Project 2:

Market design: multi-player equilibrium model versus centralized model

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Abstract

This project has four steps:

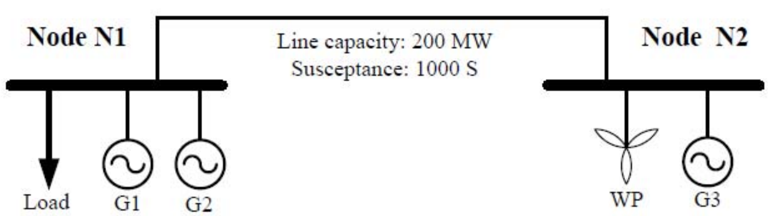
- Step 1) This step develops a market design, in which each market player solves its own two-stage stochastic optimization problem. The only sharing constraints are nodal balance conditions. The collection of all optimization problems as well as sharing constraints leads to a multi-player equilibrium problem.
- Step 2) This step develops a centralized market design, in which the market operator solves a single two-stage stochastic optimization problem.
- Step 3) This step derives Karush-Kuhn-Tucker (KKT) conditions of both models developed in Steps 1 and 2, and compares them.
- Step 4) This step solves the equilibrium model of Step 1 as a mixed complementarity problem (MCP), and solves the optimization problem of Step 2 as a linear programming (LP) problem.

Hints

- Any relevant programming software, e.g., GAMS and Python, can be used. All codes should be included in the final group's report.
- Relax each binary variable, i.e., treat it as a continuous variable between 0 and 1.

Description

Consider a perfectly competitive electricity market with two nodes, three conventional generators (G1, G2, and G3), a single wind power producer (WP), and a single inelastic load.



The following table gives the technical characteristics of conventional generators:

Generator	Minimum level of production (Pmin) [MW]	Capacity (Pmax) [MW]	Ramp rate [MW/h]	Marginal cost [€/MWh]	Start-up cost [€]	Initial commitment
G1	30	100	40	10	10000	1
G2	20	90	40	15	5000	1
G3	0	80	60	30	1000	0

A three-hour time period (t1, t2, and t3) is considered. The load in hours t1, t2, and t3 is 200 MW, 250 MW and 220 MW, respectively. The involuntarily load curtailment cost is €100/MWh. The wind power producer has a stochastic forecast, and generate five equiprobable scenarios. Each scenario contains the wind production forecast over three hours:

Scenario	Hour t1 [MW]	Hour t2 [MW]	Hour t3 [MW]
s1	50	55	40
s2	70	60	30
s3	40	30	50
S4	20	50	15
S5	35	45	40

The wind power producer offers its production at zero price, and its installed capacity is 70 MW.

Step1) Develop an "*equilibrium-based"* two-stage (day-ahead and real-time) market design, in which each market player solves its *own* two-stage stochastic optimization problem. In particular:

- Each conventional generator maximizes its expected profit (i.e., profit in day-ahead plus expected profit in real-time), constrained by its technical constraints (Pmin, Pmax, ramp rates, start-up cost, etc). Assume that conventional generators cannot change their binary commitment (on/off) decisions in real-time. In addition, assume that the marginal cost of each conventional generator in both day-ahead and real-time stages is identical.
- The wind power maximizes its expected profit, constrained by its production limits in day-ahead and real-time. The wind power spillage is allowed.
- The load minimizes its expected load curtailment cost.
- The grid operator maximizes its congestion revenue profit, constrained by network constraint.

In addition to above optimization problems, one per agent, the market operator enforces the nodal power balance conditions as sharing constraints, whose dual variables provide locational market prices (LMPs).

Step 2) Formulate a centralized market design, which is indeed a two-stage stochastic "*optimization"* problem. The market operator minimizes the total expected system cost, constrained by all physical constraints of market players and nodal power balance constraints.

Step 3) Derive the KKT conditions corresponding to equilibrium model in Step 1 and those of optimization model in Step 2. Interpret why these two models are equivalent.

Step 4) Solve the linear optimization model of Step 2 using a LP solver (e.g., CPLEX). In addition, solve the equilibrium model developed in Step 1 using a MCP solver, e.g., PATH.

A useful reference:

J. Kazempour and B. F. Hobbs, "Value of flexible resources, virtual bidding, and self-scheduling in two-settlement electricity markets with wind generation - Part I," IEEE Transactions on Power Systems, to be published, 2017. dx.doi.org/10.1109/TPWRS.2017.2699687