Overview of the Russian Energy Market. Optimization model for scheduling generation units

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Structure of energy price, RUR/MWth

Example: Moscow region, Sept. 2015 (VAT not incl.), Source: Mosenergosbyt, http://www.mosenergosbyt.ru

- Grid services, infrastructural and retail surplus
- Capacity price
- Energy price
Energy market: System Structure

- Most part of the territory from western border to Siberia is interconnected and works a synchronously
- The 500-kV backbone grid is used to transfer large amounts of power from generation to load centers and throughout the time zones
- 7 joint territorial dispatch centers and the central dispatch unit (CDU) provide dispatch control of the system
Energy market: Generation Mix

RF Europe+Urals:
• Most thermal plants are base load/ half-peak
• High share of CHPs (most are capable of operating in condensing mode)
• Total capacity is about 160 GWt

Siberia:
• Share of HYDROs in the regional balance is around 50%
• Total capacity is about 40 GWt
Energy market design

- **Unit Commitment (UC)**
  - Aimed at defining a start up/shut down schedule for units for the three coming days based on unit bids under security and reserve constraints
  - Results are not financially binding (except start up costs)

- **Day Ahead Market (DAM)**
  - Energy auction for generators and consumers that determines next day hourly energy contract schedule and prices
  - 97% of energy volumes are traded through DAM
  - The computation is subject to feasibility constraints

- **Balancing market**
  - Deviations from Day Ahead contracts are traded
  - The balancing schedule is based on SO demand forecast and is updated every 2 hours
  - The balancing schedule set points are treated as regular SO commands for generators
Day ahead market mathematical model set up

\[ \sum_{t} (b_c^t p_c^t - b_G^t p_G^t) \rightarrow \text{max} \]

\[ F(\delta^t, V^t, p_c^t, p_G^t, q) = 0, \quad t = 1, \ldots, T \]

\[ f_s^t \leq f_s^t(\delta^t, V^t) \leq f_s^t \]

\[ p_c^t \in P_c^t, \quad p_G^t \in P_G^t \]

+ additional linking constraints:
  - ramp-rate constraints
  - integral fuel constraints

Nodal power balance constraints (active and reactive)

Power flow constraints

- The model is used at day-ahead market and balancing market to produce hourly schedule for an upcoming period
- Network model consists of 8000+ nodes and 12000+ lines
Pricing mechanism

- Based on locational marginal principle:

\[ \lambda_{node} = \lambda_0 \left( 1 + \frac{\partial \ell}{\partial p_{node}} \right) + \sum_s \sigma_s \frac{\partial f_s}{\partial p_{node}} \]

where \( \ell \) – loss function; \( f_s \) – power flow at constraint \( S \)
\( \lambda_0 \) – locational marginal price at swing bus
\( \lambda_0 \frac{\partial \ell}{\partial p_{node}} \) – marginal loss value at bus \( node \)
\( \sigma_s \frac{\partial f_s}{\partial p_{node}} \) – marginal value of constraint \( S \) at bus \( node \)
Marginal loss illustration

- LMPs at nodes are different due to the marginal loss factor
- Loss factor indicates the marginal loss increment corresponding to the increment in the line power flow
- Load at node 2 (in the example) pays at price of Gen at node 1 \((1 + \text{marginal LossFactor})\) which is greater than the amount supplied by the Gen to cover the load itself plus losses. *Hence the financial surplus at the market*
Day Ahead Market: hourly LMPs, RUR/MWh

Source: Administrator of Trading System, atsenergo.ru
Balancing market: scheduled vs. actual dispatch

Source: System Operator, so-ups.ru
Market price growth is far below the gas price (the dominant fuel in 1 Pricing Zone)

- Crisis 2008-2009 is clearly reflected in LMPs
- New capacity built due to “DPMs” increases competition while the load growth lags
Price dynamics: 2015 vs 2014

- 2014, daily LMPs (Day Ahead Market), RUR/MWh
- 9M2015, daily LMPs (Day Ahead Market), RUR/MWh

01 July 2015 - 7.5% gas price growth

1 Pricing Zone
Unit Commitment (UC)

- **Equipment**
  - Base load/half peak
  - Old
  - High share of CHPs
- **Nonstandard UC model restrictions, for example:**
  - Prevent frequent unit start/stops
UC model

\[
\begin{align*}
\lambda_0^t & \quad \sum_{n=1..N^t} p_{n}^t l_{n}^t = \sum_{n=1..N^t} d_{n}^t + \text{const}_0^t \\
\lambda_s^t & \geq 0 \quad \sum_{n=1..N^t} p_{n}^t f_{ns}^t \leq F_s^t + \text{const}_s^t, \quad s = 1, \ldots, S \\
\rho_p^{+t} & \geq 0 \quad -\sum_{i \in p} r_{ip}^{+t} \leq -RU_p^t, \quad p = 1, \ldots, P \\
\rho_q^{-t} & \geq 0 \quad -\sum_{i \in q} r_{iq}^{-t} \leq -RD_q^t, \quad q = 1, \ldots, Q \\
\mu_n^t & \quad p_n^t - \sum_{i \in n} g_i^t = 0, \quad n = 1, \ldots, N^t \\
\pi_i^{+t} & \quad g_i^t + \sum_{p=1..P_i} r_{ip}^{+t} - s_i^t PMAX_i^t = 0, \quad i = 1, \ldots, G \\
\pi_i^{-t} & \quad -g_i^t + \sum_{q=1..Q_i} r_{iq}^{-t} + s_i^t PMIN_i^t = 0, \quad i = 1, \ldots, G \\
\tau_i^{+t} & \geq 0 \quad -s_i^{t-1} + s_i^t - u_i^t \leq 0, \quad t = 2, \ldots, T, \quad i = 1, \ldots, G \\
\tau_i^{-t} & \geq 0 \quad s_i^{t-1} - s_i^t - d_i^t \leq 0, \quad t = 2, \ldots, T, \quad i = 1, \ldots, G
\end{align*}
\]

System balance of power
Power transfer constraints
Reserve to ramp up and to ramp down
Generation of active power at a node
Max and min capacity of unit w.r.t. its state
Constraints linking unit states and start up/ shut downs indicators
UC model (cont.)

- Min up/down times
  - Min time a unit must remain down after shut down or up after start up
- Unit ramp rates
- Max number of state changes for a unit during a time period
- Max number of units that could be started simultaneously
- Special equipment models: CCGT, dual boiler units
- ...

Goal function:

\[
V^* = V(x^*) = \min_{x: (1)-(9)} \sum \sum [B_i^t PMAX_i^t h^t s_i^t + CU_i^t u_i^t + CD_i^t d_i^t]
\]
Day Ahead vs. UC in 2015

• In recent years capacity growth due to “DPM” program amounted to 3-5 GWt per year, while “old” capacity continues to operate and demand growth is close to zero

• The fall in Day Ahead prices is prevented through UC goal function by “filtering out” the units above forecasted load plus required reserve
Visible change in generator bidding strategy in UC, April vs October 2015:

- **April:**
  - nearly 87% of committed units with non-zero bids are self-scheduled or RMR;
  - only few price-cap bids;
  - high competition – 3-4 GWt of price-taking bids are not committed

- **October:**
  - only 60% of committed price bids are self-scheduled or RMR;
  - share of price-cap bids increased dramatically