

OPTIMIZATION IN DAY-AHEAD PLANNING OF ENERGY TRADING

Minja Marinović*

Faculty of Organizational Sciences, Belgrade, Serbia

Dragana Makajić - Nikolić

Faculty of Organizational Sciences, Belgrade, Serbia

Milan Stanojević

Faculty of Organizational Sciences, Belgrade, Serbia

In the twentieth century electricity was produced and transmitted by and between monopolistic public electric power companies. Over the last twenty years, electricity markets have been deregulated allowing customers to choose from a number of competing suppliers and producers. On one hand electricity market participants try to first satisfy their own country's demand and, on the other hand, to transmit electricity across borders into neighborhood markets. Cross-border transmission is part of a competition where market participants have non-discriminatory access to interconnected transmission lines. This paper examines the problem of day-ahead planning at trading sections of electricity companies. The underlying assumption is that the demand and supply are known in advance. Available transmission capacities are also known as well as additional transmission capacities that can be purchased. The prices and amounts of trading and transmission are subjects of auctions. The problem of day-ahead planning is here discussed from the perspective of a decision maker of an energy trading company (ETC). Decisions to be made are: where and how much electricity should the ETC buy and sell, and which transmission capacity will be used in order to maximize daily profit. The problem is formulated according to real-life experience of a Serbian ETC which trades in Central and South-East Europe. It is further modeled as a directed multiple-source and multiple-sink network and then represented by linear programming (LP) mathematical model in which the total daily profit is maximized subject to market constraints and flow capacities. The main goal of this model is to provide a useful tool for preparing auction bids. Numerical examples are given in order to illustrate possible applications of the model.

Key words: Energy trading, Day-ahead planning, Network flow, LP model

INTRODUCTION

Single European electricity market provides seamless competition within the electricity supply chain. Energy trading companies (ETCs) buy transmission capacities from transmission system operators (TSOs) [05]. TSOs consistently release actual maximum amounts of a cross-border transmission capacity to the market. ETCs operate in the middle stage of an energy supply chain [20], and, by buying and selling electricity contracts, they try to manage the risk associated with fluctuating prices. Both traders and end-users are prone to apply different financial instruments such as futures contracts, options, and derivatives to protect themselves against price speculations and fluctuations.

There are few ways of producing electricity: nuclear [04], thermo, hydro, solar, wind [03, 10], as well as several ways of trading electricity but the two most common ones are either by the telephone in bilateral transactions (so called "Over The Counter" or OTC, usually through the intermediation of a broker), or through futures markets such as Nordpool or EEX [02]. Some of the key factors to influence energy prices include geopolitical factors, global economic growth, short term weather condition with possible impact on demand, supply disruptions from maintenance or unexpected outages, fuel price fluctuations, and product swapping in response to relative prices [07].

* Faculty of organizational sciences, Jove Ilića 154, 11000 Belgrade, Serbia;
marinovic.minja@fon.bg.ac.rs

The literature on different aspects of energy trading and transmission is extensive. Kristiansen [11] analyses the auction mechanisms at the cross-border annual, monthly or daily transmission capacity auctions in the area of energy trading between Denmark and Germany. Detailed analysis of the perspective for South-East Europe to become a regional wholesale electricity market or electricity exchange zone is given in [12]. Oggioni and Smeers [17] analyse the impact of emission allowance prices on electricity prices and test two different average cost pricing policies, regional and zonal with different effects on electricity markets of Central and Western Europe. Triki et al. [21] consider multiple interrelated electricity markets, and they propose a multi-stage mixed-integer stochastic model for a capacity allocation strategy in a multi-auction competitive market. Quelhas et al. [19] propose a generalized network flow model of the national integrated energy system which incorporates production, transportation of coal, natural gas, and electricity storage with respect to the entire electric energy sector of the U.S. economy. The authors have formulated a multi period generalized flow problem in which the total cost is minimized subject to energy balance constraints. The problem of energy allocation between spot markets and bilateral contracts is formulated as a general portfolio optimization quadratic programming problem by Liu and Wu [13]. Purchala et al. [18] propose a zonal network model, aggregating individual nodes within each zone into virtual equivalent nodes, and all cross-border lines into equivalent border links. Using flow-based modeling, the feasibility of the least granularity zonal model where the price zones are defined by the political borders is analyzed. Hsieh and Chen [08] consider network systems with multiple-source multiple-sink flow such as electrical and power systems. They examine the problem in which resources are transmitted from resource-supplying nodes to resource-demanding nodes through unreliable flow networks. Nowak et al. [16] analysed the simultaneous optimization of power production and day-ahead power trading and formulated it as a stochastic integer programming model. In this paper we proposed an LP mathematical model of total daily profit maximization subject to arranged demand and supply and additional MW and transmission capacity constraints. [15]

We present the problem by a directed multiple-source and multiple-sink network and model using linear programming. Since the right to buy and

sell energy and utilize transmission capacity is acquired in auction, the proposed model can be also used as a tool to help decision makers to create bids for auctions. We illustrate this approach with an example of a Serbian ETC trading.

The paper is structured as follows. Section 2 is dedicated to a description of the main assumptions of the observed problem; Section 3 presents an LP model for day-ahead planning; in Section 4 we report and discuss numerical results to illustrate two different ways of model's application. First, we present the solution of an LP model with fixed parameters, and then we investigate the impact of prices on trading capacities and amounts in order to create bids for auctions. Conclusions along with perspectives regarding further study are given in Section 5.

PROBLEM DESCRIPTION

The focus of this paper is on electricity trading from the perspective of an ETC. The main task of a trading section of an ETC is to meet each and every customer requirements regardless of the circumstances. The trading section also enables the ETC to respond to the ever-changing state of the regional transmission grid and production capacities. Besides, this section deals with spot and long term arrangements, creating schedules, cross-border capacity allocations, optimization of the whole portfolio, managing different energy sources, customers in different countries and cross-border energy flows and costs.

The efficiency of a trading section of an ETC can be improved by considering at least two optimization problems: long term and short term (day-ahead) planning. Long term planning includes assessment of electricity market e.g. buyers and suppliers interested in cooperation, and transmission capacity to be purchased for the next period. Day-ahead planning refers to finding an optimal plan for selling and buying electricity, which will maximize the daily profit considering the available transmission capacities.

Day-ahead planning starts from an established network of potential buyers and suppliers and purchased transmission capacities based on long term decisions. The example of a simplified electricity network where all buyers and suppliers from one country are represented by one node is shown in Figure 1. This network will be used in the later numerical example.

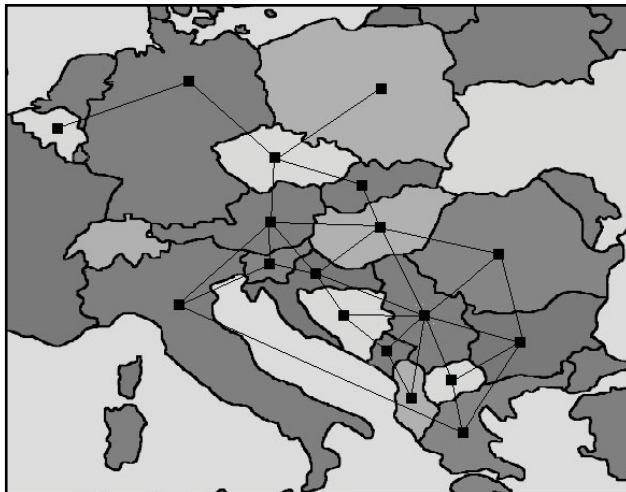


Figure 1: Simplified Central and South-East Europe electricity market

Daily demand and daily supply of each country (node) are known. Data about energy efficiency [09] and losses caused by transmission are already included in quantities of ordered and offered electricity. Electricity trade is carried out during the whole day. At all times decisions are made based on the information collected earlier that day. As the information about demand or supply arrives, new decisions are made. Some electricity trades are already arranged and they must be fulfilled. All the electricity bought during one day has to be sold the same day. Therefore, if there is a surplus or shortage of arranged supply, it will be traded through the futures markets. The futures markets such as EEX and EXAA [23] are the places where an ETC can buy or sell the electricity at less favorable prices. The amounts of surpluses and shortages are different for every day.

If an ETC wants to purchase transmission capacities to be at their disposal for a longer period, it is necessary to announce the amount that will be used. This amount is calculated based on assumptions and represents only an approximation of the real-time situation forecasted on the previous day [12]. Only the amounts announced one day before the day-ahead planning are considered available. The transmission capacity which is not announced is subject to a "use it or lose it" principle and will be reoffered at the daily auction [11]. If daily trading exceeds the amount of announced capacity, it is possible to buy additional daily transmission capacities at the auction price.

Each trade is initiated at an auction. Auction items are:

- Amounts of electricity that will be bought or sold, and the prices;
- Transmission capacity prices for the capacities that will be used in addition of those previously purchased and announced

The Serbian ETC in question trades on the electricity market where a uniform price auction type is used. This assumes that each bidder bids a price and amount. The price bid refers to a maximum price they are willing to pay per item, and the amount refers to the number of units they wish to purchase at that price. Typically these bids are sealed - not disclosed to the other buyers until the auction closes. The auctioneer then serves the highest bidder first, giving them the number of units requested, then the second highest bidder and so forth until the supply of the commodity is exhausted. All bidders then pay the unit price equal to the lowest winning bid (the lowest bid out of the buyers who actually received one or more units of the commodity) regardless of their actual bid [22].

In practice, bidders make several bids with different amounts and prices in order to make sure they will buy needed amounts, and at the lowest possible prices.

The goal of this paper is to create a useful tool which will help a decision maker in a trading section of an ETC to simulate market and network situations for different amounts and prices of electricity and transmission capacities. Optimization results should provide a decision maker with the information how to make bids at auctions in order to maximize the ETC total profit.

MODEL FORMULATION

The described problem can be modeled as a directed multiple-source and multiple-sink network [01].

The notation used to define sets, parameters, and decision variables is as follows.

- Sets
 - N – set of all nodes;
 - S – set of all nodes representing sellers, $S \subseteq N$;
 - B – set of all nodes representing buyers, $B \subseteq N$;
 - A – set of arcs representing transmission capacity between nodes, $A \subset N \times N$;

- Parameters
 - su_j – upper bound of electricity that can be bought from supplier $j, j \in S$;
 - sl_j – lower bound (arranged buying) of electricity that can be bought from supplier $j, j \in S$;
 - bu_i – upper bound of electricity that can be sold to buyer $i, i \in B$;
 - bl_i – lower bound (arranged sale) of electricity that can be sold to buyer $i, i \in B$;
 - f_{ij} – announced daily transmission capacity of arc $(i, j) \in A$;
 - hu_{ij} – maximal additional daily transmission capacity which is possible to be bought on arc $(i, j) \in A$;
 - c_j – purchasing price for supplier $j, j \in S$;
 - d_i – selling price for buyer $i, i \in B$;

- a_{ij} – price for additional transmission capacities on arc $(i, j) \in A$;
 - t_{ij} – taxes for additional transmission capacities on arc $(i, j) \in A$.
- Variables:
 - x_j – amount of electricity that should be bought from supplier $j \in S$;
 - y_i – amount of electricity that should be sold to buyer $i \in B$;
 - h_{ij} – amount of additional transmission capacities on arc $(i, j) \in A$.

All electricity amounts and transmission capacities are expressed in MWh. Unit for all prices and taxes is Euro per MWh.

Using given notation the LP mathematical model for day-ahead planning can be stated.

(MMDAP)

$$\max Z(x, y, h) = \sum_{i \in B} d_i y_i - \sum_{j \in S} c_j x_j - \sum_{(i, j) \in A} (t_{ij} + a_{ij}) h_{ij} \quad (1)$$

s.t.

$$\sum_{j \in S} x_j - \sum_{i \in B} y_i = 0 \quad (2)$$

$$\sum_{(i, j) \in A} (f_{ij} + h_{ij}) - \sum_{(j, i) \in A} (f_{ji} + h_{ji}) = \begin{cases} 0 & j \in N \setminus (S \cup B) \\ -x_j & j \in S \setminus B \\ y_j & j \in B \setminus S \\ y_j - x_j & j \in B \cap S \end{cases} \quad (3)$$

$$sl_j \leq x_j \leq su_j, j \in S \quad (4)$$

$$bl_i \leq y_i \leq bu_i, i \in B \quad (5)$$

$$0 \leq h_{ij} \leq hu_{ij}, (i, j) \in A \quad (6)$$

Objective function (1) represents the difference between total income and costs of buying electricity and additional transmission capacities. Constraint (2) provides that quantities of electricity that is bought and sold in one day are equal. Since all nodes are transition nodes, a flow conservation constraint (3) must hold. This constraint has four different interpretations depending on a node type. $N \setminus (S \cup B)$ is a set of nodes without demand and supply. For each node from $N \setminus (S \cup B)$ constraints (3) ensure that the amount of electricity entering the node must be equal to the amount of electricity leaving the node. $S \setminus B$ is a set of source nodes in which the amount of electricity entering a node and electricity bought in this node must be equal to the amount of electricity leaving the node while $B \setminus S$ is a set of sink nodes in which the amount of electricity entering a node must equal the amount of electricity

leaving the node and electricity sold in this node. $B \cap S$ is a set of source-sink nodes. For each node from $B \cap S$ constraints (3) ensure that the amount of electricity entering the node and electricity bought in this node must equal the amount of electricity leaving that node and electricity sold in that node. Optimal amounts of electricity that should be bought and sold lie between their upper and lower boundaries given by constraints (4) and (5). Constraint (6) refers to the maximal additional daily transmission capacity which can be bought on an arc.

NUMERICAL EXAMPLES

In order to assess the proposed model we consider two different ways of its application. The first one consists of obtaining an optimal day-ahead plan where all parameters have fixed val-

ues. The second application is based on a more realistic situation where some parameters may vary within certain boundaries. Such approach can help the ETC decision maker to create bids for an auction. Both applications are shown on a CSEE network consisting of 18 nodes and 62 arcs (Figure 2).

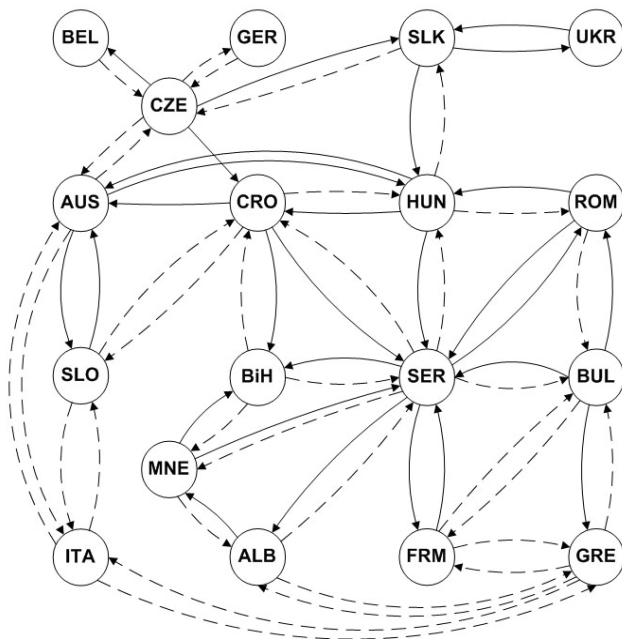


Figure 2: Graph representation of CSEE electricity market

Each country is presented by a node which is characterized by its lower and upper bounds of electricity that can be bought and/or sold in/from that country as well as purchasing and selling prices. All arcs (in Figure 2, both, solid and dashed lines) represent cross-border connections where it is possible to buy additional transmission capacity. Arcs represented by solid lines indicate the existence of announced transmission capacities purchased earlier, while arcs represented by dashed lines represent the unannounced transmission capacities which can be purchased on the daily base. Amounts of announced and maximal additional daily transmission capacities (Table 1) as well as prices and taxes of each arc are also given.

Due to confidentiality issues, in this paper we present a slightly modified data which are within the boundaries of common real-life situations.

The model has been implemented and solved using GNU Linear Programming Kit software intended for solving linear programming (LP), mixed integer programming (MIP), and other related problems [06]. The optimal solution for one scenario is given in Table 2. Marks “/” mean that there were no suppliers or buyers in the corresponding country.

Table 1: Upper bounds for additional transmission capacities

	BEL	GER	AUS	SLO	ITA	GRE	CZE	HUN	CRO	BiH	MNE	POL	SLK	SER	ALB	FRM	UKR	ROM	BUL
BEL							200												
GER							500												
AUS				360	280		150	430											
SLO			40		100				200										
ITA			250	150		50													
GRE					300										280	610			410
CZE	180	50	240										200						
HUN			320						110				500	140				340	
CRO				300				100		200				350					
BiH									59		210			300					
MNE									320					50	120				
POL																			
SLK							420	250									85		
SER								500	300	200	200				200	400		100	200
ALB						85					300			200					
FRM						250								460					250
UKR													390						
ROM								230						170					155
BUL						455								49		145		450	

Table 2: Optimal solution

node	Buying in MWh			Selling in MWh		
	min	Optimal	max	min	Optimal	max
BEL	18	40	40	25	25	67
GER	2	70	70	0	70	80
AUS	1	31	31	0	0	60
SLO	/	/	/	5	5	35
ITA	0	36	50	31	41	41
GRE	0	0	86	/	/	/
CZE	0	61	85	0	0	38
HUN	0	0	10	/	/	/
CRO	/	/	/	22	22	44
BIH	36	52	52	42	49	49
MNE	/	/	/	5	5	60
SLK	/	/	/	12	12	33
SER	0	46	46	0	80	80
ALB	5	10	35	/	/	/
FRM	0	40	40	3	3	57
ROM	/	/	/	4	70	70
BUL	/	/	/	14	14	25
UKR	10	10	20	/	/	/

In addition to optimal trading amounts, the solution determines additional transmission capacities that should be purchased. In this scenario we obtained: 45 MWh on arc BEL-CZE, 5 MWh on arc SLO-ITA, 41 MWh on arc GRE-BUL, etc. Total daily trade is 396 MWh. The total daily income is 34068 €. The cost for buying electricity is 26803 €, while the cost for additional transmission capacities is 3078 €. The total profit based on this optimal solution is 4187 €. In order to obtain this total profit certain corrections of objective function has to be made:

- Taxes for announced transmission capacities and costs of long term purchased transmission capacities evaluated on a daily basis should be subtracted;
- Unit prices for previously arranged buying and selling (blj and slj) can differ from actual prices. These differences should be taken into account

Nevertheless these corrections do not influence the optimality of the obtained solution. In further analysis we will use term "profit" for the value of goal function, although it is just an approximation.

The possibility of buying and selling electricity on futures markets, as well as the possibility of

buying additional transmission capacities, will provide the feasibility of all solutions. Since we enabled surpluses and shortages the model will always provide an optimal solution. Based on experiments done so far we noticed that the solution may not always be unique, but that there might be more than one; which one will be chosen depends entirely on the decision maker.

To demonstrate the second way of using MMDAP we have simulated a situation where a decision maker creates bids at an auction for buying electricity from one supplier. In the presented example we observed a supplier in node CZE which offers the amount of 85 MWh.

We analysed the influence of the purchasing price changes on the optimal amount of electricity that should be bought and an optimal solution as a whole. Based on the experience we have supposed that the electricity price for the supplier in node CZE can vary from 75 to 93 €/MWh. A series of optimizations was made for all integer values of prices in the given interval. Table 3 shows the optimal amounts of electricity that should be bought and the corresponding profits for some characteristic prices of electricity, assuming that all other parameters remain the same.

Table 3: The impact of prices on optimal amount and profit

Price	Optimal amounts	Profit
75	85	4442
⋮	⋮	⋮
77	85	4272
78	61	4187
79	15	4126
⋮	⋮	⋮
91	15	3946
92	0	3931
93	0	3931

The decrease of optimal amount of electricity and profit was expected because the purchasing price increased, but all the solutions were optimal if the corresponding price became the lowest winning bid. In other words, for different prices established by auction competition, different amounts of electricity that should be bought (and corresponding profits) are optimal.

Table 4: List of bids derived from optimal solutions

Bids	Amounts of el.	Price	Accumulated amount	Guaranteed profit
B1	15	79-91	15	4126-3946
B2	46	78	61	4187
B3	24	75-77	85	4442-4272

On the basis of presented optimal solutions we can suggest the ETC decision maker to make bids shown in the first three columns in Table 4. Depending on the price equal to the lowest winning bid (which will not be known till the end of the auction), the ETC will buy 0, 15, 61 or 85 MWh from node CZE. For prices that are presented as intervals in Table 3, the ETC decision maker can give any price from that interval for which they estimate that it can win. In any case the corresponding amount will be optimal. The profits given in the right column represent the optimal profit if the corresponding bid becomes the lowest winning bid. If any lower bid wins, the profit becomes larger.

CONCLUSIONS

This paper considers the optimization problems which appear in a trading section of energy trading companies, and one of them, day-ahead energy planning, was formulated as a linear programming problem. Day-ahead energy planning implies finding the optimal amounts of electricity that should be bought from each supplier and sold to each buyer and the optimal routes which can satisfy the daily demands using the purchased and additional energy transmission capacities.

We have formulated LP mathematical model in order to optimize day-ahead energy plan. In addition, the proposed model can be used by an ETC decision maker as a tool for determining optimal bids in auctions for buying or selling electricity as well as for trading transmission capacities.

Two hypothetical numerical examples that demonstrate the use of the model were presented in this paper. Since the developed model is linear, it can be used to solve real-life problems of large dimensions.

We suggest that trading through futures markets be taken into consideration as a topic of further research. Another interesting and useful topic for future study may be the modeling of a long-term planning strategy of energy trading companies.

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