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Deregulated Serbian Electricity Market Optimal Dispatch with Congestion Constraints

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Abstract: With newly adopted Energy Law, market in Serbia will become more deregulated in following years. Price and quantities of energy traded will be formed through an open pool competition of several producers and consumers by market mechanism which tends to maximize welfare. Due to congestion some of this welfare will be lost. We are suggesting and discussing 5 market indicators to quantify changes arising in the dispatch with congestion constraints.

Keywords: Linear programming, Dispatch problem, Market clearing price, Maximum welfare, Congestion.

1 Introduction

Regarding to the models of competition, electricity markets evolved from monopolies with no competition, to retail competition [1].

Traditionally, in Serbia, there was a typical vertically integrated utility at one and consumer at another side. The difference from a classical monopoly is in regulatory government board which is in charge of determining prize of electrical energy per kWh sold to the consumer. Since year 2005 and adoption of Energy Law 05, vertically integrated utility separated into generation and distribution. Generation company EPS owns all generation facilities while transmission company EMS owns all transmission and distribution facilities.

With adoption of new Law of Energy 2011 there is more competition to be seen in the future. Besides bilateral and balancing market, there is a space for open electricity market under the rules defined by regulator body proposed by the government. The open market participants are: Genco's, Disco's, Transco's, retailers, consumers and operator of open market but with certain specificities. These specificities are in time frame and open market in Serbia will be introduced sequentially. The transition to the open market will be accomplished in tree steps. Firstly, from year 2013 the largest consumers attached directly to transmission system will be capable of participating in the open market.

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Secondly, middle consumers attached to 0.4 kV or 10 kV are market participants from year 2014 and finally, from year 2015 all consumers participate in the open market [2].

Once new market is established the price of the electricity will change. Consumers are interested to receive demanded quantity of electricity at the best prize while producers are interested to sell at the highest prices. Price may differ at the ground of different generation technologies. Prices at consumer side are demand bids. They are usually introduced to illustrate Genco's potential of obtaining desired amount of energy at the location of the consumer. Transportation of electricity is obtained at economic grounds, which means that no electricity will be transferred if the price at consumer side is less than price of generation plus price of transportation and some additional welfare for all participants. Bids at consumers' side should be higher than the highest price at generation side in order to account for the transmission. Usually, there is something like the retail/Transco/Disco operator in between, which is also adding to the price, but this example is going to be simplified to producer-consumer scenario without loosing the big picture. The optimum is achieved at the intersection of supply and demand curves and it is called the maximum welfare [3].

In order to fulfill maximum welfare, we are suggesting applying linear optimization model. We model the energy market with several producers and consumers as a dispatch problem with demand bids [3]. Every consumer can buy from every producer or many producers. We assume that external trade is in balance, while quantities of exported and imported energy are equal. Solution to the dispatch problem with demand bids is obtained via Excel Solver 2007 [4].

Congestion occurs due to an operating condition that causes limit violations of one or more components in the system network [5]. We are looking at congestion cost at the side of producer and consumer. Furthermore, we are suggesting five market indicators to answer a question: what is impact of network congestions to the market clearing price (MCP) and market clearing quantity (MCQ) in the deregulated market? We are adding constraints to the transmission network to find if the customers are obliged to pay higher prices because of congestion, which occurs occasionally in an open assessed transmission network. Additionally, we are simulating the open market mechanism trying to maximize global welfare (W) and to quantify deadweight loss (DL) [1].

Finally, we are going to perform sensitivity analysis of the optimization problem and show how to obtain MCP.

2 Method

Problem of optimal customer prizes is formulated as a dispatch problem with demand bids. We are looking at all Genco's and their offer prices and at consumers demand bids to find the MCP in order to achieve maximum welfare. In order to achieve maximum welfare at the open electricity market we will determine the values of X matrix, by using Excel Solver.

Furthermore, in order to explain effects of congestion to the MCP we have modified the dispatch problem by adding:

1. Transportation matrix X to the dispatch problem with demand bids;
2. New constraints to simulate congestion of the one line Z_1 and Z_2, shown in Fig. 1.

Mathematical formulation: Chose x_{ij} to maximize objective function:

$$\max\left\{W=\sum_{i=1}^{s}Q_iP_i-\sum_{j=1}^{b}Q_jP_j\right\},\tag{1}$$

subject to:

$$\sum_{i=1}^{i=s}Q_i=\sum_{j=1}^{i=b}Q_j\ ,\tag{2}$$

$$Q_i\le S_i,\quad i=1,2,\ldots,s\ ,\tag{3}$$

$$Q_j\le D_j,\quad j=1,2,\ldots,b\ ,\tag{4}$$

$$Q_j\le CON_j\ ,\tag{5}$$

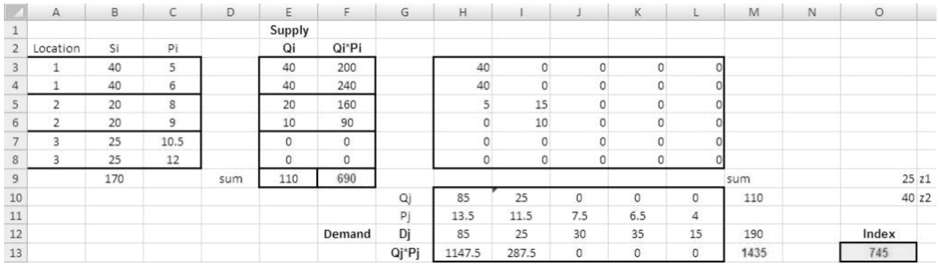
$$x_{ij}\ge 0\ ,\tag{6}$$

where:

$$Q_i=\sum_j x_{ij}\,,\, j=1,2,\ldots,b\ ,\tag{7}$$

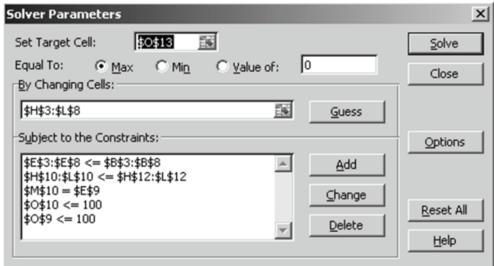
$$Q_j=\sum_i x_{ij}\,,i=1,2,\ldots,s\ ,\tag{8}$$

where P_i and $Q_i, i=1,2,\ldots,s$ are prices and quantities of energy at the supply side, P_i and $Q_j, j=1,2,\ldots,b$ are demand bids and quantities of energy at the demand side, x_{ij} are values of matrix X, the energy transported from Genco i to the constumer j, S_i is the maximum offered energy at the Genco, D_i is the maximum energy that may be sold to the consumer, $CON_j, j=1,2,\ldots,b$, is a congestion on the line from the Genco i to all consumers.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1					Supply											
2	Location	Si	Pi		Qi	Qi*Pi										
3	1	40	5		40	200		40	0	0	0	0				
4	1	40	6		40	240		40	0	0	0	0				
5	2	20	8		20	160		5	15	0	0	0				
6	2	20	9		10	90		0	10	0	0	0				
7	3	25	10.5		0	0		0	0	0	0	0				
8	3	25	12		0	0		0	0	0	0	0				
9		170		sum	110	690							sum		25	z1
10							Qj	85	25	0	0	0	110		40	z2
11							Pj	13.5	11.5	7.5	6.5	4				
12						Demand	Dj	85	25	30	35	15	190		Index	
13							Qj*Pj	1147.5	287.5	0	0	0	1435		745	

(a)



(b)

Fig. 1 – *Modified demand dispatch with demand bids*: (a) *Table*, (b) *Solver parameters*.

Cells B3:C8 show the quantity and price of supply offers to sell energy in increasing order and cells H11:L12 show demanded quantities and price bids for energy at consumers' side in decreasing order. Choice variables are in cells H3:L8. Cells E3:E8 are accepted supply offers at Genco i to all consumers in open market that are buying its energy. Cells H10:E10 are accepted demand bids of customer j from all Genco's that are selling energy.

Summations in (1) are calculated in cells M9 and F13, while their difference, market welfare and objective function are in cell O13. Constraint given in (2) showing that energy cannot be stored is calculated in cells M10 and E9 and formulated as a third constraint in *Solver parameters* Fig. 1b. First two constraints are (3) and (4). Constraints illustrating congestion Z_1 and Z_2 are cells O9 and O10. Additionally, choice variables should be nonnegative.

3 Results and Discussion

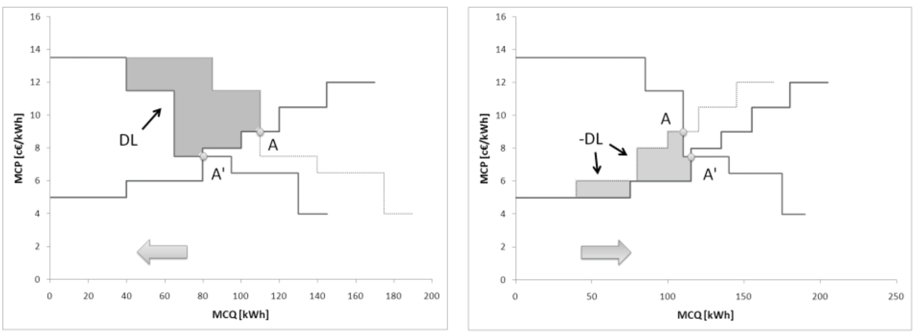
Basic scenario is model of open market with 6 Genco's and 5 consumers. Prices and quantities are chosen randomly. Scenarios to illustrate changes in open market with market indicators are shown in **Table 1**.

Fig. 2. shows how changes in demand and supply affect market indicators. Fig. 2a showing that decreasing in demand at the marginal prices is higher than

MCP leads to the decrease in MCP and MCQ. Since consumers are not anymore interested to bid energy at high prices, global welfare is decreased and deadweight loss is positive. Changes at supply side are shown in Fig. 2b. Increasing in quantity of energy at supply side on generators with lower marginal costs than MCP decreases MCP and increases MCQ. Global welfare is rising while deadweight loss is negative.

Table 1
Market indicators for base case and different scenarios.

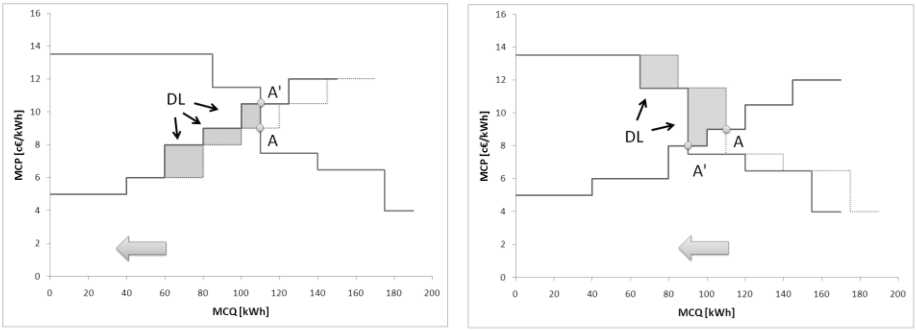
	Base case	Change in		Congestion at	
		supply	demand	supply	demand
Rate [kWh]	0	35	–40	20	20
MPC [c€/kWh]	9	7.5	7.5	10.5	8
MCW [kWh]	110	115	80	110	100
W [c€]	745	857.5	530	670	645
DL [c€]	0	–112.5	215	75	100
SP [c€/kWh]	0	3.2	–5.4	–3.8	–5.0



(a) (b)

Fig. 2 – (a) *Decrease in demand*; (b) *Increase in supply.*

Fig. 3 shows effects of congestion. Congestion may happen at both sides when flows of energy at open market are constrained with network capacity or network failure. Congestion at generator with lower marginal cost then MCP is shown at Fig. 3a. As a result, MCP raises, MCQ is constant while the global welfare is decreased by the deadweight loss. Scenario with the congestion at the demand side with higher marginal costs than the MCP is shown at Fig. 3b. In this scenario MPC, MCQ and global welfare decrease, while the deadweight loss is positive.



(a) (b)

Fig. 3 – *Congestion*: (a) *Supply side*; (b) *Demand side.*

3.1 Sensitivity analysis

Sensitivity analysis is a byproduct of optimization in Excel Solver. The most valuable product of this procedure is the MCP obtaining procedure. The MCP is obtained at the intersection of the supply and demand curves. All constraints have its *shadow prices*. The MCP is associated with the *shadow price* of quantity of energy procured at the market. The market clearing quantity (MCQ) is shown at Fig. 4. It is also known as the *marginal price* of energy. It shows how much consumer must pay for the additional kWh of energy and the price of additional kWh of energy to be sold by Genco's.

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
H10	Qj	84.99999999	4.500000021	85	10.00000001	9.999999994
I10	Qj	25	2.500000021	25	10.00000001	9.667666667
J10	Qj	0	0	30	1E+30	30
K10	Qj	0	0	35	1E+30	35
L10	Qj	0	0	15	1E+30	15
E3	Qi	40	3.999999979	40	9.999999994	10.00000001
E4	Qi	40	2.999999979	40	9.667666667	10.00000001
E5	Qi	20	0.999999997	20	9.999999991	10.00000001
E6	Qi	9.999999991	0	20	1E+30	10.00000001
E7	Qi	0	0	25	1E+30	25
E8	Qi	0	0	25	1E+30	25
M10	Qj sum	110	8.999999987	0	0	10.00000001
O10	Qj	40	0	100	1E+30	60
O9	sum	0	0	100	1E+30	100

Fig. 4 – *Sensitivity analysis of constraints.*

Another product of optimization is a *reduced cost* for choice (decision) variables. A reduced cost for offers or bids not selected is les or equal zero. It shows how the objective function is changed if variable is chosen. Since this is a maximization problem, variables with lower negative reduced costs are more likely not to be chosen.

With increasing in production of 35 kWh we are achieving global welfare rising for 112.5 c€ showing that the shadow price of production is 3.2 c€ per kWh of a newly constructed production unit. Shadow prices of congestion at supply and demand side are shown in last column of **Table 1**.

4 Conclusion

The process of deregulation in Serbia will eventually result in opening of the electricity market, in the year 2015. Due to possible transmission congestions and capacity shortages, market clearing price will not always be formed freely, which might result in the deadweight loss and in declining instead of the expected increase of the global welfare. With possible less demand for energy the market clearing price could decline, as well as the global welfare and the market clearing quantity. Investments in new generation and transmission might result in lower market clearing prices and larger global welfare.

5 Acknowledgement

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6 References

[1] D.S. Kirschen, G. Strbac: Fundamentals of Power System Economics, John Wiley & Sons, Chichester, UK, 2004.

[2] Republic of Serbia, Ministry of Infrastructure and Energy, Energy Law, 2011.

[3] N.S. Rau: Optimization Principles: Practical Applications to the Operation and Markets of the Electric Power Industry, IEEE Press, John Wiley & Sons, Piscataway, NJ, USA, 2003.

[4] Microsoft Corporation, Microsoft® Office Excel®, 2007.

[5] I. Skokljev, V. Maksimovic: Congestion Management Utilizing Concentric Relaxation, Serbian Journal of Electrical Engineering, Vol. 4, No. 2, Nov. 2007, pp. 189 – 206.