On the Fairness of Centralised Decision-Making Strategies in Multi-TSO Power Systems

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Power System Computation Conference, 2008

Multi-TSO power system optimization

- Need for coordination in multi-TSO power system control.
- Potential benefits of a centralized control scheme:
  - Operate the system with optimal control settings.
  - Better prediction of inter-area power flows.
- Problem: **design a fair scheme for multi-TSO power system optimization.**

Outline of the talk

- Introduce a fair centralized optimization scheme for multi-TSO power systems
  (when the objective of every TSO can be formalized as a single objective cost function).
- Study the notion of fairness in economics.
- Fairness analysis in the context of the reactive power dispatch problem in a multi-TSO system.

Formalization of the multi-TSO optimization problem

- System with *nbArea*.
- Every area i is controlled by a system operator (TSO_i).
- Each TSO_i has a cost function $C_i(\mathbf{u})$.
- $\mathbf{u}$ represents the control variables.
- Multi-TSO optimization problem:

$$\min_{\mathbf{u}}[C_1(\mathbf{u}), C_2(\mathbf{u}), \ldots, C_{nbArea}(\mathbf{u})] \quad (1)$$

- Constraints: $g(\mathbf{u}) = 0$ and $h(\mathbf{u}) \geq 0$.

Utopian minimum

- Let $\mathbf{u}_i^*$ be the solution of the problem:

$$\mathbf{u}_i^* = \arg\min_{\mathbf{u} \in U} C_i(\mathbf{u}) \qquad (2)$$

- Then, the utopian minimum is defined as follows.

$$C^{ut} = [C_1(\mathbf{u}_1^*), C_2(\mathbf{u}_2^*), \ldots, C_{nbArea}(\mathbf{u}_{nbArea}^*)] \qquad (3)$$

- If the utopian minimum were a possible solution, that would naturally satisfy every party!
- Our approach: **minimize the (Euclidian) distance to the utopian minimum in a normalized cost-space.**

Normalization of the cost-space

- for a cost $C_i(\mathbf{u})$,

$$\overline{C_i}(\mathbf{u}) = \frac{C_i(\mathbf{u})}{C_i^\circ \times \chi_i} \quad (4)$$

With:

- C_i°, the “average overcost”:

$$C_i^\circ = \sum_j \frac{C_i(\mathbf{u}_j^*) - C_i(\mathbf{u}_i^*)}{nbArea} \quad (5)$$

- And χ_i, the “penalization factor”:

$$\chi_i = \sum_j \frac{C_j(\mathbf{u}_i^*) - C_j(\mathbf{u}_j^*)}{C_j^\circ} \quad (6)$$

Optimization procedure

- Objective: **minimize the Euclidian distance to the “utopian minimum” in the normalized cost space.**
- Formalization:

$$\mathbf{u}^* = \arg\min_{\mathbf{u}\in U} \sum_{i=1}^{nbArea} (\overline{C_i}(\mathbf{u}) - \overline{C_i}(\mathbf{u}_i^*))^2 \tag{7}$$

- Remark: the solution is on the Pareto-front.

Fairness criteria

- Attributes of fairness have been vastly studied in politics, mathematics, economics, etc...
- Different approaches have been proposed: *equity*, *reciprocity*.
- We will rely on three main criteria as proposed in [J. Konow, 1996]:
  - **Performance**.
  - **Altruism**.
  - **Accountability**.

Benchmark system

- Reactive power dispatch problem.
- IEEE 118 bus system with three TSOs.
- Three types of objective functions:
  - Minimize active power losses (TSO_1).
  - Minimize reactive power support (TSO_2).
  - Minimize a weighted function of the two criteria (TSO_3).
- Constraints:
  - Load-flow equations.
  - Bus voltages, reactive power injections.
  - Inter-area active power export.

Benchmark system

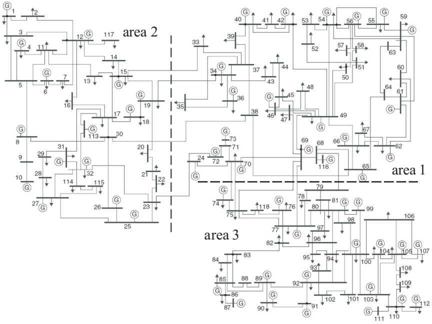

Figure: IEEE 118 bus system with 3 TSOs.

Results for the IEEE 118 bus system with 3 areas

	$i=1$	$i=2$	$i=3$
$C_i(\mathbf{u}_1^*)$	43.02	1359.8	66.65
$C_i(\mathbf{u}_2^*)$	59.40	0.0	211.70
$C_i(\mathbf{u}_3^*)$	51.79	1999.9	37.84
C_i°	8.38	1119.9	67.56
χ_i	1.64	4.53	2.83
$\overline{C_i}(\mathbf{u}_1^*) - \overline{C_i}(\mathbf{u}_i^*)$	0	0.2682	0.1506
$\overline{C_i}(\mathbf{u}_2^*) - \overline{C_i}(\mathbf{u}_i^*)$	1.1910	0	0.9088
$\overline{C_i}(\mathbf{u}_3^*) - \overline{C_i}(\mathbf{u}_i^*)$	0.6375	0.3944	0
$C_i(\mathbf{u}^*)$	43.17	60.65	38.85
$\overline{C_i}(\mathbf{u}^*) - \overline{C_i}(\mathbf{u}_i^*)$	0.0111	0.0120	0.0053

Performance and altruism

- Performance criterion satisfied since the solution is on the Pareto-front.
- Altruism:
  - Interpretation: the overcosts should be shared according to the "efforts" made by the different TSOs.
  - The terms χ_i and C_i^0 carry out notions of altruism.

Accountability

- Idea for assessing the accountability: relaxing the constraints can be seen as more investments.
- The scheme is accountable if, a relaxation of TSO_i's constraints reduces its costs C_i.
- Accountability results:

Effort	$C_1(\mathbf{u}^*)$	$C_2(\mathbf{u}^*)$	$C_3(\mathbf{u}^*)$
None	43.17	60.65	38.85
TSO 1	42.34	49.40	38.58
TSO 2	43.13	44.25	38.45
TSO 3	43.10	61.00	38.59

Conclusions

- Design a “fair” scheme for multi-party optimization problems.
- This scheme has some properties of fairness in the sense of economics.
- Fairness is subjective in essence... and choosing this method, or another, is subject to achieving a consensus among the different TSOs.
- New challenge: how should fairness be formalized when the objective of each party cannot be expressed as a real-valued function?

Game theory approaches

- Many possible approaches.
- Some examples:
  - Asymetric game where every TSO successicely assesses its optimal control based on the scheduled controls of the other TSOs.
  - Symetric game where the TSOs agree to represent the neighboring areas with external network models.
- Problems:
  - **No guarantee to elect a solution on the Pareto-front.**
  - **The process may take some time to converge.**

Other approaches

- Methods to elect one solution on the Pareto-front:
  - Weighting the objectives.
  - Keeney-Raiffa method.
  - Prioritization of the objectives (ϵ-constraint method).
  - Goal-attainment method (Proritization of the objectives).
- Problem: **We are looking for a solution where all TSOs are considered equally**.

Sensitivity to biased information

- Motivations for providing biased information:
  get a higher weight for its own objective.
- Means of providing biased information:
  - Formulating wrong constraints.
  - Formulating wrong objectives:
    linear transformation, non-linear transformation
- Potential gaming strategies for formulating the individual objectives.