2018 IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)

Evaluation of the district heating market efficiency as the function of its size and number of competing suppliers

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Abstract— **In this paper, the dependence of the district heating system efficiency on the number of heat energy suppliers and the volume value of heat energy consumption is considered. The critical point at which functioning of the heat energy market becomes expedient is determined. The estimation of the introduction possibility of the heat energy market in Eastern European cities is given. Introduction of the district heating market was considered on the example of Latvia (city of Riga), but evaluation of technological and economic efficiency district heating market on the example of Ukraine.**

Keywords - heat energy market, district heating system, market efficiency evaluation model, heat energy prices, optimization.

I Introduction

In the question of creating a district heating market, there are always issues about the feasibility of its implementation, since there are settlements where individual heating is sufficiently developed, and therefore it's not possible to talk about the market. Nevertheless, there is number of cities in Eastern European countries, where there are district heating companies, which implement activities in production, transportation and supply of heat energy within its own responsibility [1, 2]. Typically, these utility companies are monopolies in cities where they supply heat and where heat tariffs are determined by the regulators (public utility commissions). Tariffs are formed on cost basis where only current expenses are taken into account, but there are no motivational components which are results of competition. Such a scheme for determining tariffs for a district heating company is called "cost +" [3].

The urgency of creating a competitive district heating markets in Eastern European cities is increasing year by year, as the unpredictable situation with fossil fuels (natural gas, coal, etc.) leads to an unstable situation in the energy sector. At the same time, from the point of view of state policy, it is very important to use local fuels and renewable energy sources [4].

Encouraging the use of these resources should take place through the functioning of competitive district heating markets, which can provide the technological and economic feasibility of this process.

Efficient use of local and renewable energy resources for heat production is an important aspect in the operation of the district heating market from the point of view of the state policy in the field of energy. When creating the heat energy market, the analysis of the energy potential of available resources is fundamental, since it is this information that provides the use of the objective indicator of market share as a constraint in combination with the characteristics of the district heating market, such as the amount of heat energy consumption and number of producers.

In this paper we have considered introduction of the district heating market in Latvia and Ukraine.

In the capital of Latvia, in Riga city, there two large district heating systems (DHS): of the Right Bank and the Left Bank of Daugava river. A very competitive situation is evolving in the Right Bank district heating system of Riga. Peak heating load (at ambient temperature -20.7°C) is around 1000 MW, while in the summer period it is only 75-95 MW. The existing heat energy sources (figure 1), gas fired combined heat and power (CHP) plants of Latvenergo (1, 2) and Juglas Jauda (3) has overall capacity of 1630 MW, but the new biomass-fired plants (4, 5 7, 8), which were recently connected to the network has total capacity of circa 150 MW.

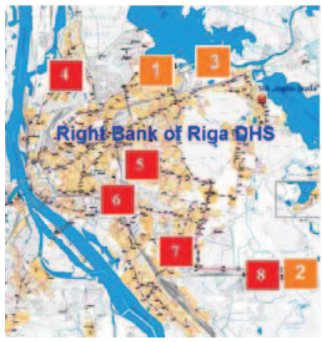

Fig. 1. Existing heat energy sources on the Right Bank of Riga DHS

This work has supported by Latvian Council of Science, project: Management and Operation of an Intelligent Power System (I-POWER) (No. lzp-2018/1-0066)

To ensure a fair and transparent competition between heat producers, a sophisticated heat procurement principles and procedures shall be in place. Nowadays it operates as the weekly auctions for heat supply. Overall heat demand is divided into two segments, where trading is happening: 1) base load (fixed part of the load) and 2) peak load (variable part of the load). Biomass energy producers normally offering their bids to the base load segment, while gas fired generation is more competitive in the peak load segment and providing auxiliary services for the district heating network. The auctions takes place on Thursdays and bids are offered for weekly volumes. The market operator is ranking them into the merit order (figure 2).

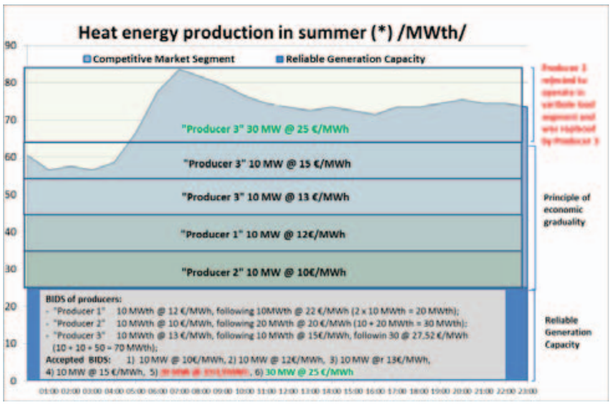

Fig. 2. Separation of the load graph into competitive market segment and reliable generation capacity

In the future when new entrants supposed to join the market, the system shall be enhanced. Division of competitive market segment into two parts (fixed and variable) is not technically and economically founded. One of the proposals to have trades in the single segment. The other proposal of heat market enhancement is transition from weekly auctions to day-ahead market, similarly to the trades which are taken place in the Nord Pool power exchange, but with daily volumes instead of hourly one. Daily auction could have motivated more volatile and competitive market.

Several publications [5, 6, 7] were devoted to computational modelling of heat energy market in the capital of Latvia and CHP operational mode planning at electricity market conditions. Heat production from different sources (figure 1) was simulated taken into account availability of generating facilities, operational parameters (start-up, shut-down time, ramp rates, capacity limitations) and production costs. The example of results of these simulations is provided in the figure 3.

This article should answer the question: "At what conditions is it feasible to create a heat energy market in the city?" On the basis of the modeling of the heat energy market [8], it is determined that, with a certain number of participants and the volume of heat energy consumption, it is possible to assess the degree of efficiency of its operation, comparing this scenario with the current situation in the heat supply sector.

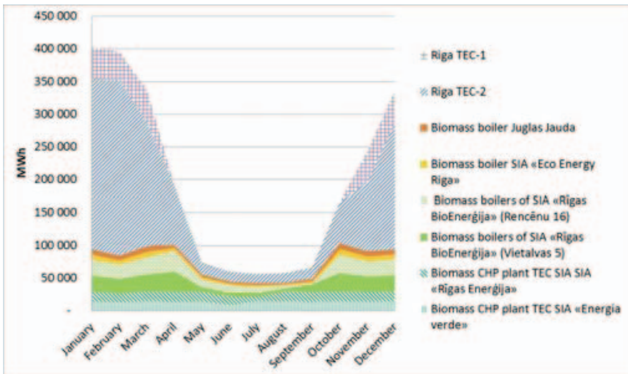

Fig. 3. Heat production in the Right Bank heating network of Riga

II Purpose and Objectives

The goal of the work is the determination of the district heating market technological and economic efficiency in Eastern European cities, with the definition of the volumes of heat energy consumption and the number of heat energy suppliers based on the simulation model [9]. Also, the purpose of the work is to determine the critical point at which the market of thermal energy becomes appropriate for implementation in different cities of the Eastern Europe.

To achieve the objectives, it is necessary to determine a number of tasks:

– simulation of the heat energy market functioning process with a constant number of heat energy suppliers with variation of the parameter of the volume of heat energy consumption;
– simulation of the heat energy market functioning process at a constant volume of heat energy consumption with the variation of the parameter of the number of heat energy suppliers;
– definition of the feasibility critical point of the thermal energy market implementation;
– determination of the total technological and economic efficiency of the heat energy market implementation in Eastern Europe.

III Description of the Model

The urgency for Latvia of the model of the heat energy market analysis developed for Ukraine is confirmed by the affinity of the stages of the heat supply systems development of these countries, their technical and constructive similarity. Therefore, the results of simulation for the settlements of Ukraine are adequate and can be used for Latvia without additional refinements.

The model, which is created based on the functioning of the thermal energy market within the average size of a city with a population of 50 to 150 thousand inhabitants, where there is a municipal heat supply company, which has its own thermal networks, which in size can be attributed to the centralized heat supply system.

In this system, there are the following rules for conducting an auction on the purchase and sale of thermal energy:

- auction is conducted once a month during the heating period;

- applications from each producer are submitted before the auction on the amount of heat energy that the heat supplier is ready to sell during the month, and the price at which the heat supplier is ready to sell this volume;

- the results of the auction are the distribution of applications that have won, according to the schedule of heat loads for the next month;

- for applications that have won, the weighted average price for the next month for the generation of heat energy is formed, according to which the district heating network operator forms a tariff for resale taking into account the components of transportation and supply by consumers.

For each of the technologies, the calculation of full-cost functions and the forecast tariff taking into account the profitability of each of the heat energy suppliers was performed.

The full cost function for each technology is presented in the following way [10]:

$$T_C = (A_1 + A_2 + A_3) \text{ x } Q + (B_1 + B_2 + B_3 + B_4) \quad (1)$$

where:

T_C – total cost of the production of heat energy per year, EUR (or other currency);

A_1 – variable cost of the energy resource for the production of thermal energy, EUR/Gcal;

A_2 – variable cost of delivery of energy resources for the production of heat energy, EUR/Gcal;

A_3 – variable cost of the electricity for the production of thermal energy, EUR/Gcal;

B_1 – fixed cost for salaries of working personnel for heat energy production per year, EUR;

B_2 – fixed cost for other costs on heat energy production per year, EUR;

B_3 – fixed depreciation costs for heat energy production per year, EUR;

B_4 – fixed cost for the administration salaries for the production of thermal energy per year, EUR;

Q – amount of thermal energy produced per year, Gcal.

In this model of the local heat energy market, as a constraint, the notion of market share is introduced, that is, the maximum limit of the amount of heat energy that can be released by each producer for each month. Market share for i-th manufacturer (except for the main) is determined by the coefficient of market share:

$$Q^s_{m_{i,j}} = Q_{d_j} \cdot q, \quad (2)$$

where:

$Q^s_{m_{i,j}}$ – market share for i-th producer by j-th month, Gcal;

Q_{d_j} - demand for thermal energy in j-th month, Gcal;

q – coefficient of market share.

For the formation of the matrix of the potential for the production of heat energy in the market, the following conditions are used:

If $Q^p_{m_i} < Q^s_{m_{i,j}}$ then:

$$Q^b_{m_{i,j}} = Q^p_{m_i};$$

if $Q^p_{m_i} \geq Q^s_{m_{i,j}}$ then:

$$Q^b_{m_{i,j}} = Q^s_{m_{i,j}};$$

where:

$Q^p_{m_i}$ - energy production potential for i-th producer by j-th month, Gcal;

$Q^b_{m_{i,j}}$ - bid amount of thermal energy for the i-th producer of the j-th month, Gcal;

Consequently, each producer, having the full cost function and the level of planned profit, based on market conditions and the possible amount of heat sold, calculates the forecasted heat energy price, and submits as a bid for the auction. The estimated heat energy price for each producer will be:

$$T_i = \frac{A_i \cdot \sum_n^{j=1} Q^b_{m_{i,j}} + B_i + P}{\sum_n^{j=1} Q^b_{m_{i,j}}} \quad (3)$$

where:

Ti - estimated heat energy tariff for each producer, EUR/Gcal;

A_i - amount of variable cost of i-th producer, EUR/Gcal,

B_i - amount of fixed cost of i-th producer, EUR/Gcal,

On the basis of submitted bids of producers, which specify such parameters as T_i and $Q^b_{m_{i,j}}$ an auction is conducted, which determines the winners who will be submitted to sold thermal energy in the i-th month.

Bids are sorted by price offers in the direction of increase (in merit order). The sum of the winners' applications for the j-th month is determined by the condition:

$$\sum_n^{i=1} Q^b_{m_{i,j}} = Q_{d_j} \quad (4)$$

where:

n – the number of the last winning producer.

If the bid of the last winning producer does not completely cover the demand for the j-th month, then only the part of the bid volume of thermal energy is taken into account [11]:

$$Q^{b}_{m_{n,j}} = Q_{d_j} - \sum_{n-1}^{i=1} Q^{b}_{m_{i,j}} \quad (5)$$

where:

$Q^{b}_{m_{n,j}}$ - part of the bid volume of thermal energy of the last winning producer covering the demand for the j-th month.

As a result of the auction conducted, a matrix of producers-winners of the auction is formed.

Based on the matrix of producers-winners of the auction, the total cost of the consumed heat energy in the j-th month is:

$$C_{d_j} = \sum_{n}^{i=1} (Q^{b}_{m_{i,j}} \cdot T_i) \quad (6)$$

where:

C_{d_j} - total cost of consumed heat energy in the j-th month, EUR

Weighted average price for heat energy release in the j-th month:

$$T_j^{wa} = \frac{C_{d_j}}{Q_{d_j}} \quad (7)$$

After conducting auctions for each month of the heating season, each of the producers will have a financial result that will reflect the success of the work of this manufacturer in the heat energy market. The main indicators that characterize the success of the company in the market of heat energy are:

- total revenue of the i-th producer,

- total cost of i-th producer,

- total profit of the i-th producer,

- the difference between the planned profit and the actual profit of the i-th producer

- the profitability of the i-th producer.

Considering the situation in Ukraine with regard to the systems of heat supply, it is necessary to take into account that in almost all large cities of Ukraine there are utilities that perform the function of the heat supplier and are in fact monopoly. By creating market relations in the heat supply systems of such cities, it is natural that the demand that covered the utility will decrease, and therefore the financial success of these enterprises will also be reduced. It is also possible that the utility will suffer losses.

Since utility companies are the main suppliers of heat energy in cities, it is necessary to introduce a mechanism to stimulate these enterprises in the event of losses due to constant costs.

There are several ways to ensure this condition:

1. Full compensation of damages.

2. Partial compensation of damages with a constant percentage of compensation

3. Partial compensation of damages with a stimulating percentage of compensation.

4. Null compensation to Monopoly Company (covers their losses themselves).

For simplicity, the first version of damages is selected in this model, distributing this value relative to the annual volume of released thermal energy in the market.

The annual average weighted tariff for heat energy, taking into account the compensation of losses to the main producer, is:

$$T_{wac} = \frac{\sum_{n}^{j=1} C_{d_j} + U_1}{\sum_{n}^{j=1} Q_{d_j}} \quad (8)$$

where:

U_1 - the value of losses of the main producer per year, EUR.

The benefits from the implementation of competitive district heating market need to be considered in terms of the difference in the value of the consumed heat energy and the average weighted prices for heat energy in its operation and absence [12]. On the other hand, the total amount of profits of producers is considered. The sum of these two indicators is a target function of the model of the district heating market.

In the absence of competitive district heating market, the forecasted heat price for the main producer is:

$$T_1 = \frac{A_i \cdot \sum_{n}^{j=1} Q_{d_j} + B_i + P}{\sum_{n}^{j=1} Q_{d_j}} \quad (9)$$

Difference in heat prices in the functioning and absence of the market of thermal energy, EUR/Gcal:

$$\Delta T = T_1 - T_{wac} \quad (10)$$

Benefit from introduction of the thermal energy market for consumers, taking into account the compensation of losses of the main producer, EUR:

$$V = \Delta T \cdot \sum_{n}^{j=1} Q_{\text{сп}_j} \quad (11)$$

Benefit from introduction of the competitive district heating market for producers, taking into account the compensation of losses of the main producer, EUR:

$$P = \sum_{n}^{i=1} TP_i - U_1 \quad (12)$$

The efficiency of the competitive district heating is calculated as the sum of compensation of losses of the main producer and the amount of profits of independent producers [3], EUR:

$$E = V + P \quad (13)$$

IV CASE STUDY NO. 1

Case Study No. 1 - Simulation of the district heating market functioning process with a constant number of heat energy suppliers with variation of the parameter of the volume of heat energy consumption.

For the simulation process, a number of assumptions must be made to determine the preconditions that reflect the technical state of the heat supply system [13]. This series of assumptions may serve as the source data for constructing a simple model.

Assumptions:

1. Heat energy losses in the district heating system are not taken into account.

2. In the heat supply system under consideration, the total heat energy production per year changing from 10,000 to 100,000 Gcal with a discreteness of 30,000 Gcal. Distribution of heat energy consumption by months of the heating period for the year is shown in Fig. 4.

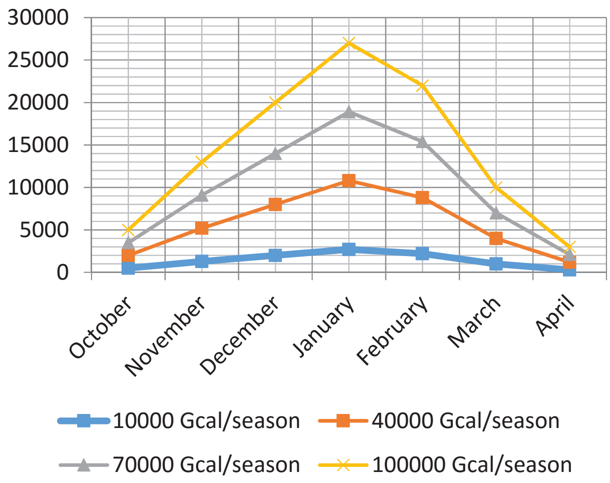

Fig. 4. Distribution of thermal energy consumption by months, Gcal

3. In this model of the district heating market, the concept of market share is introduced as a limit, that is, the maximum amount of heat energy that can be released by each producer for each month.

4. There are 10 producers in the heat energy market that use different technologies for the production of heat energy , such as fossil fuel, biomass, solar, geothermal and other heating plants.

The determined indicators derive from the calculation of the difference between financial results of the year in the functioning of competitive district heating market and its absence.

The aforementioned indicators were obtained by varying the market share coefficient in the range from 0.01 to 0.5.

The simulation results are shown in Fig. 5. According to the results of modeling, it is determined that when the market share coefficient increases, the overall benefit for consumers increases, and therefore the price for heat energy is reduced. But, from a certain point, the weighted average price of independent producers begins to exceed the price of the main producer. In this case, there is a situation in which independent producers actually finance a price reduction for consumers. Therefore, this zone cannot be considered effective in functioning of the market of heat energy.

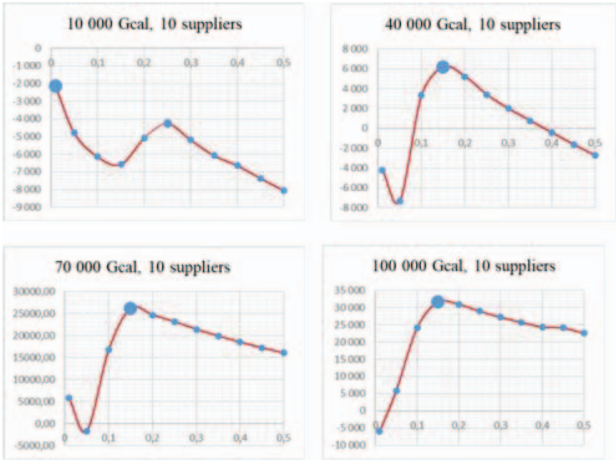

Fig. 5. Results of modeling the dependence of the thermal energy market efficiency on the coefficient of market share, by changing of the volume of consumption

On the other hand, when the market share factor is small, the amount of heat generated for each independent producer leads to an increase in the price of heat energy at the expense of the constant costs of each of the independent producers.

Consequently, we have a zone in which the weighted average heat price is lower than the price of the main manufacturer. Therefore, we can say about the effective zone of operation of the heat energy market under given conditions.

V Case Study No. 2

Case Study No. 2 - Simulation of the district heating market functioning process at a constant volume of heat energy consumption with the variation of the parameter of the number of heat energy suppliers.

For the simulation process, a number of assumptions must be made to determine the preconditions that reflect the technical state of the heat supply system. This series of assumptions may serve as the source data for constructing a simple model.

Assumptions:

1. Concerning heat losses and maximum amount of thermal heat energy that can be released by each producer are the same as in previous example.

2. In the considered heat supply system, the total heat production in the year is 100,000 Gcal.

3. In the heat energy market, the number of producers varies from 5 to 10. With a decrease in the number of producers, the market remains with the highest level of efficiency.

Simulation results are shown in Fig. 6:

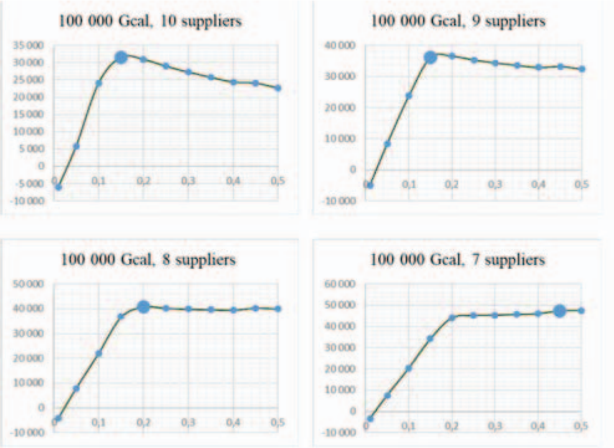

Fig. 6. Results of modeling the dependence of the thermal energy market efficiency on the coefficient of market share, by changing of the number of producers

V Definition of the feasibility critical point

Based on the results of process simulation of the thermal energy market functioning, critical points of expediency of the competitive district heating market implementation as such have been identified. The critical amount of heat energy consumption and the number of producers on the market are determined. The results of calculations of the efficiency of the thermal energy market are presented in Table. 1

Table 1 Efficiency of the district heating market, depending on the number of producers and volume of consumption

Num of producers / Vol of consumption	6	7	8	9	10
10000	3 429	3 774	2 293	-287	-4 271
40000	21 639	18 181	18 351	14 279	6 209
70000	41 184	36 172	36 172	29 863	26 154
100000	49 454	44 043	40 790	36 182	31 587

In fig. 7 shows a graph of the dependence of district heating market specific efficiency on the volume of heat energy consumption in the local heat energy market.

A regression analysis was performed where the dependence of specific efficiency of the district heating market on the volume of heat energy consumption on the local heat energy market was determined. The specific efficiency of the heat energy market is a parameter that shows cost savings as a result of the introduction of the heat energy market by 1 Gcal.

The following equation with the coefficient of correlation is defined $r_2 = 0{,}9234$:

$$e = 318{,}31 \cdot \ln(Q) - 3258{,}4 \quad (14)$$

where,

e - specific efficiency of the heat energy market, EUR/Gcal,

Q - total amount of heat energy consumption, Gcal.

Thus, in order to calculate the total annual savings in the functioning of the local heat energy market, it is necessary to use the value of annual heat energy consumption for the respective city:

$$E = e \cdot Q \quad (15)$$

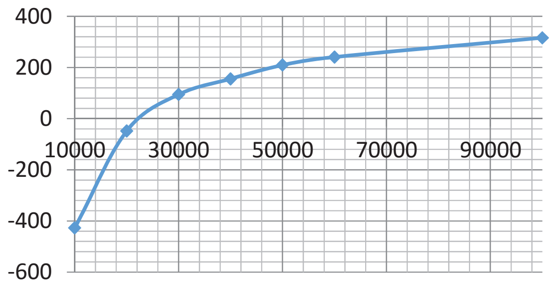

Fig. 7. Graph of the dependence of the district heating market specific efficiency on the volume of consumption

IV Conclusions

Presented model allows to estimate the level of efficiency of functioning of the territorial market of thermal energy. When using the model for calculations, the thermal energy market can be either existent or projected. The simulation results allow us to assess the technical and economic parameters of the heat supply system that is being analyzed. At the same time, based on the results of calculations, an appropriate policy of regulation of the thermal energy market by the state and local governments can be formed. A variational approach to the analysis of the thermal energy market within its territory allows us to gain a deep understanding of the market in accordance with the given conditions. In this case, it is possible to forecast and plan the development of the heat supply system within the local thermal energy market. Optimization of the "market share" factor plays an important role in creating or changing market rules, for introducing fair conditions for thermal energy producers, and for determining the optimal use of different types of resources for the production of thermal energy. Presented model allows to divide all the settlements of the state into 2 groups: territories where the heat energy market is economically expedient, and territories where creation of the market of thermal energy makes no sense.

The dependence of the district heating market efficiency on the volume of consumption is obtained. It is determined that with increased consumption, the heat energy market efficiency increases, due to smoothing of constant costs of producers and the level of compensation of expenses to the main producer.

The dependence of the heat energy market efficiency on the number of producers is obtained. It has been determined that with the decrease of the number of producers in the market, the district heating market efficiency is increasing.

According to the results of the simulation of the interaction of 10 heat suppliers the critical points of expediency of the implementation of the local heat energy market are determined. With the consumption of more than 22,000 Gcal, and the number of producers less than 9, the introduction of a local heat energy market becomes expedient.

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This is a post-print of a paper published in Proceedings of the 2018 IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2018) https://doi.org/10.1109/RTUCON.2018.8659907 and is subject to IEEE copyright. ISBN 978-1-5386-6904-4. e-ISBN 978-1-5386-6903-7.