# Decentralized reactive power dispatch for a time-varying multi-TSO system

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# Motivation of the talk

- Formalize the multi-TSO reactive power dispatch problem.
- Introduce the decentralized optimization scheme.
- Propose some adaptive methods to track changes in the power system configuration.
- Evaluate those strategies in the context of the reactive power dispatch problem for a multi-TSO system.

# Formalization of the multi-TSO optimization problem

- $N$ areas controlled by different system operators.
- Every $TSO_i$ has:
  - local knowledge of the system,
  - its own objective $C_i^{k+1}(\mathbf{u})$.

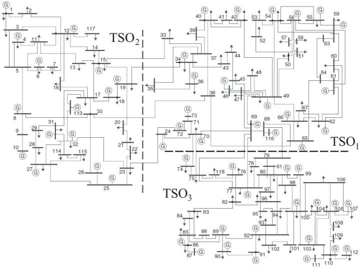


Figure: Example of a 118 bus multi-TSO power system.

# Formalization of the multi-TSO optimization problem

- Iteratively-varying operation conditions

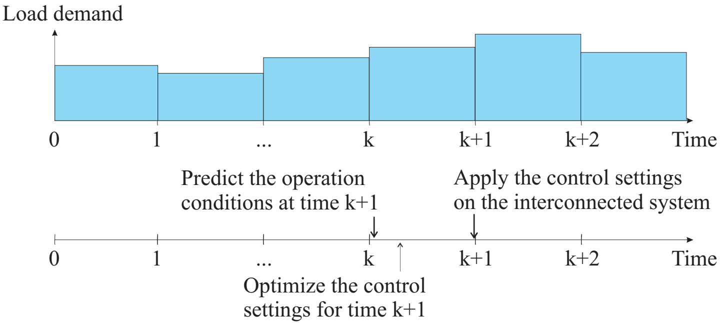


Figure: Reactive power dispatch model in a time-varying system.

# Principle of the scheme

At every instant $k$, every $TSO_i$:

- has a perfect prediction of the operation conditions within its own control area for the instant $k+1$.
- solves its own optimization problem,

$$\min_{\mathbf{u}_i,\mathbf{x}_i} \hat{C}_i^{k+1}(\mathbf{u}_i,\mathbf{x}_i)$$

under the constraints,

$$\begin{aligned} \hat{\mathbf{g}}_i^{k+1}(\mathbf{u}_i,\mathbf{x}_i) &\leq 0 \\ \hat{\mathbf{h}}_i^{k+1}(\mathbf{u}_i,\mathbf{x}_i,\mathbf{z}_i^*(k+1)) &= 0 \end{aligned}$$

where the other TSOs are modeled by external network equivalents represented by $\hat{\mathbf{h}}_i^{k+1}(\mathbf{u}_i,\mathbf{x}_i,\mathbf{z}_i^*(k+1)) = 0$.

# Principle of the scheme

At the instant $k+1$,

- locally optimized control settings are applied to the interconnected system:

$$\mathbf{u}^*(k+1) = [\mathbf{u}_1^*(k+1), ..., \mathbf{u}_{nbArea}^*(k+1)]$$

- In case of constraint violations, secondary control actions are modeled by:

$$\mathbf{u}^m(k+1) = \min_{\mathbf{u}} ||\mathbf{u}^*(k+1) - \mathbf{u}||$$

  such that:

$$g^{k+1}(\mathbf{u}) \leq 0$$

- Then, voltage and current $\mathbf{z}_i^m(k+1)$ are measured at the interconnections.

# Previous observations

- Close to optimal performance is obtained with PQ equivalents in time-invariant systems.
- Constraint violations are extremely small.
- Problem: design a suitable parameter fitting procedure to assess $\mathbf{z}_i^*(k+1)$ in time-varying systems.

# Exponential recursive least squares approach

- Approach: track system changes through past observations at the interconnections.
- Design a suitable function $f(j, k+1)$, such that

$$\mathbf{z}_i^*(k+1) = \min_{\mathbf{z}_i} \sum_{j=0}^{k} f(j, k+1)^{j-k} \times ||\mathbf{z}^m(j) - \mathbf{z}_i||^2$$

  leads to optimal performance in time-varying systems.
- Preliminary approach: constant memory factor $\beta$.

$$f(j, k+1) = \beta$$

# Environment dependent exponential recursive least squares approach

- Approach: relate the fitting function $f(k+1,j)$ to the load demand $r(j)$ faced by the system at the instant $j$.

$$f(j,k+1) = N^{\sigma}_{r(k+1)}(r(j))$$

where $N^{\sigma}_{r(k+1)}(\cdot)$ is a Gaussian function with mean $r(k+1)$ and variance $\sigma$.

# adaptive forgetting factor approach

- Approach: relate the weight factor to past prediction errors and to similarity with past operation conditions.

$$f(j, k+1) = N^{\sigma}_{r(k+1)}(r(j)) \times \psi(k+1)$$

- where $\psi(k+1)$ is a second weight factor, which depends on the prediction error at each instant $k$. $\epsilon_i(k) = \left|\left|\mathbf{z}_i^m(k) - \mathbf{z}_i^*(k)\right|\right|$.

$$\psi(k+1) = exp(-\tau \times \epsilon_i(k))$$

where $\tau$ is a constant forgetting factor.

# Benchmark system

- Reactive power dispatch problem.
- IEEE 118 bus system with three TSOs.
- Two types of objective functions for all TSOs:
  - Minimize active power losses.
  - Minimize reactive power support.
- Comparison with a global minimization $\mapsto ASO(\%)$.
- Constraints:
  - Load-flow equations.
  - Bus voltages, reactive power injections.
  - Inter-area active power export.

# Benchmark system

- Iterative load variations.

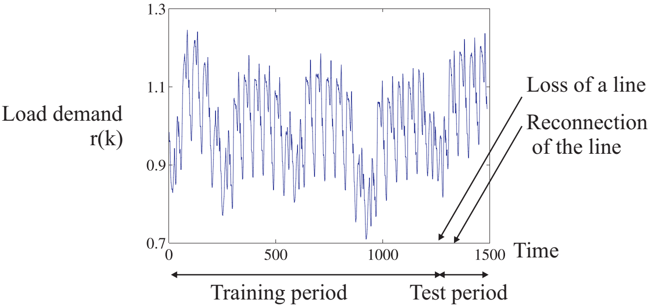


Figure: Load demand factor $r(k)$ evolution over the test period.

# Results with the ERLS approach

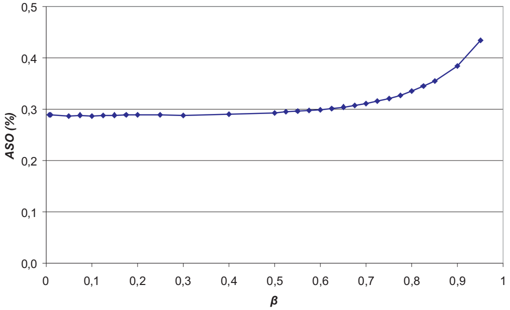


Figure: Average suboptimality index as a function of $\beta$ for the minimization of active power losses through the decentralized control scheme with an ERLS fitting algorithm.

# Results with the ERLS approach

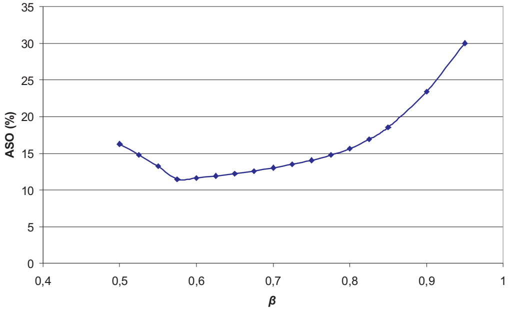


Figure: Average suboptimality index as a function of $\beta$ for the minimization of reactive power support through the decentralized control scheme with an ERLS fitting algorithm.

# Results with the ED-ERLS approach

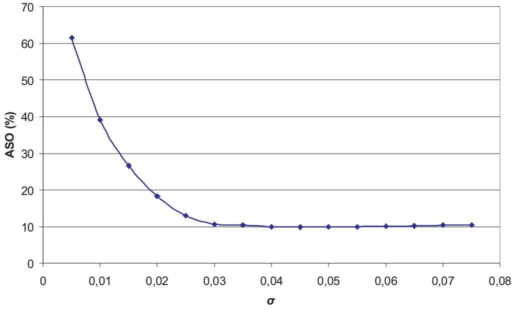


Figure: Average suboptimality index as a function of $\sigma$ for the minimization of reactive power support through the decentralized control scheme with an ED-ERLS fitting algorithm.

# Results with the AFF approach

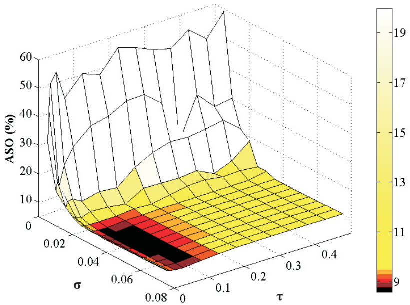


Figure: Average suboptimality index as a function of $\sigma$ and $\tau$ for the minimization of reactive power support through the decentralized control scheme with an AFF fitting algorithm.

# Conclusions

- Upgrade of the decentralized control scheme for time-varying systems.
- The scheme leads to close to optimal MVAr dispatch.
- Performance depends on the fitting procedure's parameters.
- The same results have been observed, when the TSOs have different types of objectives.
- New challenge: design of a systematic procedure to assess optimal parameters values.

# Coordination problem in a multi-TSO power system

- Need for coordination in multi-TSO power systems.
- Potential benefits of coordinated operation:
  - Operate the system with optimal control settings.
  - Better prediction of inter-area power flows.
- Two classes of approaches:
  - Centralized control scheme with a coordination entity.
  - **Decentralized control scheme** with/**without information exchange**.

# Summary of the algorithm

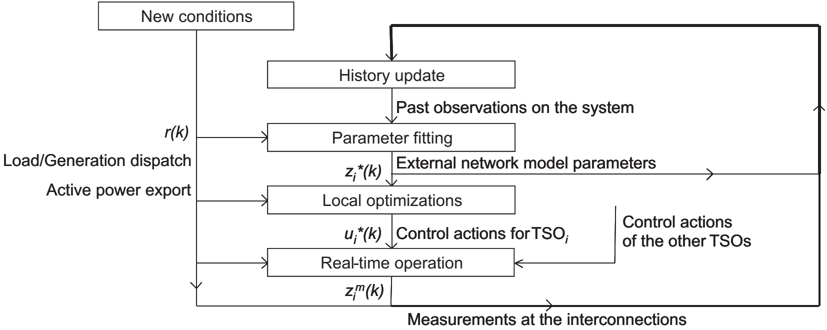


Figure: Proposed control scheme for multi-TSO optimization problem.