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

Y. Phulpin\textsuperscript{1} M. Begovic\textsuperscript{2} M. Petit\textsuperscript{1} D. Ernst\textsuperscript{3}

\textsuperscript{1}Department of power and energy systems, Supélec, Paris, France

\textsuperscript{2}School of electrical and computer engineering, Georgia Tech, Atlanta, USA

\textsuperscript{3}FNRS and University of Liège, Belgium
### 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 $C_i^{k+1}(u)$.

Figure: Example of a 118 bus multi-TSO power system.
Formalization of the multi-TSO optimization problem

- Iteratively-varying operation conditions

![Diagram showing reactive power dispatch model in a time-varying system](image)

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

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,

$$\min_{u_i, x_i} \hat{C}_i^{k+1}(u_i, x_i)$$

under the constraints,

$$\hat{g}_i^{k+1}(u_i, x_i) \leq 0$$
$$\hat{h}_i^{k+1}(u_i, x_i, z_i^*(k + 1)) = 0$$

where the other TSOs are modeled by external network equivalents represented by $\hat{h}_i^{k+1}(u_i, x_i, z_i^*(k + 1)) = 0$. 
Proposed Approach

Principle of the scheme

At the instant $k + 1$,

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

$$u^*(k + 1) = [u_1^*(k + 1), \ldots, u_{nbArea}^*(k + 1)]$$

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

$$u^m(k + 1) = \min_u ||u^*(k + 1) - u||$$

such that:

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

- Then, voltage and current $z_{i}^m(k + 1)$ 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 $z_i^*(k + 1)$ 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

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

leads to optimal performance in time-varying systems.

- Preliminary approach: constant memory factor $\beta$.

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

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

where $N_{r(k+1)}^\sigma(\cdot)$ is a Gaussian function with mean $r(k + 1)$ and variance $\sigma$. 
Parameter fitting procedures

Adaptive forgetting factor approach

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

\[ f(j, k + 1) = N_r(k+1)(r(j)) \times \psi(k + 1) \]

- where \( \psi(k + 1) \) is a second weight factor, which depends on the prediction error at each instant \( k \).

\[ \epsilon_i(k) = \|z_i^m(k) - z_i^*(k)\| \]

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

where \( \tau \) is a constant forgetting factor.
Illustrative example

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.
<table>
<thead>
<tr>
<th>Motivation</th>
<th>Contribution</th>
<th>Simulation results</th>
<th>Conclusions/Perspectives</th>
</tr>
</thead>
</table>

Y. Phulpin, M. Begovic, M. Petit, D. Ernst

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