On lost profit calculations and pricing in liberalized power markets

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Power production (and, in some cases, power consumption as well) involves activities described by the non-convex functions. The supply-side non-convexities typically originate from the non-zero minimum capacity limits, start-up and no-load costs of generating units, whereas the demand-side non-convexities are usually related to discrete cycles of power consumption. The non-convex nature of power production (and, in certain cases, power consumption) may result in the absence of the uniform market price for power that yields economic equilibrium in the centralized market. This problem is typical for the Russian wholesale power market as a number of generating units that are not scheduled to operate in the unit commitment process have the marginal cost of output lower than the corresponding (locational) marginal price for power set by the economic dispatch optimization problem. Therefore, an alternative approach to calculate the cost of power should be implemented in these cases.

Pricing in power markets with non-convexities is a long-standing problem with proposals ranging from the introduction of the new products and services (such as individual prices for the online statuses of the generating units) to generalized uplifts and minimum-uplift pricing. The latter is also known as the convex hull pricing (CHP) and produces the uniform price for power that minimizes the total uplift payment to the market players needed to ensure the economic stability of the centralized market outcome. At present, CHP is used in MISO (in a simplified version) and NYISO (for the fast start units with equal minimum and maximum capacity limits).

The CHP pricing compensates both consumers and producers for the economic opportunities that are foregone by accepting the centralized market dispatch. For a given market price, the uplift payable to the market player is calculated as the difference between the maximum value of the profit function over the market player private feasible set and the profit received by the market player when following the centralized market outcome. Therefore, in CHP method it is assumed that all power volumes belonging to the private feasible set of a market player are attainable in the absence of the centralized market and should be accounted for in the lost profit calculation. Since any uplift payments reduce transparency of the market pricing, it is critical developing a pricing algorithm that reduces these payments.

We question the assumption of CHP that all the power production/consumption volumes belonging to the private feasible set of a market player should be used in the lost profit calculation since some of these volumes may not be attainable in both centralized and decentralized market (such as bilateral trade only market). This modification of CHP method was proposed in. For each producer/consumer we propose identifying the power production/consumption volumes attainable in the decentralized market. These volumes are defined as a set of the power volumes that are optimal points of the optimization problem that is formulated as the centralized

market optimization problem with the potentially reduced maximum capacity of generators/maximum consumption volumes of the consumers. (Thus, this approach involves finding a solution to a family of the optimization problems.) The reductions of maximum capacity/consumption volumes reflect the cases when the market players are able to buy/sell only some of the needed/available volumes at the decentralized market. For each market player we define the modified private feasible set as the subset of the private feasible set that contains both the power volumes attainable in decentralized market and the power volumes that corresponds to the option not to produce/consume any electric power (with the proper treatment of the sunk cost/benefit due to initial conditions of a given market planning horizon). The inclusion of the latter volumes is needed to ensure non-confiscatory pricing. Also, the original centralized market outcome belongs to the modified private feasible sets of the market players.

Further, we argue that only the volumes belonging to the modified private feasible set of a market player should be utilized in its lost profit calculation. Since the modified private feasible set is a subset of the original private feasible set, the resulting uplift payment to the market player (as well as the total uplift payment) needed to provide economic stability of the centralized market dispatch is potentially reduced (mathematically, it cannot be higher than that in the case of CHP). According to the proposal, the revenue function of a generator equals the sum of the following three terms:

- "Standard term" in the form of the market price times the output volume
- "Uplift term", which is paid only if the generator follows the centralized market dispatch. The uplift payment equals the difference between the maximum value of the profit function over the market player modified private feasible set and the profit received when it follows the centralized market outcome
- "Penalty term", which provides economic incentives to stay inside the modified private feasible set.

The expense function for the consumer is defined analogously. Also, in the case of no non-convexities present in the power market, the proposed approach generates a standard marginal price as the uniform market price and zero uplift payment.

We developed some methods that allowed straightforward calculations of the modified private feasible set of the market players in many cases and showed that application of the proposed pricing approach resulted in the total uplift payment reductions in a number of examples.

If the full-scale implementation of the proposed pricing method is complicated by the computational difficulties, it can be partially introduced for generating units of a selected type (as it is the case with CHP method).