

Transmission and Optical Networks Creating by Using a Cooperative Game Theory Approach

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Abstract – This paper is dedicated to the task of planning energy supply systems in the market environment. The possibilities of forming coalitions between companies are considered. In this case, for justifying the decisions and distributing the gains, cooperative game theory is used. The example with the proposed strategy is based on a real project of 330 kV and 110kV high voltage lines and optical communication line between two substations and shows the rationality and efficiency of using the considered approach.

Keywords – Electrical engineering, optical communication lines, power transmission, transmission lines, game theory, decision-making.

I. INTRODUCTION

The aspiration of the global community towards increased power supply efficiency and reducing the influence of power generation on the environment has motivated a process of restructuring of power systems, intended for ensuring market conditions and free competition within the generation and sales of energy [1].

As a result of restructuring, the monopolies that ensure power supply are replaced by a number of independent companies which are striving to increase their gain and competing with each another. As a result of the restructuring and creation of a regulated energy market with the participation of independent companies, the task of power system development planning changes substantially.

Power supply planning problems are formulated in the form of revenue maximization or cost minimization tasks, more specifically, the strategic task of investment minimization. In this paper, supposing that the revenues or costs of the companies can be calculated, we will concentrate on the task of choosing the best of the possible decisions. Considering the market environment, all the companies that are operating within the system under consideration have to solve the task of energy supply system planning with the objective of maximizing their revenues and minimizing the costs at the same time.

In this process, it has to be taken into account that the decisions regarding the choice of the structure and parameters of the elements of the power supply system that are taken by companies influence the effectiveness of the decisions taken by other companies. Since, in the general case, the decisions taken by each of the companies are of confidential nature, it becomes necessary to introduce into the problem optimization of the variables that have an uncertain nature. In order to avoid the difficulties that might arise in this process, the scenario approach is used, according to which the possible strategies (plans) of each company considering all the possible

combinations of the strategies of the other companies are searched for. With this approach, the variables describing the strategies lose their uncertain nature. However, this simplification is achieved due to the fact that the final decision-making process becomes more complicated. As a result of the scenario approach, a set of decisions corresponding to all the combinations of possible scenarios is obtained. Usually, the scenario approach is used for variables that describe the players' actions and the status of the power system in distant future (energy prices, level of consumption, etc.).

The final decision is made based on the methods and criteria of the decision and game theory: (Min-Max, Minimal Risk, Hurwitz, Laplace) [4],[5]. The choice of criteria and methods depends on the nature of available information. When planning power systems, two basic cases are possible:

- ✓ Absence of information about the decision-making of the competing companies. In this case, depending on the subjective personal preferences of the decision-makers, one of the above criteria is chosen.

- ✓ Presence of complete information about the results of the decision-making of each company and the possibility to make an assumption that these decisions will be rational and will be aimed at getting maximum gain. In this case, the nature of the uncertainty changes considerably, which can be used for obtaining better decisions and, consequently, increasing the gains [2].

This paper is dedicated to the second particular case, making the additional assumption that it is possible to form a coalition with the other company. In this case there is a mutual benefit expected.

The proposed strategy is based on the part of real project with planned 330kV high voltage transmission and optical communication lines construction and 110kV high voltage transmission line reconstruction between substations Grobina and Ventspils, named "action 1", which is intended to construct so called "Kurzeme Ring" (see Fig.1). The total costs of the "action 1" constitute approximately 400000 r.u./km*.[13]

In the given example, it is assumed that there are three independent companies two of which are engaged in the creation of power transmission lines and the third company is interested in implementing optical communication line. The one of power transmission companies is engaged in the

* - To avoid disclosure of commercial information, the prices are given in relative units (r.u.)

creation of a 110 kV transmission line and the other in the creation of a 330 kV transmission line. The alternatives that are advantageous for each company have to be chosen as the decision. It is also necessary to show the costs of the project and the potential benefit for each company in the case of an individual approach, implementing the whole project separately, and check if it is possible to form different variants of coalition. Then there is the task of analyzing the outlook for forming coalitions with other companies. The example is based on a real Latvian project; however, today the system for dividing the power supply including transmission lines is somewhat different. All power transmission above 110kV belongs to one company. Therefore all the revenue of the project in the case of combining 110kV and 330kV transmission lines is the profit of mentioned company. The cooperative game approach is typical for other countries of Europe and the Russian Federation where the issue of cooperation is more topical because of the potential profit for each company.

II. THE DEVELOPMENT PLAN OF THE TRANSMISSION NETWORK OF THE BALTIC REGION

The Kurzeme Ring (KR) is an energy infrastructure project involving the construction of a 330kV overhead line and the reconstruction of an existing 110kV transmission line in the western part of Latvia. At the same time there is an aim to improve the optical network of the region creating additional optical communication line with a larger quantity of fibers. It is a part of the larger NordBalt project, the implementation of which includes the installation of the interconnection Latvia – Estonia – Sweden with a view of improving power supply reliability in the Baltic countries [6]. This solution will result in the reduction of bottlenecks in the network of Kurzeme region, increasing the limited possibilities of the development of generating capacities in Latvia as well as ensure the potential of connecting new electrical installations of consumers. Thus, the Baltic electricity market will be developed. The implementation of this project will be a significant step forward for the Baltic States, which are planning complete opening of their electricity market by 2013.

The KR will not only help to improve energy supply in Latvia, it also promotes full integration of the country in the transmission network of Europe [13].

The restoration of the national independence of the Baltic region countries and the concurrent sweeping economic changes have led to considerable changes in the structure of the power system (the closure of Ignalina Nuclear Power Plant as well as a number of economically inefficient plants running on heavy fuel oil) and significant changes in the power flows over the transmission grid [7].

The throughput of the transmission network of the Baltic region in normal mode is providing a quality reserve and a reliable supply of electricity, as well as a unified electric power system. However, expansion of the electrical connections among countries will be required (see Fig.1), especially if the capacity of the new nuclear power plants (NPP Visaginas, Kaliningrad, Belarus) is to be 3000 MW and

more. Besides, the great impact of renewable energy sources is expected to play an important role in energy supply, for example, the large number of new wind power plants. The

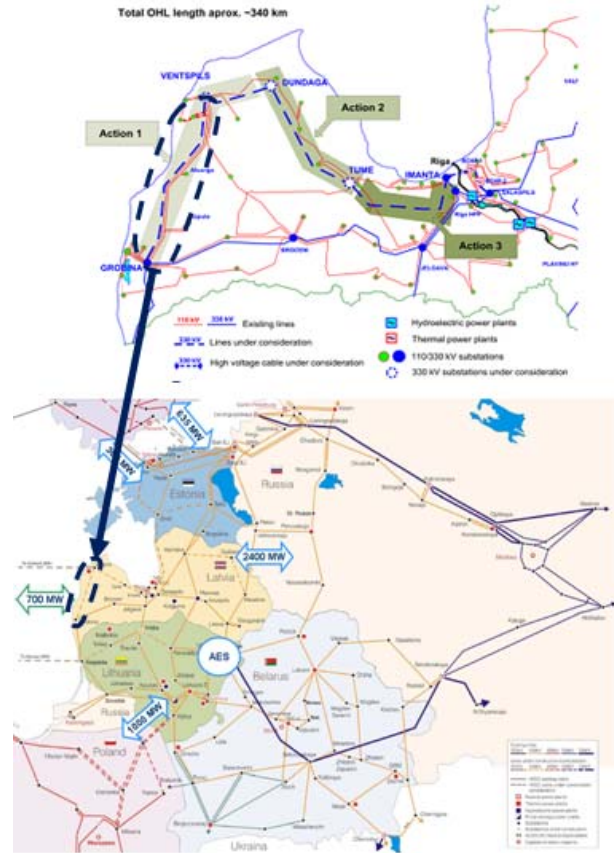


Fig. 1. New electrical connection of the Baltic power systems.

output and export of electric power of the new nuclear power stations to the Nordic countries will also require expansion of the internal power grid of the Baltic region, for example, between Latvia and Lithuania; Estonia and Latvia (Sindi – Rīga TEC-2) [8].

III. CONSIDERATION OF FORMING COALITIONS IN ENERGY SUPPLY PLANNING TASKS

A. Game - Theoretical Approach to the Planning Task

Let us imagine the task of power supply development planning in the form of a static game with complete information [9]. The game is presented in normal form as the following:

$$\{I, S = \prod_i \{S_i\} \mid i \in I, R = \{R_1, R_2 \dots R_n\}\} \quad (1)$$

where I is a list of players, $\{S = \prod_i \{S_i\}\} \mid i \in I$ is all situation combinations and revenues R are of each player at all his strategies and at each combination of the competitors' strategies.

It is assumed that the list and number of the players is known; also, that each player knows the revenues at any combination of structures and parameters of all the players. It is necessary to solve the following problems:

✓ Determining the rationality and possibility of organizing a coalition among the players.

✓ Choosing the methods for organizing the coalition and distributing additional revenues among the participants of the coalition.

If the possibility to form a coalition is taken into account, the formulation of the optimization task is modified once more. Due to the need to consider not only the strategies of individual companies, but also those of possible coalitions in various combinations, the dimension of the task increases considerably. Resulting from the solution of this task, the set of the sub-optimum plans for each company and their coalitions at various combinations of possible competitors' plans can be obtained.

B. Distribution of the Gain among the Members of the Coalition – Shapley Value

In case of cooperative behavior, there is a problem of revenue distribution among the members of the coalitions. The simple approach would be to give to each player his contribution c_i :

$$c_i = R(S \cup \{i\}) - R(S) \quad (2)$$

where $R(S)$ is the revenue of the coalition S , $R(S \cup \{i\})$ is the revenue of the coalition S with participation of the actor i .

However, such an approach is not anonymous, i.e. ordering of the players makes difference in the amount they are rewarded.

In game theory, a Shapley value [10] describes one approach for the fair allocation of gains avoiding the mentioned drawback. Fair allocation ensured by selecting uniformly a random ordering and rewarding each player the expected marginal cost in ordering. Since players can form $n!$ possible random orderings, the probability of set S being ranked exactly before player i is:

$$\frac{|S|!(n-1-|S|)!}{n!}$$

Thus the additional amount that the player i gets is:

$$\phi_i = \sum_{i \notin S \subseteq N} \frac{|S|!(n-1-|S|)!}{n!} (R(S \cup \{i\}) - R(S)) \quad (3)$$

where n is the total number of players, $|S|$ is the size of the set S , the sum extends over all subsets S of N not containing player i .

In the simplest case, when only two players participate in the game, the expression (3) is simplified and obtains the following form:

$$\phi_1 = \phi_2 = \frac{(R(S \cup \{i\}) - R(S))}{2} \quad (4)$$

The Shapley value describes the fair (in a sense determined by the accepted axioms) [10] distribution of additional gains in

the case of formation of the coalition. In particular, the definition is based on the assumption that possible combinations of the players who form the coalition are equally probable.

IV. THE TECHNICAL BASIS OF A PROPOSED TASK

The energy supply of Kurzeme region is one of the power transmission grid "narrow" places. In the perspective, this region is predicted with significant changes in both generating capacities connected to the structure and creation of new interconnections, for example, the cogeneration power plant is expected as well as a wind farm construction of the western part of Latvia, and the proposed new cross-connection from the Baltic to Sweden and Finland construction. Consequently, the existing transmission network throughput capacity must be sufficient to provide the normal mode and the planned reconstruction mode to the winter peak and summer peak-load regimes. As a result, in order to ensure the operational modes, it is necessary to determine the appropriate technical performances: the throughput capacity increasing of an existing equipment and new facilities construction of the transmission system [13].

The current situation of the region under consideration receives electricity from three 110 kV lines: a 110 kV double circuit transmission line from Grobina (see Fig. 2),

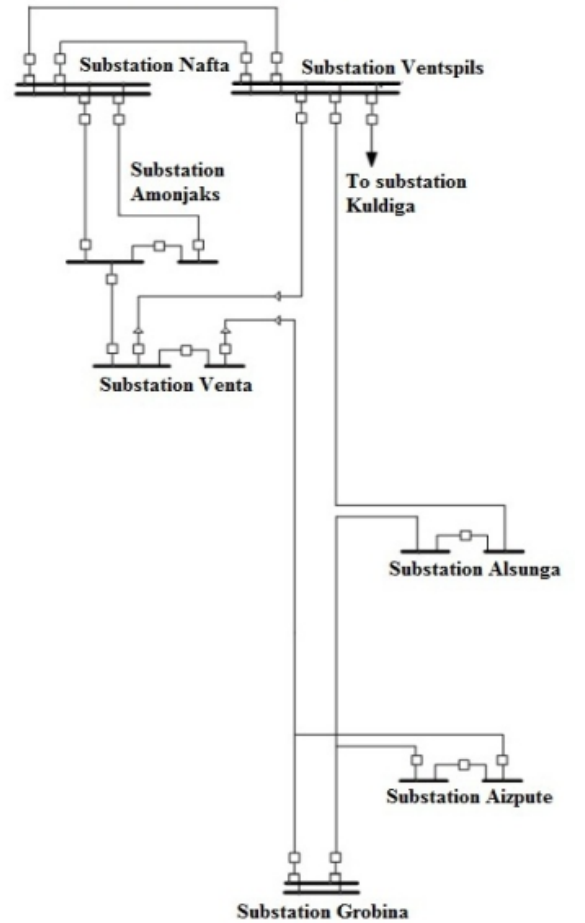


Fig. 2. The scheme of an existing 110 kV system.

from Tukums and Broceni. Existing power line stages are physically and morally obsolete with insufficient capacity, as well as the allowable voltage levels are maintained after the 'n-1' reliability criteria of the existing situation is problematic. Consequently, these lines cannot guarantee the reliable supply of electricity now, and especially in perspective. In addition, the examined area is planned to be installed with a large capacity of 30-80 MW of wind projects. As a result, the Latvian region of Kurzeme development creates the need for a powerful new power lines, new substations and construction of the substation expansion or reconstruction.

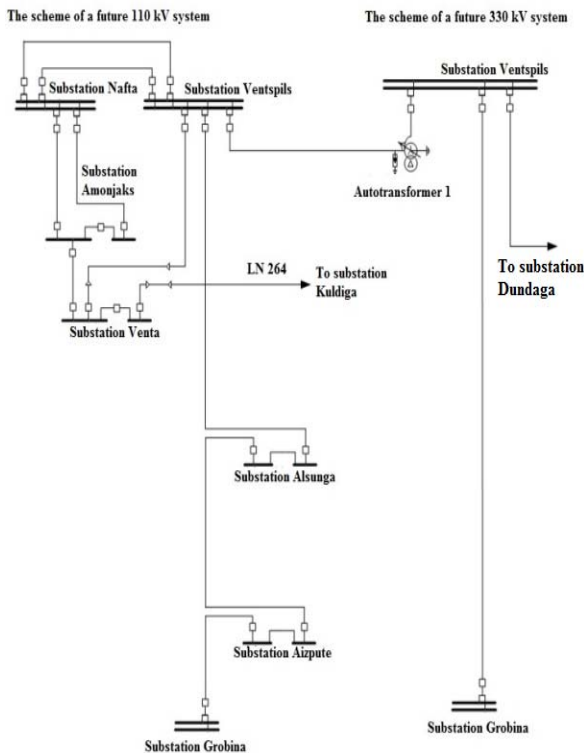


Fig. 3. The scheme of a future cooperative circuit, which consists of the 110 kV and 330 kV systems.

Since the existing 110 kV circuit cannot provide an adequate level of power supply, 330 and 110 kV transmission network connection 'Kurzeme Ring' is to be created. KR includes the construction of a new 330 kV transmission line Liepaja (Grobina) - Ventspils - Dundaga - Tukums (Tume) - Riga, but this paper will consider only "action 1" (see Fig. 1). This means that 110 kV overhead line will be reconstructed, reinforcing it with a 330 kV transmission line. Reconstructed overhead line length is 118 km. Reconstruction design is based on the 110 kV overhead transmission lines perspective connections (see Fig. 3).

V. THE ECONOMIC BASIS OF THE PROPOSED TASK

The necessary throughput capacity of the examined power line can be provided adopting the following two conditions:

- a) if there is a 330 kV circuit, then 2000A is needed;
- b) if there is a 110 kV circuit, then 1200A is needed.

Based on the accepted limits, the examined part of the "Kurzeme Ring" project („action 1") was evaluated at three main variants for power lines:

1) There is a double circuit 110 kV overhead line with the steel aluminium conductor; a phase is divided into two conductors (2xAS-240/32), as a result such variant provides 1210A;

2) There is a single circuit 330 kV overhead line with the steel aluminium conductor; a phase is divided into three conductors (3xAS-400/51) with an installed ampacity of 2475A;

3) There is a cooperative circuit, which consists of a single circuit 110 kV overhead line with the steel aluminium conductor; a phase is divided into three conductors (3xAS-400/51) with an installed ampacity of 2475A; and 330 kV overhead line with the steel aluminium conductor; a phase is divided into two conductors (2xAS-240/32) with an installed ampacity of 1210A.

As it was mentioned before in the example there is also a necessity of creating optical communication line which is managed by the third company. There are four different ways of realizing this part of the project:

1) To create the optical line individually without any dependence of power transmission companies.

2) To create the optical line making coalition with the first company and to construct the optical communication network using an optical ground wire (OPGW) on the supports of the 330kV transmission line.

3) To create the optical line making coalition with the second company and to construct the optical communication network using an optical ground wire (OPGW) on the supports of the 110kV transmission line.

4) To create the optical line joining the coalition of both power transmission companies making complex coalition of three companies and to construct the optical communication network using an optical ground wire (OPGW) on the common supports of the 330kV and 110kV transmission lines.

The economic comparison of variants is made for a 118 km long overhead line, for the particular climatic conditions of the region near the Baltic Sea: a wind pressure of $Q = 65 \text{ kg/m}^2$, the thickness of ice and frost on the conductor $C = 5 \text{ mm}$. The selected area is interesting having location in the Baltic Sea near the coast, where the combinations of weather conditions specific for the Baltic countries are observed (high wind pressures, icing and frosting of conductors and wire ropes) [11].

The main economic advantage for power transmission part of the project was based on the support number reserve, and it was calculated with the special program "SAPR LEP 2011" [12] which was used for systematic calculation of the examined conductors and the placement of supports on an actual profile of designing lines.

For given circumstances, we have five combinations of the entire project including power transmission and optical networks. To simplify the recording of all possible variants of

designing and realizing the project we assume that company "A" manages power transmission lines 330kV, company "B" manages power transmission lines 110kV and respectively company "C" manages optical communication networks. In this scenario the combinations are presented in the following way:

1) Individual behavior of companies "A", "B" and "C". In this case it means to create the power transmission line 330kV, power transmission line 110kV and optical network line individually without any dependence of other companies.

2) Creating a coalition of companies "A" and "B" taking into account individual behavior of company "C". There is a cooperative circuit of power transmission companies, in this case it means to create the power transmission line 330kV/110kV with common supports and to build independent optical communication line.

3) Creating a coalition of companies "A" and "C" taking into account individual behavior of company "B". In this case it means to create the optical communication network using an optical ground wire (OPGW) on the supports of the 330kV transmission line and to build independent 110kV transmission line.

4) Creating a coalition of companies "B" and "C" taking into account individual behavior of company "A". In this case it means to create the optical communication network using an optical ground wire (OPGW) on the supports of the 110kV transmission line and to build independent 330kV transmission line.

5) Creating a complex coalition of three companies "A", "B" and "C". In this case it means to construct the optical communication network using an optical ground wire (OPGW) on the common supports of the 330kV and 110kV transmission lines.

The project costs can range. It depends on the finite element price (string, foundation, conductor), the quantity of the necessary electrical elements, and significant additional costs, for example, the coordination with owners of the land, where there is an overhead line route as well as lightning protection system, land costs.

Analysis of the results

As it was mentioned above, there are five possible ways of realizing the project. In the case of organizing a coalition of two or three companies it is necessary to distribute the additional revenue by using the Shapley value, which requires an agreement and approval of each company.

In our example, we consider the benefits of each company in the stage of designing, i.e. considering the cost of building the transmission and optical communications lines in each case under consideration.

The required total costs and interim calculations for all variants including individual and cooperative behavior of the companies are presented in Table I.

TABLE I.
TOTAL COSTS FOR ALL VARIANTS INCLUDING INDIVIDUAL AND COOPERATIVE BEHAVIOR

Behavior	Variants of realizing the project	Investments, r.u.		
		For coalition	For independent company	Total
Individual	A	-	25 431 435	25 431 435
	B	-	20 414 642	20 414 642
	C	-	3 657 649	3 657 649
	A, B, C	Total investments for individual behavior of A, B, C		49 503 726
Cooperative	AB/C	29 952 795	3 657 649	33 610 444
	AC/B	26 340 035	20 414 642	46 754 677
	BC/A	21 323 242	25 431 435	46 754 677
	ABC	30 861 395	-	30 861 395

It is obvious that in the case of cooperative behavior, the investments of the project reduced considerably. This means that the formation of any variant of coalition is rational and possible in terms of economy of investments. The most profitable is making a coalition of three companies and then it will be a task to divide an additional profit. Effective way to do it is using a Shapley value. We note that in the real project the revenue is the amount of tens of millions EUR.

VI. CONCLUSIONS

1) Methods based on the game theory can contribute to making the right decision about the development of power transmission and energy supply sources. In particular, the cooperative game taking into consideration the possibility of building the coalition should be used.

2) The suggested method was applied to the example based on a real project with planned 330kV and 110kV high voltage transmission lines construction. It shows a great result and high level of profit. The method is applicable in a variety of other tasks where independent companies can gain by forming the coalition with other market participants.

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VIII. REFERENCES

- [1] Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market.
- [2] ThermoFlow. Comprehensive Thermal Engineering software. ThermoFlow Inc. Apr. 2002.
- [3] J.F. Verotte, P. Panciatici, B. Meyer, J.P. Antoine, J. Deuse and M. Stubbe, "High Fidelity Simulation Power System Dynamics", *IEEE Computer Applications in Power (CAP)*, Jan. 1995.
- [4] V. Miranda, L.M. Proenca. "Probabilistic choice vs. risk analysis-conflicts and synthesis in power system planning", *IEEE Transactions on Power Systems*, Aug. 1998, Vol.13, pp. 1038-1043.
- [5] M.H. DeGroot, "Optimal Statistical Decisions", McGraw-Hill Series in Probability and Statistics, 1970.
- [6] AST Lavenergo home page. Available: http://www.lavenergo.lv/portal/page?_pageid=80.1334481&_dad=portal&_schema=PORTAL
- [7] S. Berjozkina, A. Sauhats, E. Vanzovichs, "Modeling of the Load Current of the Transmission Line", in *Proc. of 10th International Conference on Environment and Electrical Engineering Conference*, Roma, 2011, pp. 911-914.
- [8] O.Linkevics, M.Balodis, A.Babikovs, J.Andersons, A.Sauhats, V.Chuvychin "Problems of the Grid Integration of Renewable Energy Sources in Latvia Prospective HVDC interconnection of Latvia and Gotland", Wind Energy in the Baltic Sea Region, Gotland, 2005.
- [9] E.Van Geert, "Increased Uncertainty a New Challenge for Power System Planners", IEE Colloquium on Tools and Techniques for Dealing With Uncertainty (Digest No.1998/200), 1998, pp.1831-1837.
- [10] V. Neimane, "Towards Bayesian Solution for Network Planning Problem", RIMAPS 2001, Porto, Portugal, September 2001.
- [11] Svetlana Berjozkina, Vladimirs Bargels, Antans Sauhats, Edvins Vanzovichs, "A Comparative assessment of Conductors with Composite Core", in *Proc. of 52nd Annual International conference of RTU*, Riga, 2011, pp. 1-6.
- [12] The special program "SAPR LEP 2011" description. Modern design System. [Online]. Available: <http://www.bsapr.ru/prod/progs/element.php?ID=250> [in Russian language].
- [13] Igor Moshkin, Svetlana Berjozkina, Antans Sauhats "Solving of Transmission Network Development Tasks in Market and Uncertainty Conditions", in *Proc. of 9th International Conference on the European Energy Market*, Florence, 2012, pp. 1-7



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Igor Moshkin, Antans Sauhats. Pārvaldes un optisko tīklu izveide, izmantojot kooperatīvas spēles teorijas pieeju

Starptautiskās sabiedrības tieksšanās palielināt energoefektivitāti un samazināt enerģētikas ietekmi uz vidi motivē procesu restrukturizāciju. Rezultātā, monopoli, kas nodrošina jaudas piegādi, tiek aizstāti ar vairākiem neatkarīgiem uzņēmumiem, kas strādā, lai palielinātu savu peļņu un savstarpēji konkurētu. Šis raksts ir konkrētam gadījumam, kurā parādās papildus pieņēmums, ka ir iespējams veidot koalīciju ar citiem uzņēmumiem. Šajā gadījumā ir gaidāms savstarpējs izdevīgums. Piedāvātā stratēģija balstās uz daļu no reālā projekta ar plānotajām 330kV un 110 kV augstsprieguma elektropārvaldes līnijām, kā arī optiskiem sakaru kanāliem. Piemērā mēs apskatām katra uzņēmuma priekšrocības projektēšanas stadijā, tas ir, ietverot pārvaldes līniju būvniecības izmaksas un optisko sakarus katrā attiecīgajā gadījumā, kā arī kopumā nepieciešamās izmaksas un starposma aprēķinus visiem variantiem, gan individuālas, gan kooperatīvas uzņēmumu rīcības gadījumiem. Piedāvātā metode ir piemērota reālā projektā ar plānotajām augstsprieguma pārvaldes līnijām 330 kV un 110 kV, kā arī optisko sakaru līnijām. Tas parāda lielisku rezultātu un vērtīgu peļņu. Metode piemērosim dažādiem citiem uzdevumiem, kur patstāvīgi uzņēmumi var iegūt papildus izdevīgumu, ja veido koalīciju ar citiem tirgus dalībniekiem.

Игорь Мошкин, Антанс Саухатс. Создание питающих и оптических сетей с помощью кооперативного подхода теории игр

Стремление мирового сообщества к увеличению энергетической эффективности питания и уменьшения влияния энергетики на окружающую среду мотивируются процессом реструктуризации. В результате монополии, которые обеспечивают энергоснабжение, заменяются многочисленными независимыми компаниями, которые стремятся увеличить свои прибыли и конкурируют друг с другом. Эта статья посвящена конкретному случаю, в котором появляется дополнительное предположение о возможности формирования коалиции с другими компаниями. В этом случае ожидается взаимная выгода. Предлагаемая стратегия основана на части реального проекта с проектируемыми высоковольтными линиями электропередачи 330 кВ и 110 кВ, а также оптическими линиями связи. В примере мы рассмотрим преимущества каждой компании на стадии проектирования, т.е. с учетом стоимости строительства линий электропередач и оптических линий связи в каждом рассматриваемом случае, а также необходимый общий объем расходов и промежуточные расчеты для всех вариантов включая индивидуальное и кооперативное поведение компаний. Предложенный метод был применен в реальном проекте с проектируемыми высоковольтными линиями электропередачи 330 кВ и 110 кВ, а также оптическими линиями связи. Он показывает отличный результат и высокий уровень прибыли. Метод применим также в различных других задачах, где независимые компании могут получить дополнительную выгоду путем формирования коалиции с другими участниками рынка.