\mathcal{L}' = \mu \sum_{l \in N^l} g^V(V_l) + \frac{1}{k} \sum_{(ij) \in E} g^S_{ij}(S_{ij})$$

Penalty function for constraint violations

Basic vs. penalized objective function:



Optimization problem at each iteration

$$\text{Min} \quad \mu \sum_{l \in N^l} g^V(V_l^m + \Delta V_l) + \frac{1}{k} \sum_{(ij) \in E} g_{ij}^S(S_{ij}^m + \Delta S_{ij})$$

$$\text{over} \quad u := (\Delta p_g, \Delta V_g, \forall g \in N^g)$$

$$x := (\Delta V_l, \forall l \in N^l; \Delta S_{ij}, \forall (ij) \in E)$$

$$\text{s.t.} \quad x = F(u)$$

Non-linearity

$$\sum_{g \in N^g} \Delta p_g = 0$$

$$\underline{p}_g \le p_g^m + \Delta p_g \le \overline{p}_g, \quad \forall g \in N^g$$

$$|V_g^m + \Delta V_g - 1| \le \overline{v}, \quad \forall g \in N^g$$

$$-R_g t^m \le \Delta p_g \le R_g t^m, \quad \forall g \in N^g$$

$$-T_g t^m \le \Delta V_g \le T_g t^m, \quad \forall g \in N^g$$

Ramp rate limits

Simplifications

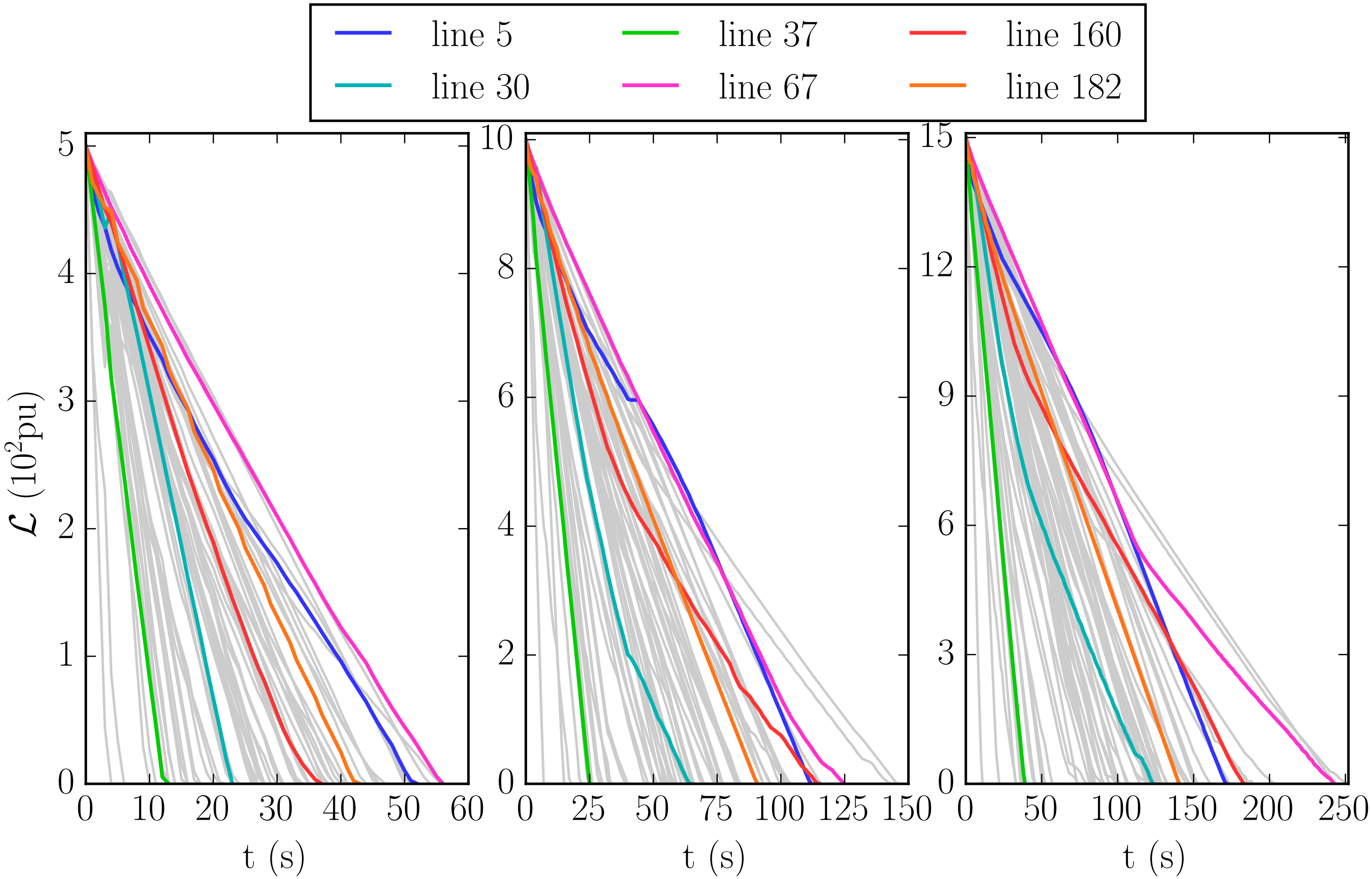
- Small steps → suitable for linearization
- Take advantage of active/reactive decoupling
- Sensitivities based on fast decoupled power flow

→ Fast LP formulation of the optimization problem

Simulations

- IEEE 118-bus system
- Three types of operating constraint violations:
  - Line overloads
  - Over and under-voltages
  - Combined overloads and voltage violations

Line overloads



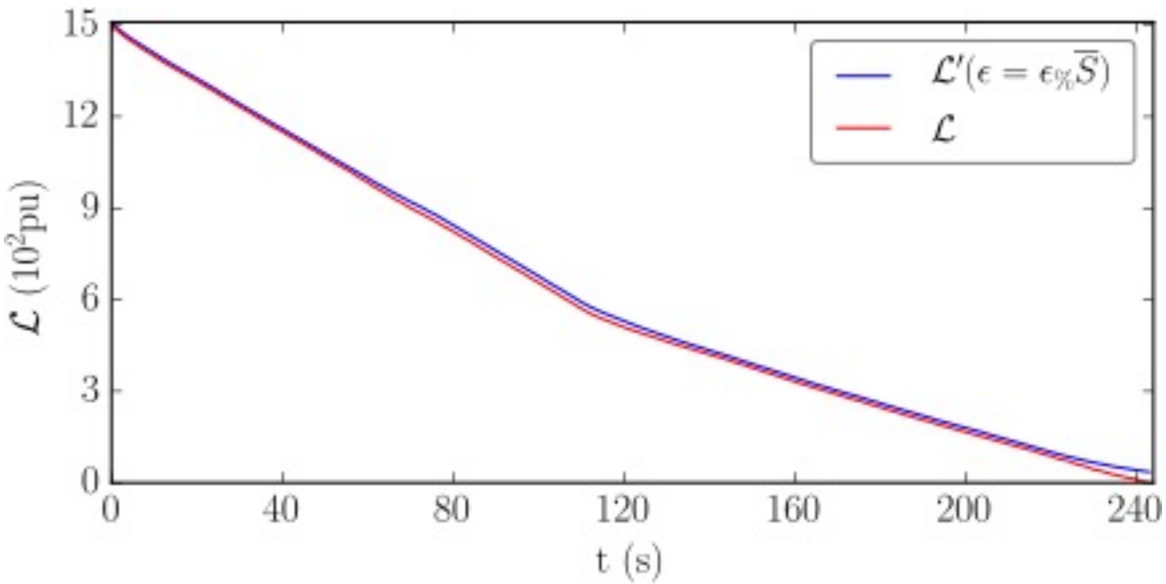
C = 5 MVA

C = 10 MVA

C = 15 MVA

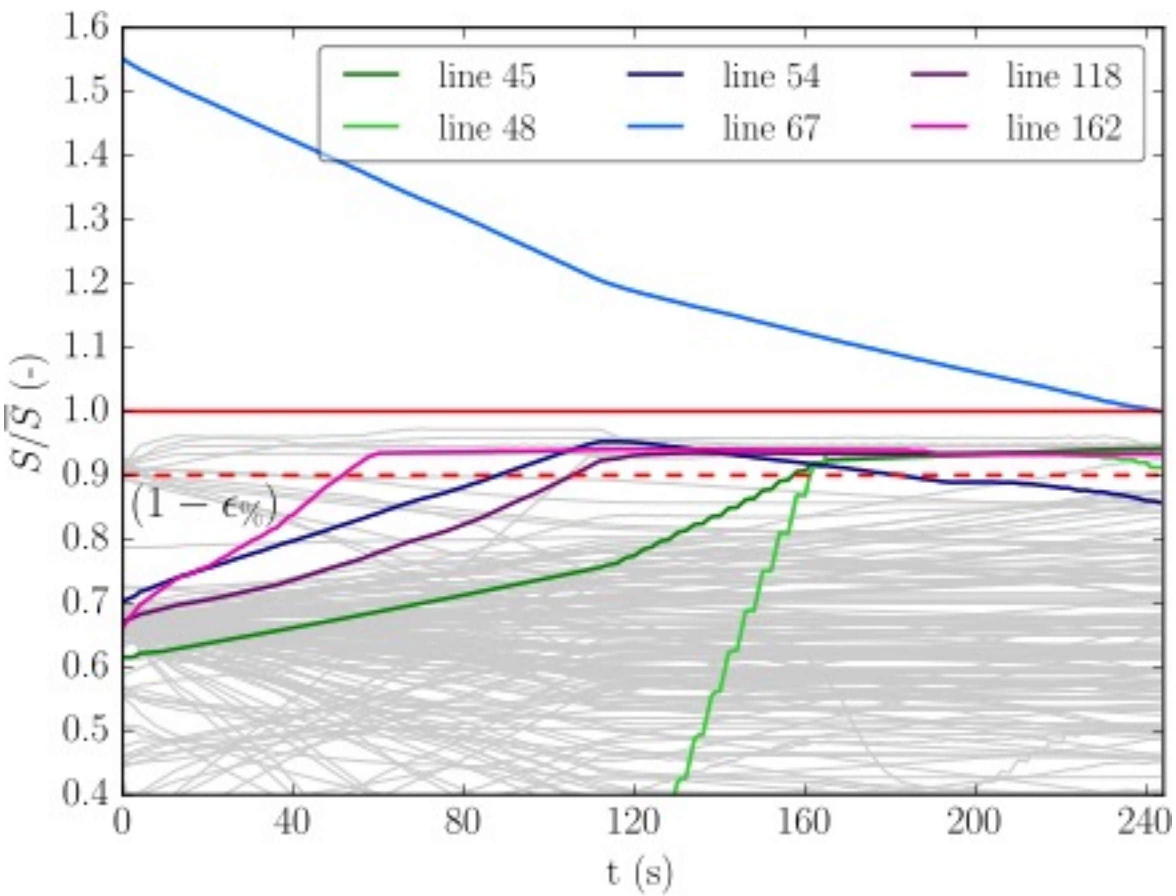
Line overloads

Basic vs. penalized objective function



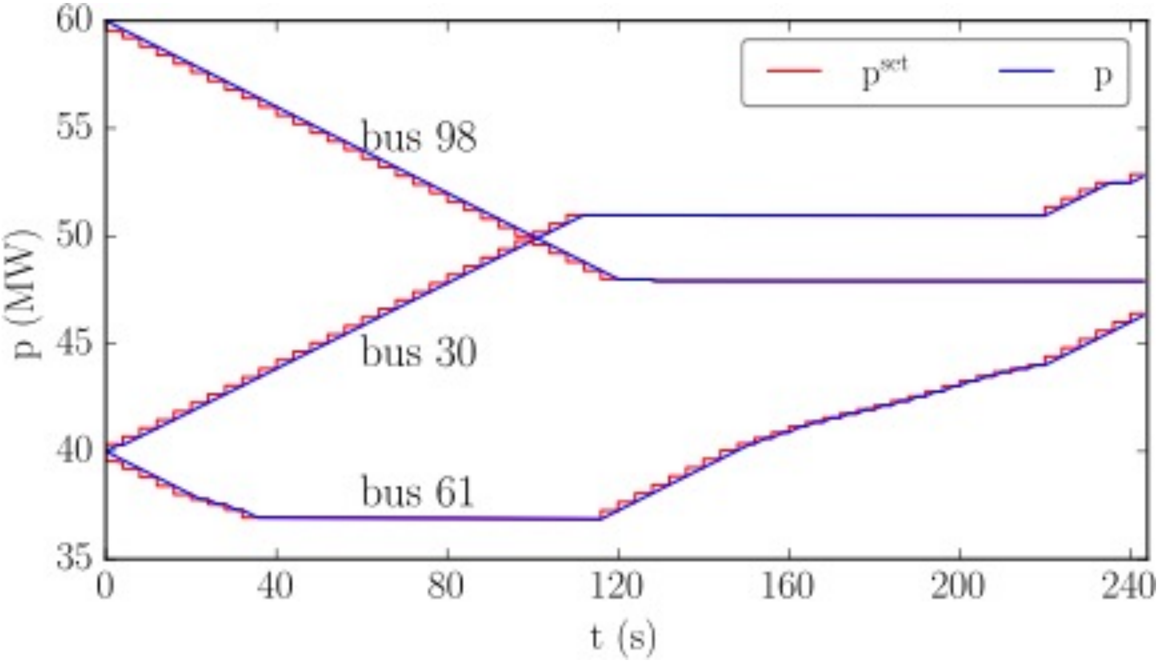
Line overloads

Normalized line flows

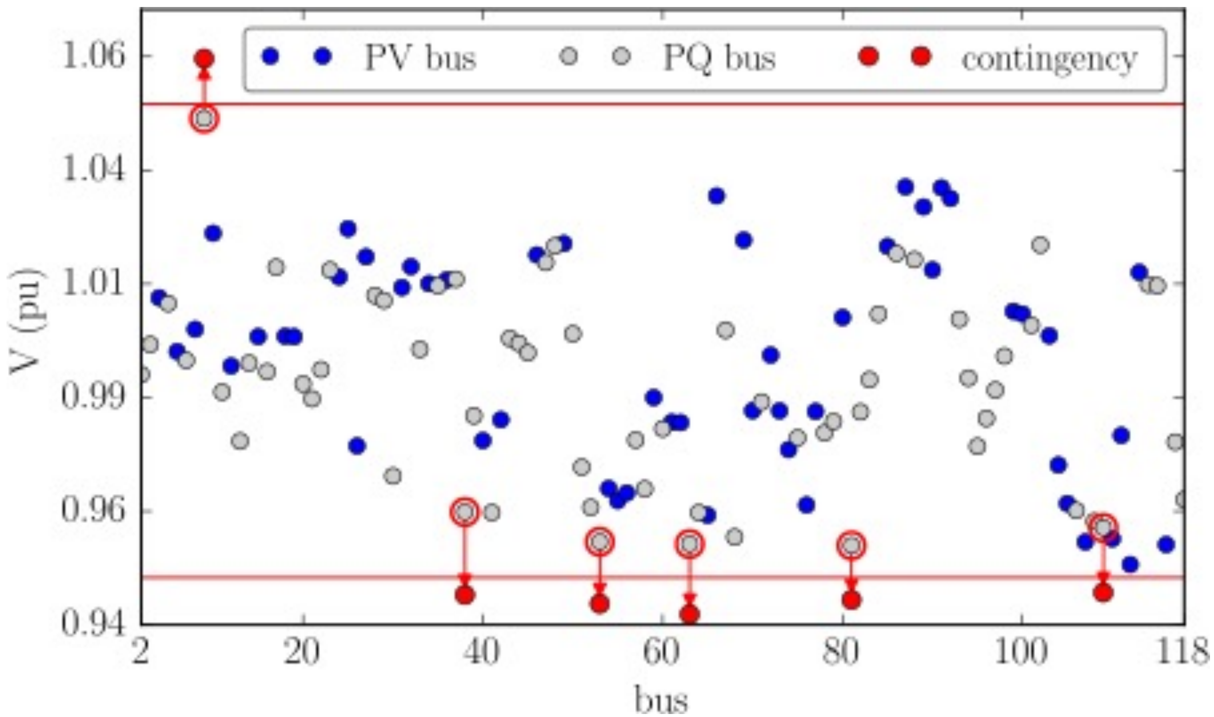


Line overloads

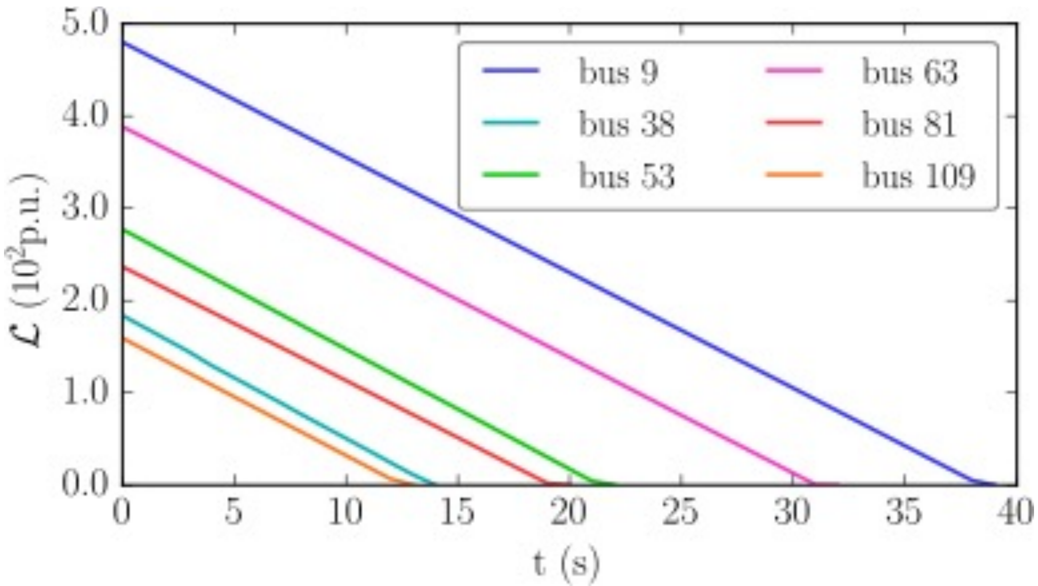
Bus active power injections



Voltage violations

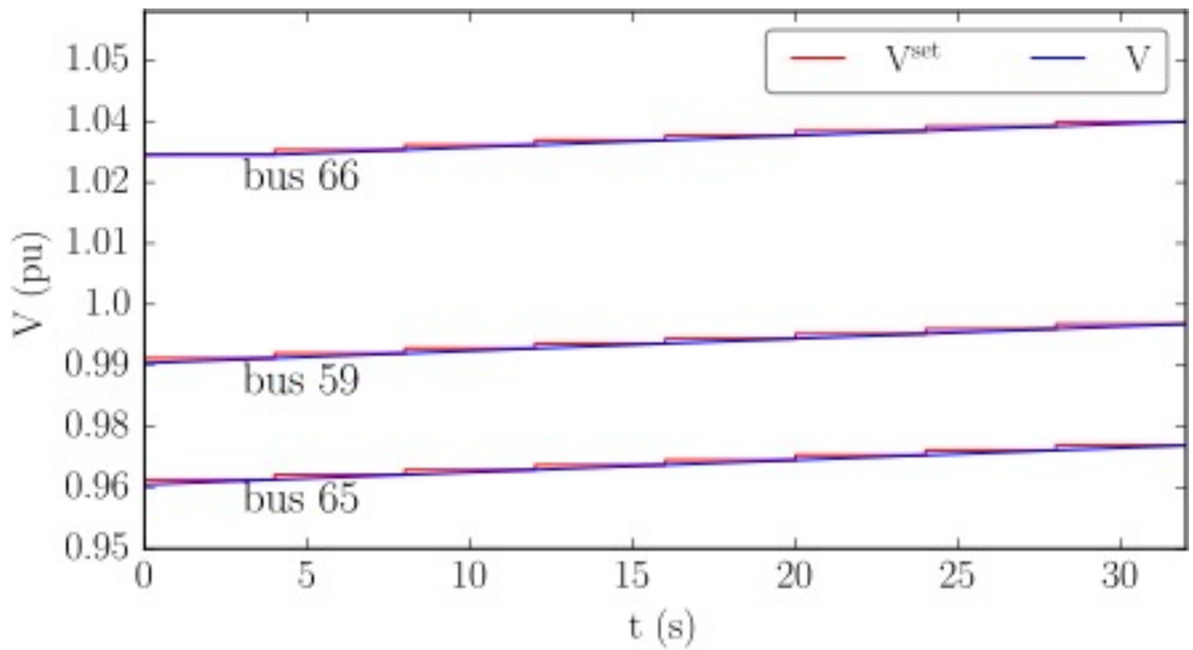


Voltage violations



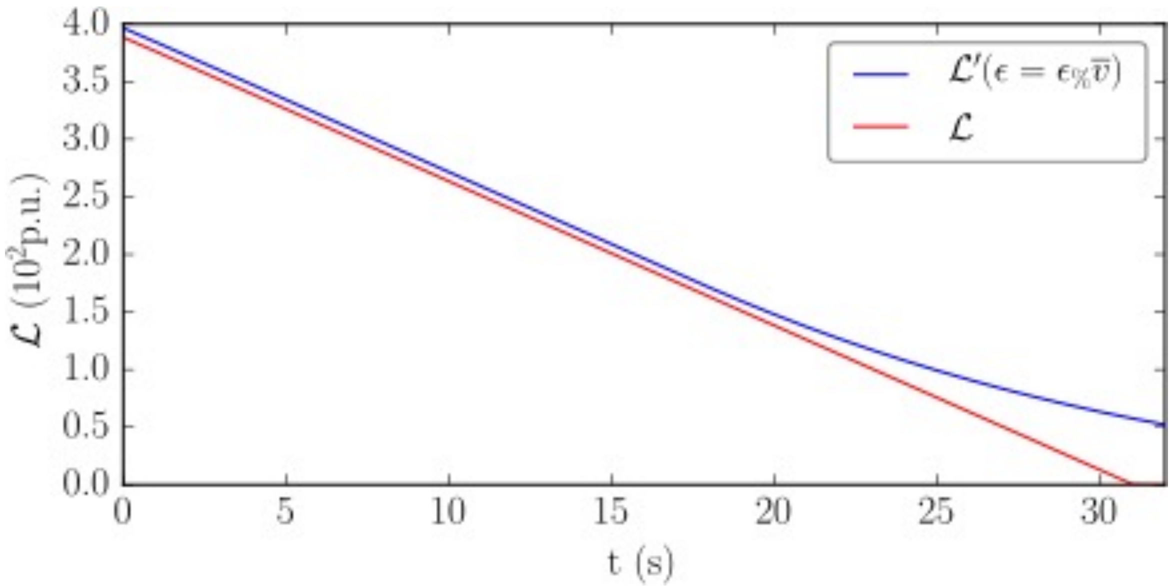
Voltage violations

Voltages and set-points for violation at bus 63



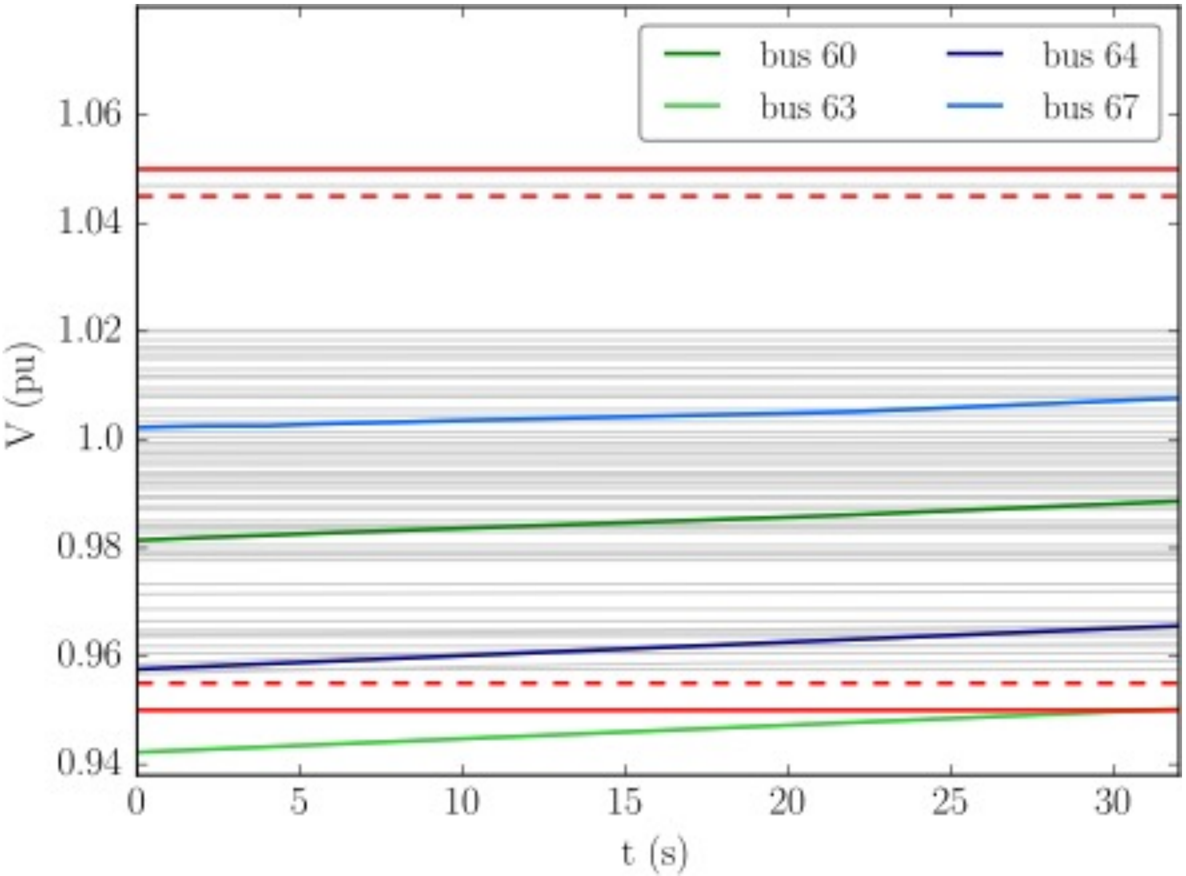
Voltage violations

Objective functions for voltage violation at bus 63



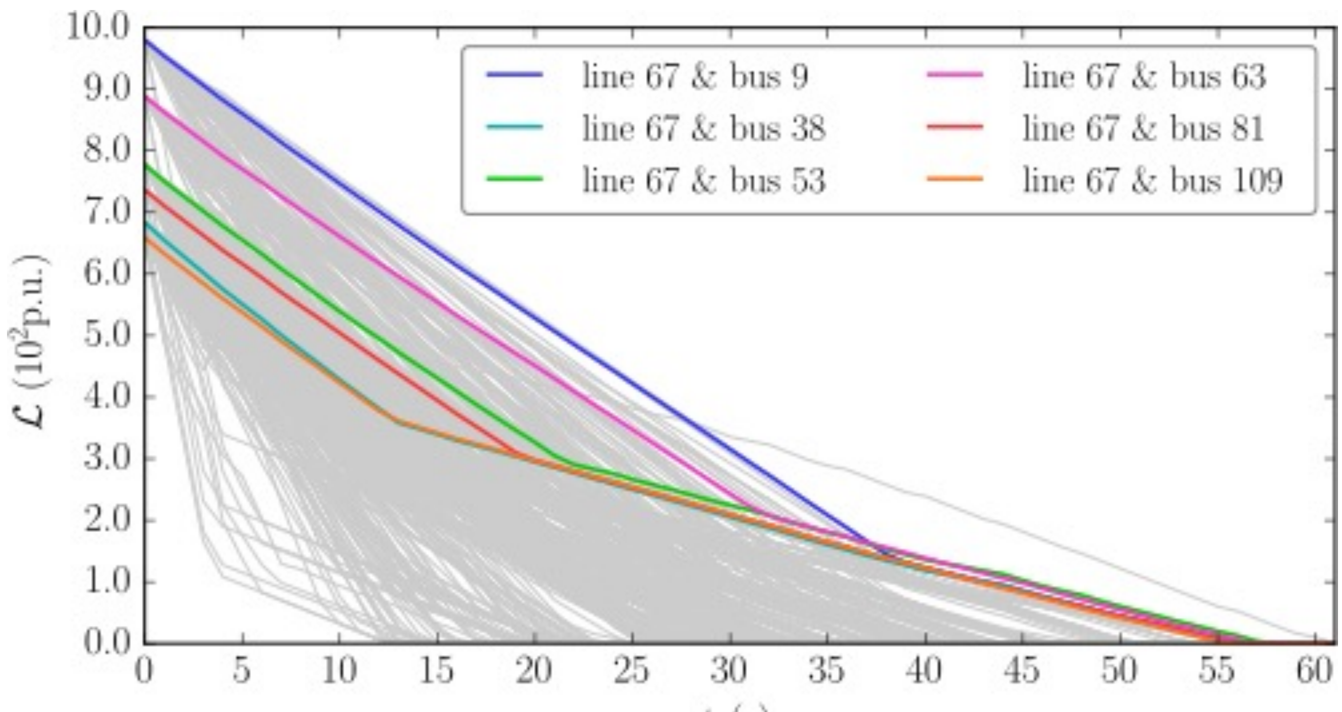
Voltage violations

Bus voltages for violation at bus 63



Combined overload and voltage violation

402 simulations: 5 voltage violations x 67 line overloads



Conclusions

- Proposed a closed-loop approach to the relief of violations of operating conditions
  - Relies on the network as a natural solver
  - Operates in parallel with the frequency control loop
  - Small steps allow linearization
  - Efficient LP solution even for large systems
- Demonstrated on 118-bus system for overloads and voltage violations