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

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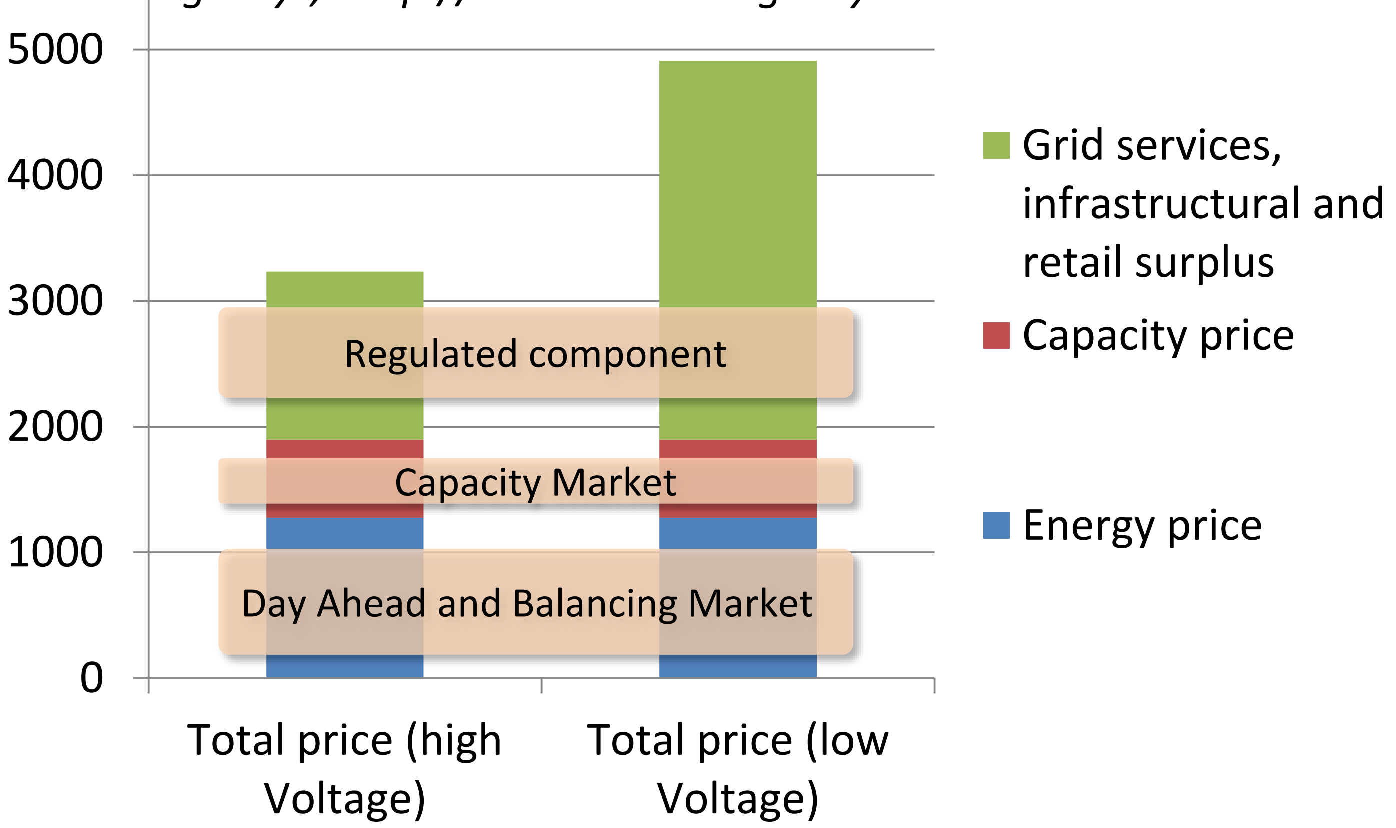
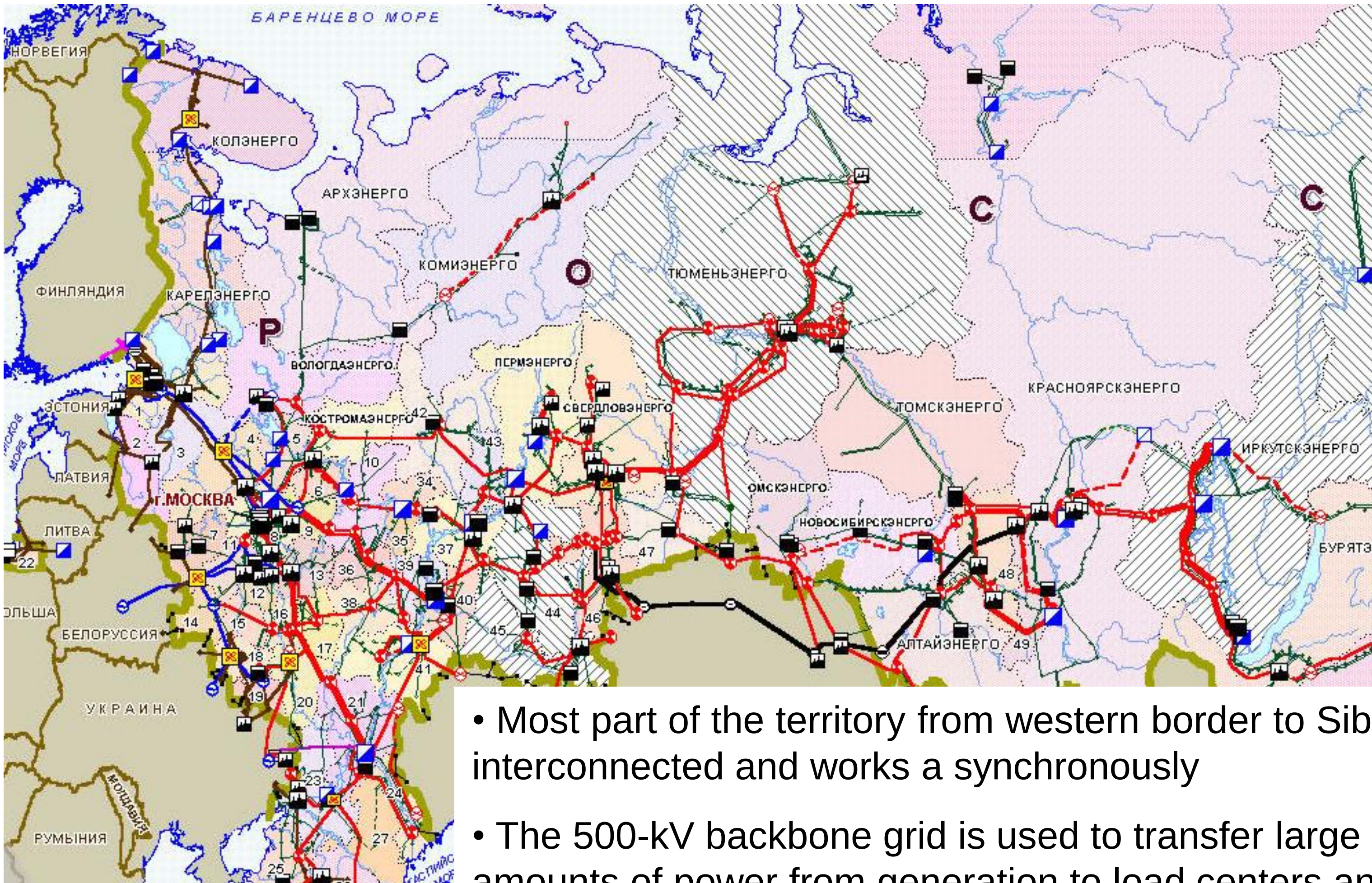
Structure of energy price, RUR/MWth

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

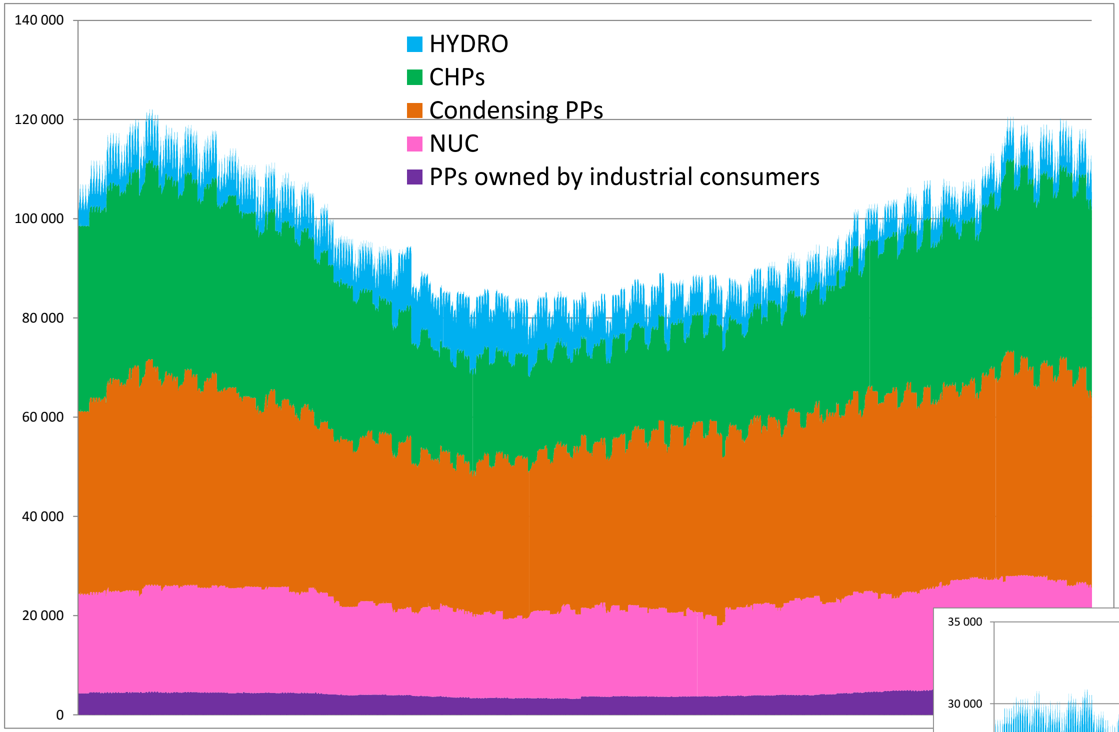


Energy market: System Structure

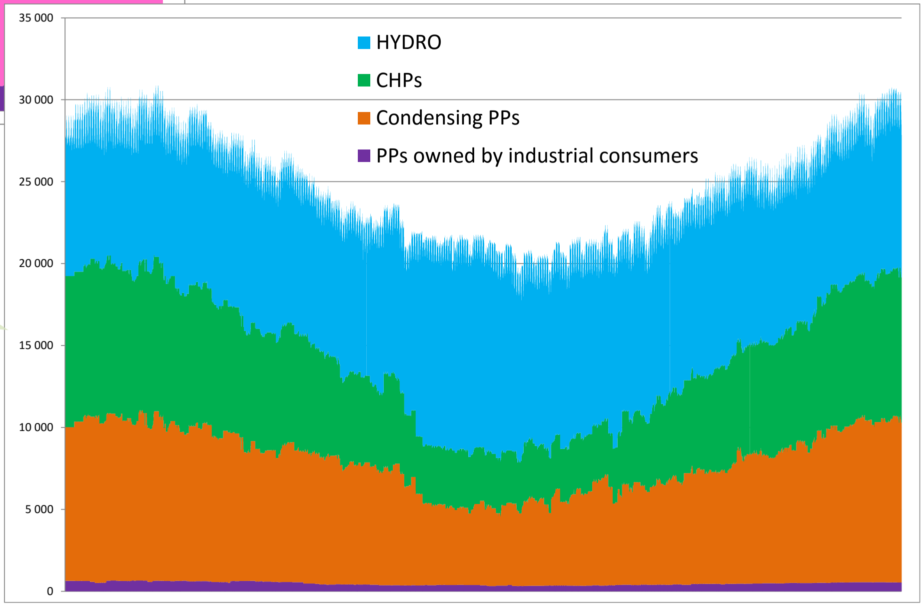


- Most part of the territory from western border to Siberia is interconnected and works a synchronously
- The 500-kV backbone grid is used to transfer large amounts of power from generation to load centers and throughout the time zones
- 7 joint territorial dispatch centers and the central dispatch unit (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 condencing 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

$$\sum_t (b_C^t p_C^t - b_G^t p_G^t) \to \max$$

$$F(\delta^t, V^t, p_C^t, p_G^t, q) = 0, \quad t = 1,\ldots,T$$

Nodal power balance constraints (active and reactive)

$$\underline{f}_S^t \le f_S^t(\delta^t, V^t) \le \overline{f}_S^t$$

Power flow constraints

$$p_C^t \in P_C^t, \quad p_G^t \in P_G^t$$

+ additional linking constraints:

- ramp-rate constraints
- integral fuel 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:

$$\lambda_{node} = \lambda_0 \left(1 + \frac{\partial \ell}{\partial p_{node}} \right) + \sum_S \sigma_S \frac{\partial f_S}{\partial p_{node}}$$

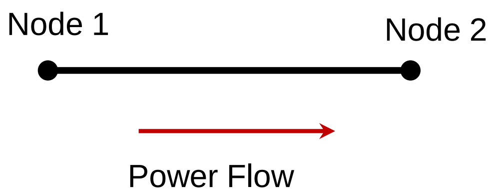
where ℓ – loss function; f_S – power flow at constraint S

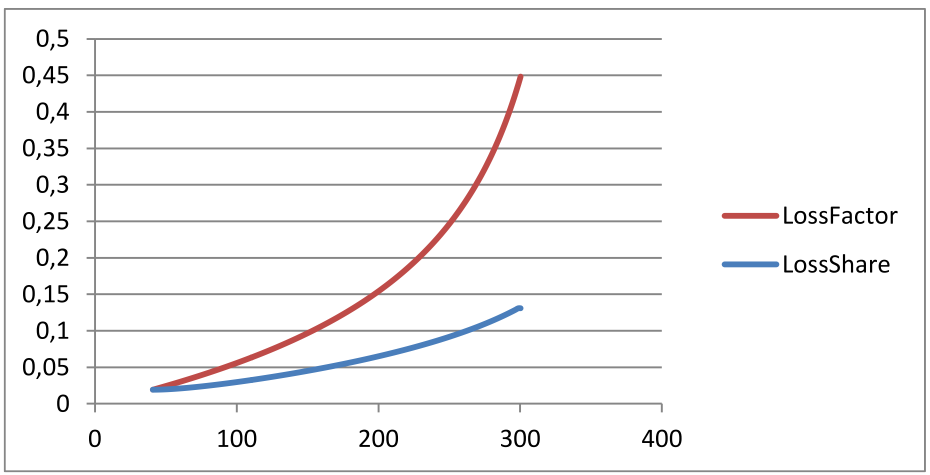
λ_0 – locational marginal price at swing bus

$\lambda_0 \dfrac{\partial \ell}{\partial p_{node}}$ – marginal loss value at bus $node$

$\sigma_S \dfrac{\partial f_S}{\partial p_{node}}$ – marginal value of constraint S at bus $node$

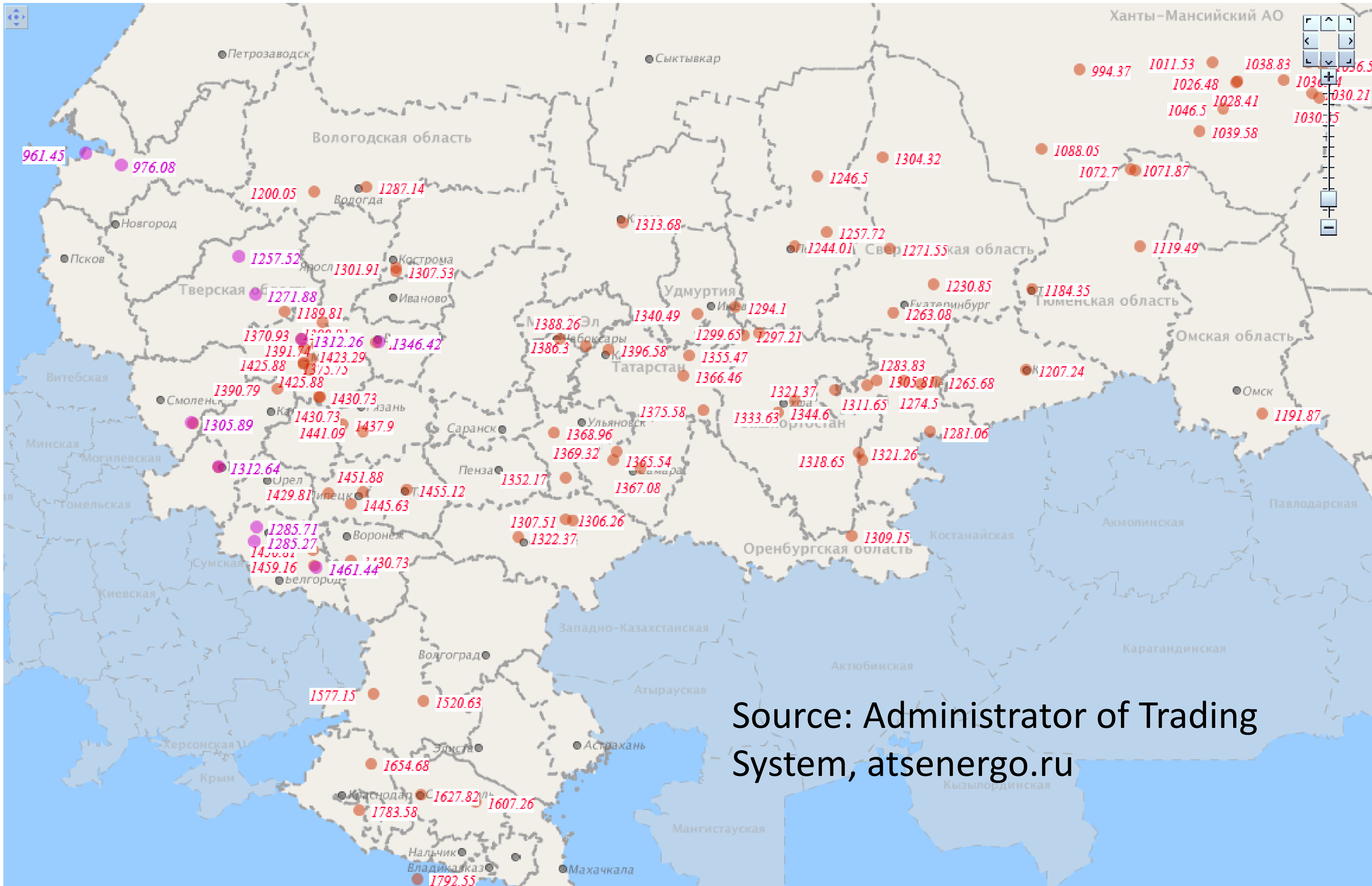
Marginal loss illustration





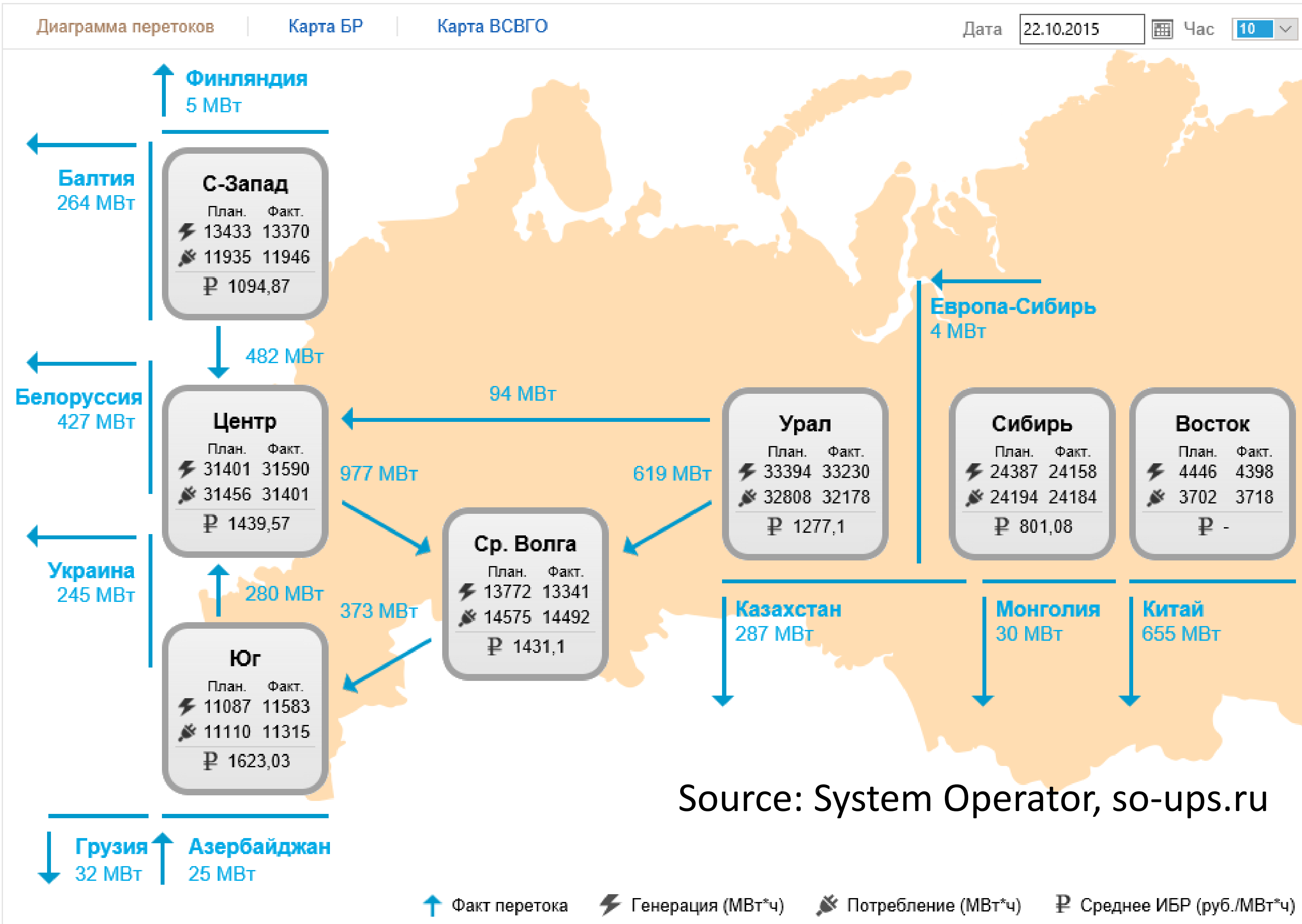
- LMPs at nodes are different due to the marginal loss factor
- Loss factor indicates the marginal loss increment corresponding to the increment in the line power flow
- Load at node 2 (in the example) pays at price of Gen at node 1 * (1+marginal LossFactor) which is greater then the amount supplied by the Gen to cover the load itself plus losses. *Hence the financial surplus at the market*

Day Ahead Market: hourly LMPs, RUR/MWh



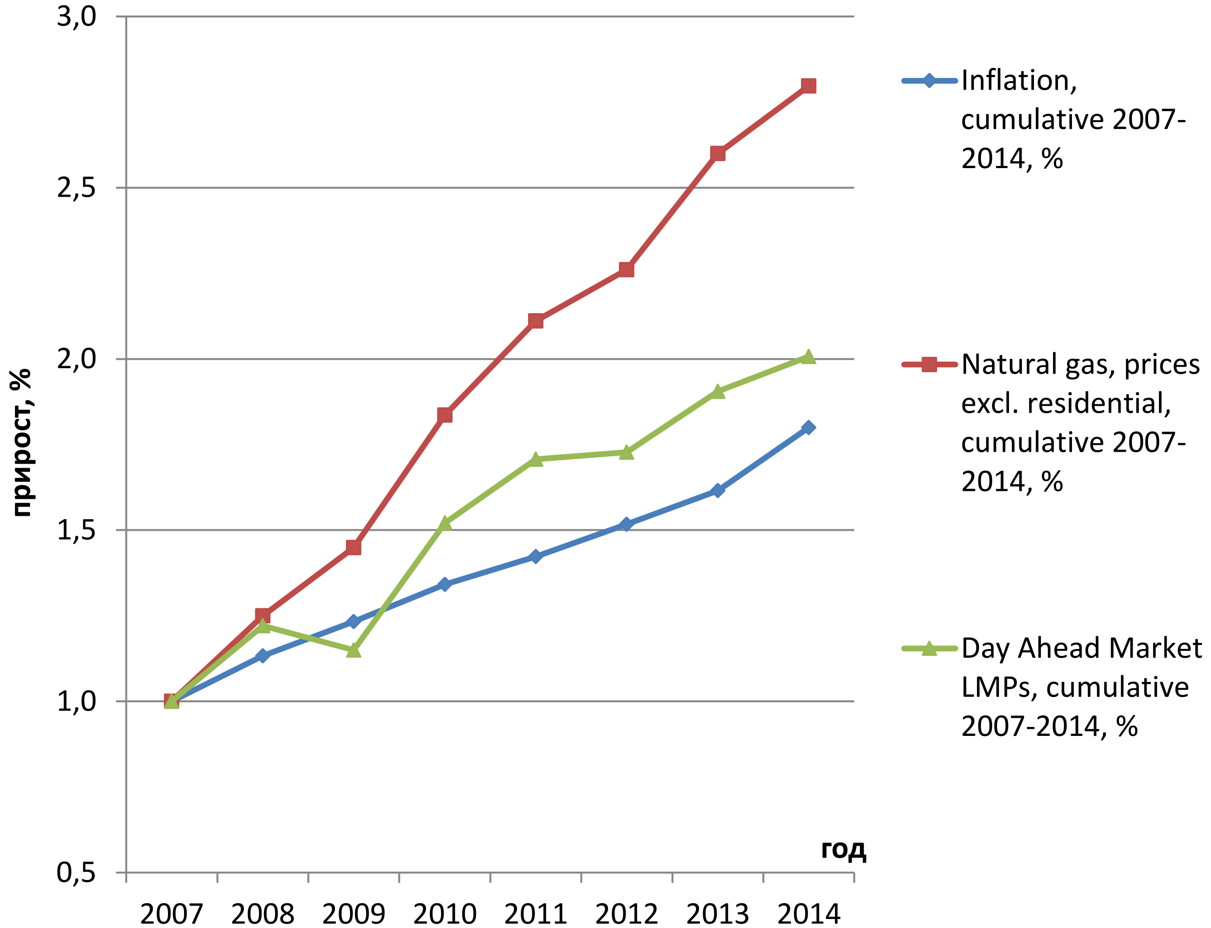
Source: Administrator of Trading System, atsenergo.ru

Balancing market: scheduled vs. actual dispatch



Source: System Operator, so-ups.ru

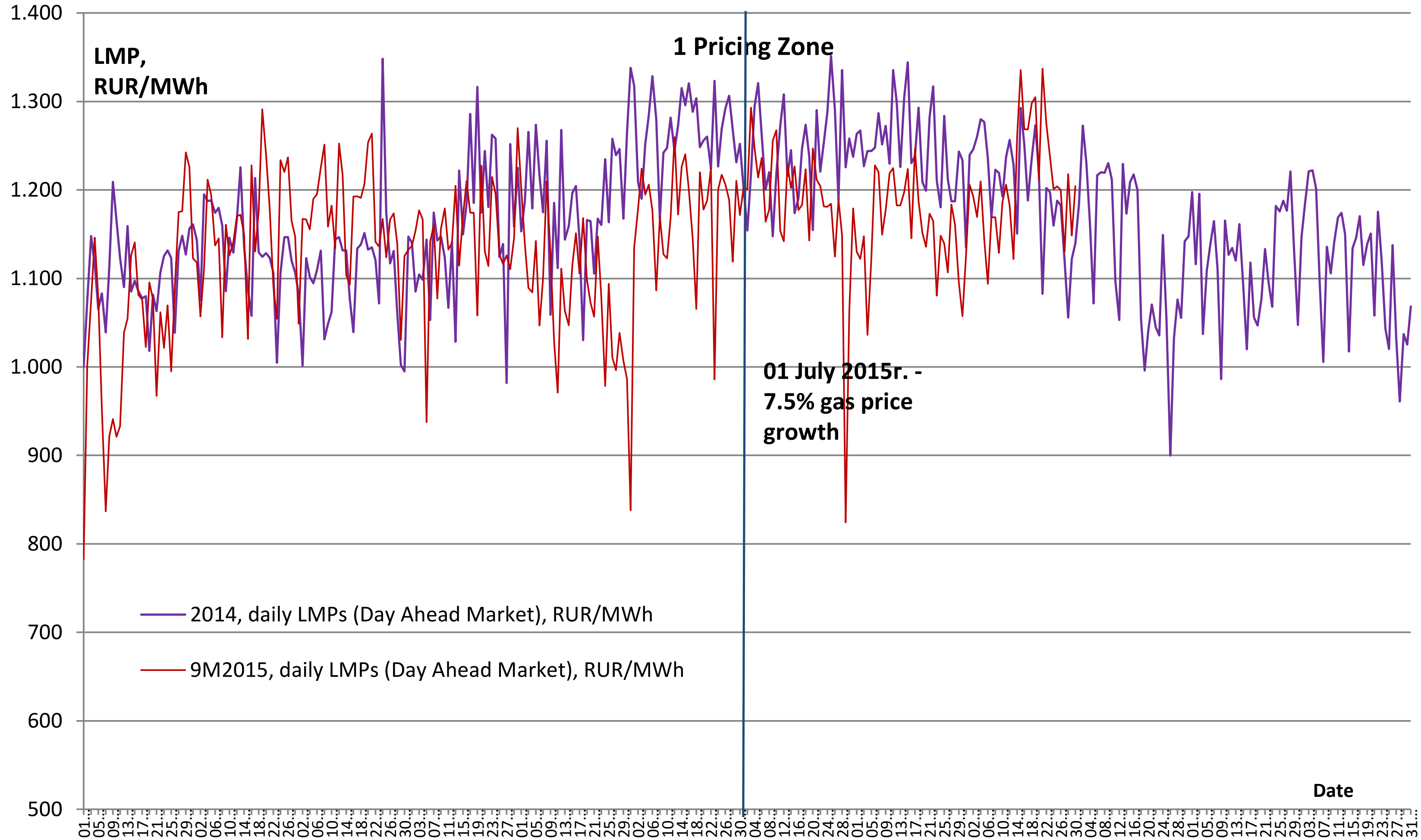
Market price dynamics, 1Pricing Zone



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



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

$$[\lambda_0^t] \quad \sum_{n=1..N^t} p_n^t l_n^t = \sum_{n=1..N^t} d_n^t + const_0^t$$

System balance of power

$$[\lambda_s^t \geq 0] \quad \sum_{n=1..N^t} p_n^t f_{ns}^t \leq F_s^t + const_s^t, \quad s = 1,\ldots,S$$

Power transfer constraints

$$[\rho_p^{+t} \geq 0] \quad -\sum_{i \in p} r_{ip}^{+t} \leq -RU_p^t, \quad p = 1,\ldots,P$$

$$[\rho_q^{-t} \geq 0] \quad -\sum_{i \in q} r_{iq}^{-t} \leq -RD_q^t, \quad q = 1,\ldots,Q$$

Reserve to ramp up and to ramp down

$$[\mu_n^t] \quad p_n^t - \sum_{i \in n} g_i^t = 0, \quad n = 1,\ldots,N^t$$

Generation of active power at a node

$$[\pi_i^{+t}] \quad g_i^t + \sum_{\substack{p=1..P: \\ i \in p}} r_{ip}^{+t} - s_i^t PMAX_i^t = 0, \quad i = 1,\ldots,G$$

$$[\pi_i^{-t}] \quad -g_i^t + \sum_{\substack{q=1..Q: \\ i \in q}} r_{iq}^{-t} + s_i^t PMIN_i^t = 0, \quad i = 1,\ldots,G$$

Max and min capacity of unit w.r.t. its state

$$[\tau_i^{+t} \geq 0] \quad -s_i^{t-1} + s_i^t - u_i^t \leq 0, \quad t = 2,\ldots,T, \quad i = 1,\ldots,G$$

$$[\tau_i^{-t} \geq 0] \quad s_i^{t-1} - s_i^t - d_i^t \leq 0, \quad t = 2,\ldots,T, \quad i = 1,\ldots,G$$

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
- …

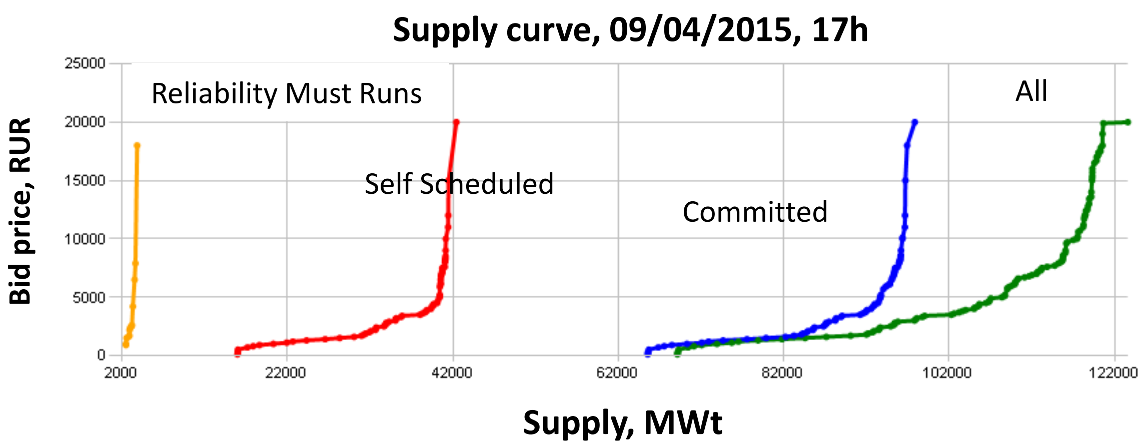
Goal function:

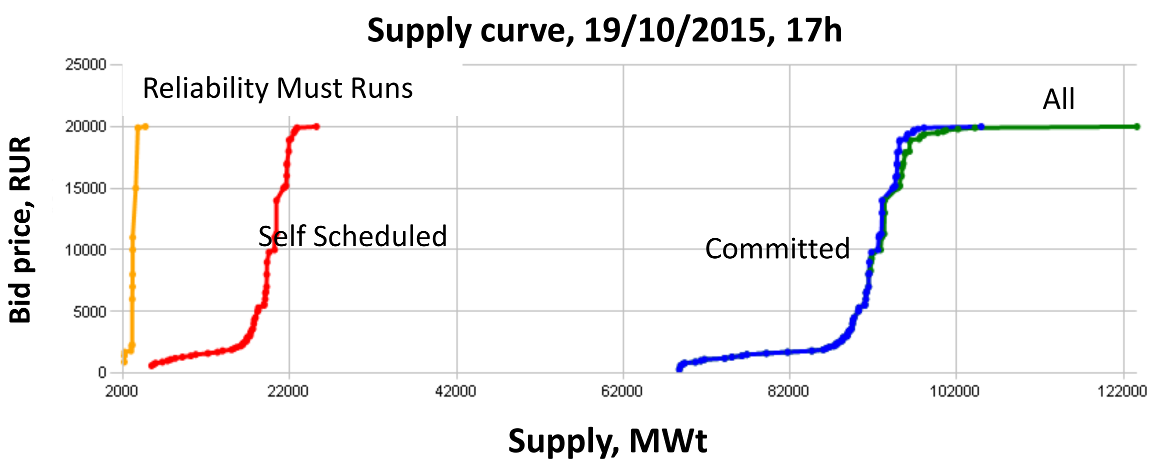
$$V^* = V(x^*) = \min_{\substack{x:(1)-(9) \\ r^+, r^-, u, d \geq 0 \\ s \in \{0,1\}}} \sum_{t=1..T} \sum_{i=1..G} \left[B_i^t PMAX_i^t h^t s_i^t + CU_i^t u_i^t + CD_i^t d_i^t \right]$$

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

UC supply curves: April, October, 2015





Source: System Operator, so-ups.ru

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