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ELECTRICITY MARKET LIBERALISATION AND FLEXIBILITY OF CONVENTIONAL GENERATION TO BALANCE INTERMITTENT RENEWABLE ENERGY – IS IT POSSIBLE TO STAY COMPETITIVE?

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Intermittent generation (solar PV and wind energy) integration in power production portfolio as well as electricity price fluctuations have changed the running manner of conventional combined heat and power (CHP) plants: the shift from base load operation to running in cyclic modes. These cogeneration power plants are not adapted to new running conditions. The level of CHP plant flexibility should be improved to operate profitably and efficiently from both technical and fuel usage point of view. There are different ways to increase the flexibility of power plants. Before any improvements, the situation at power plants should be evaluated and the weakest points defined. In this publication, such measures are presented on Riga CHP-2 plant example: installation of heat storage tank; extension of operation rang; acceleration of start-ups.

Keywords: *electricity price fluctuation, flexibility, intermittent generation.*

1. INTRODUCTION

The running conditions of cogeneration power plants have changed from base load operation to running conditions in cyclic modes due to implementation of market mechanisms, feed-in tariffs for renewable energy sources (RES) and large-scale integration of RES in energy production process [1], [2]. As an example, the changes in Riga CHP-2 plant generation profile are reflected in Figs. 1 and 2.

The base load power plants are not accommodated to such running conditions. That is why CHP plant operation is inefficient from technical and fuel usage point of view without flexibility level improvement. It results in additional costs and reduction of gains. There are two solutions: (1) to mothball power plants or (2) to keep on operation after implementation of appropriate measures. The second option is more logical than the first one, taking into account the benefits of cogeneration power plants and the forecasted increase of them [1]. Moreover, it is impossible to ensure the secure energy supply and provide the successful integration of intermittent renewable energy in energy production process without CHP plants [3].

There are plenty of various solutions (measures) to enhance the flexibility of base load power plants. The measures concerning cogeneration power plants at the *operation stage* are going to be presented. They were divided into five groups by the authors in [1]: (1) equipment upgrade; (2) storage opportunities; (3) operation optimisation; (4) new installations; and (5) competitiveness increase.

In the present research, Riga CHP-2 plant is used as an example, when proper measures are introduced with the aim to ensure profitable operation of cogeneration power plants in cyclic modes. The already implemented solution and measures under investigation are going to be reflected. The paper is organised as follows: in Section 2 the aspects of new running conditions are presented; in Section 3 the description of the investigated object is provided; in Section 4 the already implemented measure is presented; in Section 5 the measures under investigation are reflected; in Section 6 the main conclusions are made.

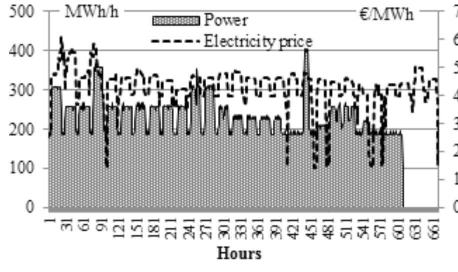


Fig. 1. Electricity generation profile of Riga CHP-2 plant from 01.02.2013 to 28.02.2013.

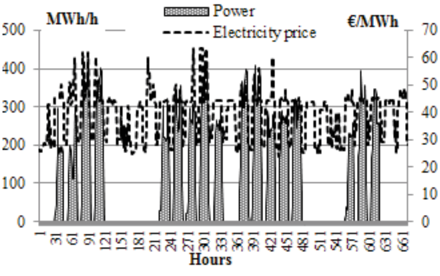


Fig. 2. Electricity generation profile of Riga CHP-2 from 01.02.2015 to 28.02.2015.

2. CYCLIC OPERATION: REASONS, AIMS AND BENEFITS

The cyclic operation means operation with frequent unit load reduction or its full stop, when energy fluctuation takes place or price of electricity is low [4]. Aspects of cyclic operation like reason-(s), aim-(s) and benefits vary according to the situation of energy system in a region. The comparison of the situation in Latvia and Germany is presented in Table 1.

Table 1

The Comparison of Situation in Latvia and Germany

Parameters	Latvia	Germany
Reasons of cyclic operation	The fluctuations of electricity price in Nord Pool market	Intermittency of renewable energy sources
Aims of flexibility increase	Adjustment to the situation in Nord Pool market	Integration of intermittent generation in energy production process
Benefits of flexible operation	Obtaining additional profit, when electricity price is high. Ensuring profitable operation of the existing power plants	Secure integration of intermittent generation in use. Opportunity to be *"the quickest"* and offer *"the first megawatts"*

Latvia does not have a plenty of intermittent generation sources. Cyclic operation became common after Latvia had joined Nord Pool market. It happened on June 3, 2013. Now fluctuations of electricity price determine the operation of power plants [4]. In contrast, in Germany the main reason of CHP plant cyclic operation is an availability of renewable energy generation (solar PV and wind energy). The flexible cogeneration power plants provide a more secure integration of renewable energy sources in energy production process. Moreover, in Germany CHP plants participate in frequency control that is why the competition between power plants increases. It is important "*to be the first and offer the first megawatts*" [5].

As of today, the provision of regulation service to the transmission system operator is not so common for CHP plants in Latvia like it is in Germany. Firstly, Latvia is part of BRELL (Belarus, Russia, Estonia, Latvia and Lithuania) power ring and the primary regulation is provided by Russian hydropower plants. Secondly, there is a cascade of Daugava hydropower plants in Latvia and Kruonis pumped storage plant in Lithuania, which are used to regulate frequency due to their ability of fast response to changes in the energy system.

3. DESCRIPTION OF RIGA CHP-2 PLANT

Riga CHP-2 plant is one of the most up-to-date power plants in Europe. It is located in Riga, Latvia. Power plant consists of two cogeneration units: Riga CHP-2/1 and Riga CHP-2/2 and a water heating boiler house. The thermal capacity of CHP-2/1 is 274 MW and electrical power – 413 MW (442 MW in condensing mode). The thermal capacity of CHP-2/2 is 270 MW and electricity power – 419 MW (439 MW in condensing mode). The water heating boiler house has five natural gas fired heat-only boilers (HOBs) (5×116 MW). Thus, the total thermal capacity of the water heating boiler house is 580 MW. Natural gas is used as primary fuel, and diesel is used as emergency fuel at Riga CHP plants [4], [6].

Riga CHP-2 plant was constructed as a based load power plant. However, now it should operate in cyclic modes since the end of 2013 (Fig. 2). That is why the flexibility level of Riga CHP-2 plant should be incremented. It should correspond to the requirements of cyclic operation, i.e., fast start-up and ramp rate; extended turndown [7]. For these reasons, the modernisation (technical minimum reduction) of gas turbine is completed at Riga CHP-2/2 (Section 4). There are also solutions under investigation: installation of heat storage system and acceleration of start-ups (see Section 5).

4. GAS TURBINE MODERNISATION OR MINIMUM TECHNICAL REDUCTION OF COGENERATION UNIT

OpFlex Turndown upgrade allows a gas turbine to operate at lower loads, maintaining stable combustion and emission compliance. This enhances power plant electricity dispatch priority, reduces number of start-ups and fuel consumption [8].

Gas turbine of Riga CHP-2/2 was equipped with *OpFlex Turndown* in 2014. The benefits of this modernisation: (1) the prevention of cogeneration unit from daily start-ups (the number of allowed start-ups is limited and it is a function from operating hours); (2) the deep unloading of unit at night, when electricity price is low. Simplified analysis (at the price of natural gas – 345.65 €/1000m^3 and CO_2 – 7 €/t) of four possible running conditions of Riga CHP-2/2 was carried out to evaluate upgrade. As a result, the marginal costs of electricity production (consumed fuel and produced emissions) are as follows:

- Mode No. 1 (operation of cogeneration unit at base load) – 246.79 thous. €;
- Mode No. 2 (cogeneration unit is not in operation and electricity is purchased at Nord Pool power exchange for 24 hours) – 245.30 thous. €;
- Mode No. 3 (operation of cogeneration unit in cyclic mode with shutdown at night) – 230.34 thous. €;
- Mode No. 4 (load reduction of cogeneration unit at night by implementing *OpFlex Turndown* solution) – 243.92 thous. €.

In condition of cyclic operation, it is not profitably and reasonably to operate a cogeneration unit at base load (Mode No. 1) or mothball it and buy electricity on the electricity market (Mode No. 2), because the costs of Mode No. 1 and Mode No. 2 are the highest ones. It is beneficial to shut-down cogeneration unit (Mode No. 3). However, owners of Riga CHP-2 plant are not interested in stopping the unit every day due to adverse affect of start-up procedure [4], the cogeneration unit is not adapted to operate in cyclic running conditions and the number of start-ups is limited. That is why the installation of *OpFlex Turndown* solution was the first step towards the improvement of Riga CHP-2 flexibility and efficiency (Mode No. 4).

5. MEASURES UNDER INVESTIGATION

5.1. Heat Storage Tank Installation – Adjustment to Variations of Electricity Price

One of the most efficient ways of increasing the flexibility of cogeneration power plants is to decouple the production of electricity and heat energy. It can be done by installing a heat storage system. Two examples of already implemented projects and proposals of Riga CHP-2 plant project are provided in Table 2.

Table 2

Comparison of Heat Energy Storage System Projects

Parameters	***GKM* CHP plant, Germany [9]**	***Sandreuth* CHP plant, Germany [5]**	**Riga CHP-2 plant, Latvia *(proposals)***
Aim	Adjustment to electricity price variations	Integration of RES and regulation service provision to transmission system operator	Adjustment to electricity price variations; increase in efficiency and competitiveness.
Benefits	Minimum technical reduction; Operation of one unit, when load is minimum	Secure RES integration; Ability to competitiveness	Stay in operation; Additional profit; Reduction of fuel used and produced emissions
Volume, m^3	43 000	33 000	20 000
High, m; Diameter, m	H = 36 m; D = 40 m	H = 70 m; D = 26 m	H/D=1.5* (H/D~0.4)**
Investments, M€***	27	12.4	10.6* (8.5)**

*correspond to a new tank; ** correspond to a heavy fuel oil tank; *** million €

The installation of heat storage tank at Riga CHP-2 is under investigation. The tank volume 20 000 m^3 was chosen. This volume ensures two options: installation of a new heat storage tank or reconstruction of the existing heavy fuel oil tank as a heat storage tank. They are compared in Table 3.

Table 3

Installation of New Heat Storage Tank or Reconstruction of Existing Heavy Fuel Oil Tank

Parameters	**New heat storage tank**	**Reconstructed heavy fuel oil tank**
Construction	Construction according to standard requirements	Inspection of construction
Type and volume of heat storage tank	Choice of tank type and volume	Adjustment to tank type and volume
Height and diameter ratio (H/D)	Choice of optimal H/D. Secure use of heat storage tank	H/D ~ 0.4. Investigation of internal process (stratification, pressure, etc.)
Installation	Opportunity to choose the site of installation	The installation site is already known
Connection to the system	Flexible connection to the system	According to the existing site condition
Investment	High investments	Equal to reconstruction costs
Additional works	Construction works	Cleaning from heavy fuel oil and its utilisation

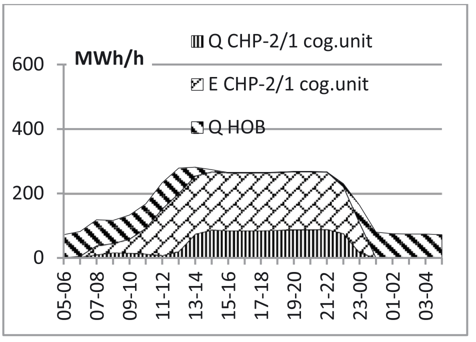
The benefits of project are evaluated taken into account four components: difference between additionally produced and purchased electricity (ΔP_{el}); difference between additionally consumed and saved natural gas ($\Delta B_{nat\ gas}$); difference between additionally produced and reduced CO_2 emissions (ΔE_{CO_2}); effect of start-up process ($Start\text{–}up_{effect}$), e.g., used fuel and produced CO_2 emissions:

$$Benefits = \Delta P_{el} + \Delta B_{nat\_gas} + \Delta E_{CO_2} + Start\text{–}up_{effect}.$$

Eight typical days were chosen to calculate the benefits: three for a non-heating period and five for a heating period. The example (at the price of natural gas – 196.25 €/1000m^3 and CO_2 – 7 €/t) of one typical day from a non-heating period is provided in Figs. 3 and 4. The cogeneration unit is shut-down during the night time, when the electricity price is low. Thus, the heat energy is provided by heat-only boilers and electricity is purchased (Fig. 3).

The installation of heat storage tank improves the efficiency of cogeneration unit and adjusts its running conditions to a situation in the electricity market: increase of electrical and heat load during the day time, when the electricity price is high. Additionally produced electricity is sold and heat energy is accumulated for further use by replacing the production of heat-only boilers at night (Fig. 4).

To produce additional electricity (Fig. 5) and heat during the day time, more natural gas is consumed (Fig. 6). The gain from produced electricity (18 602 €/24 h) exceeds the costs of natural gas (3 980 €/24 h) and CO_2 emissions (264 €/24 h). Thus, the additional profit is 14.4 thousand € per day.



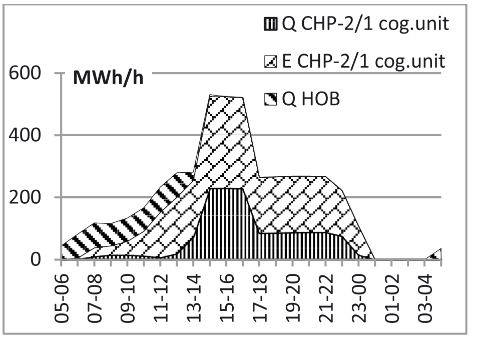
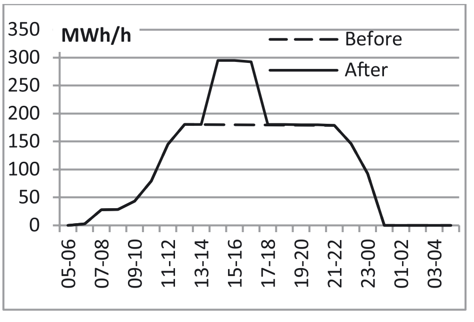


Fig. 3. Operation of Riga CHP-2/1 before the heat storage system implementation.

Fig. 4. Operation of Riga CHP-2/1 after the heat storage system implementation.

(Q – heat load; E – electrical load, cog. unit – cogeneration unit).



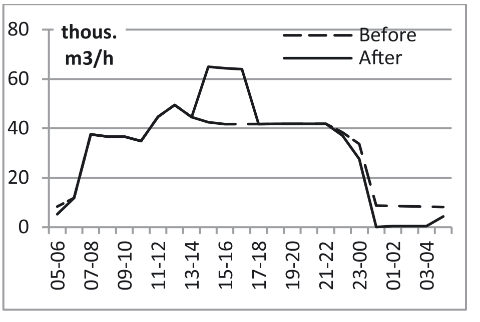


Fig. 5. Changes in electricity (MWh/h) production.

Fig. 6. Changes in natural gas (thous. m3/h) consumption.

Total savings account for ~ 1.7 million € during the year, which can be reduced to 1.3–1.4 million € in case of appearance of new heat energy sources on the right bank of Riga district heating system: biomass energy sources with total thermal capacity of 100 MW and 150 MW. Moreover, the construction of these new heat sources influences the playback time of heat storage system project. For instance, the investments of new heat energy storage are assumed to be 10.6 million €, the payback time is 10.17 years without biomass heat energy sources; 14.04 years in case of biomass heat energy sources with total heat load of 100 MW and 15.84 years under condition of biomass heat energy sources with total heat load of 150 MW.

5.2. Acceleration of Start-ups

On the one hand, the original start-ups (without improvement) are harmful from the perspective of technical and used fuel. On the other hand, the accelerated start-ups (with improvement) have a lot of benefits, which are described in detail in [10], [11]. In this subsection, the statistics and procedure of Riga CHP-2 plant starts-ups are analysed to determine the status of start-ups. The number of Riga CHP-2/1 and Riga CHP-2/2 start-ups has increased dramatically from 17 to 65 and from 22 to 99, respectively, during three years (2013–2015).

The hot start-up takes approximately 80 minutes (Fig. 7) and cold start-up is 450 minutes long (Fig. 8). It was also calculated that during the hot and cold start-ups 893.3 GJ and 5656.0 GJ of natural gas are consumed, respectively. Only hot and cold start-ups are evaluated as detrimental points. The investigation of warn run-ups is omitted in the present research.

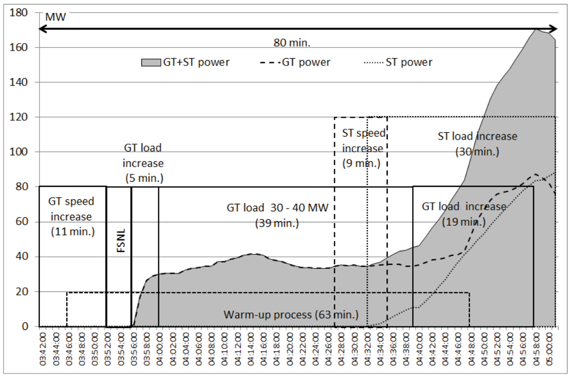


Fig. 7. Sequence and duration of hot start-up on Riga CHP-2/2 example (GT – gas turbine; ST – steam turbine; FSNL – full speed on load (gas turbine is at a full speed with little or no load)).

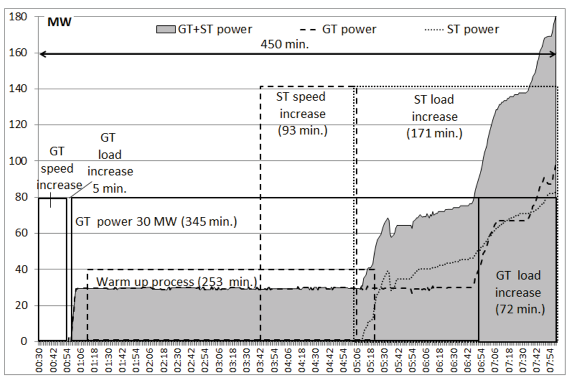


Fig. 8. Sequence and duration of cold start-up on Riga CHP-2/2 example.

The obtained results are compared with provided results in [12], which are reflected in Table 4, where start-ups are divided into four groups *"Best", "Good", "Normal", "The last"* according to the duration and consumed fuel.

Table 4

Classification and Characteristic of Start-ups

Categories	***Best***	***Good***	***Normal***	***The last***
Start-up time, minutes				
Hot start-up 0–12 h	33	41	70	97
Cold start-up >72 h	61	98	154	204
Natural gas consumption, GJ				
Hot start-up 0–12 h	508	556	756	1339
Cold start-up > 72 h	1066	1066	1070	2940

Riga CHP-2/2 plant hot start-up is close to the category *"Normal"*. The performance of cold start-up is far from the category *"The last"*. Thus, the acceleration of start-up, especially of cold start-up, can be the second step towards Riga CHP-2 plant flexibility and efficiency increase after the implementation of *OpFlex Turndown* solution. At present, three solutions are under discussion and evolution: (1) *OpFlex Variable Load* path (OpFlex VLP); (2) *OpFlex Shutdown Purge Credit*; (3) change of distributed control system logic to acceleration of the start-up of steam turbine at Riga CHP-2/2.

OpFlex VLP is gas turbine control software upgrade, which decouples gas turbine load from exhaust temperature. The upgrade provides improvements of start-ups (faster, reduction of consumed fuel, decrement of emissions, gas turbine load flexibility) and part load operation and the enhancement of maintenance and reliability [13].

OpFlex Shutdown Purge Credit provides the purge of natural gas fuel piping; isolates the fuel system with a compressed air pressurized plug; performs exhaust system and heat recovery steam generator (HRSG) purge during shut-down immediately after flameout and maintains this fully purge state by completely isolating the fuel system from the GT/HRSG flow path. The advantages and disadvantages of *VLP* and *Purge Credit* installation are provided in Table 5 [13].

Table 5

Advantages / Disadvantages and Neutral Aspects of VLP and Purge Credit

Advantages	Disadvantages	Neutral
Acceleration of start-ups is an opportunity to reduce the operation of cogeneration unit in insufficient mode – decrement of consumed fuel and produced CO_2 emissions	Expensive – approximately 1.9 million €; The risks of upgrade installation are not known completely and benefits are not completely assessed; There is not an example of *VLP* installation to 9FB machines	At present, flurry with *"the first megawatts"* is not so pronounced for CHP plants in Latvia as in other countries in Europe

There is the third option, which can be implemented instead of *VLP* and *Purge credit*. It is the acceleration of steam turbine by changing logic in distributed control system to quicken attemperator flow. This solution ensures complete use of technical resource; furthermore, the additional money investment is not necessary. It is under investigation as *VLP* and *Purge credit*.

6. CONCLUSIONS

The base load CHP plants can stay competitive after implementation of appropriate measures (solutions) with the aim to increase their efficiency and flexibility. In line with previously provided research by authors in [1], a lot of measures are proposed to improve the operation of cogeneration power plants. That is why, firstly, it is necessary to evaluate the level of CHP plant operation by assessing bottlenecks, which should be improved. Secondly, the appropriate measures should be proposed and evaluated from economical and technical point of view. Thirdly, the beneficial measures should be implemented and those unprofitable rejected. As a result of flexibility enhancement, the life time of power plants is extended.

In case of Riga CHP-2, it is necessary to reduce cogeneration unit start-up time to decrement the fuel consumption and CO_2 emission production. The installation of heat storage tank can also be beneficial, but rapid changes in energy sector in the short- and long-term impugn the implementation of this project.

REFERENCES

1. Ivanova, P., Sauhats, A., Linkevičs, O., and Balodis, M. (2016). Combined heat and power plants towards efficient and flexible operation. *2016 IEEE 16th International Conference on Environmental and Electrical Engineering (EEEIC)*, 7–10 June 2016 (pp. 230–235). Piscataway, NJ: IEEE.
2. Troy, N. (2011). *Generator cycling due to high penetrations of wind power*. Retrieved 11 May 2016, from http://erc.ucd.ie/files/theses/Niamh%20PhD%20-%20Generator%20Cycling%20due%20to%20High%20Penetrations%20of%20Wind%20Power.pdf
3. PEi. *The future role for thermal generation*. (n.d.). Retrieved 11 May 2016, from http://www.powerengineeringint.com/articles/print/volume-23/issue-5/opinion/the-future-role-for-thermal-generation.html
4. Kunickis, M., Balodis, M., Linkevics, O., and Ivanova, P. (2015). Flexibility options of riga chp-2 plant operation under conditions of open electricity market. *2015 IEEE 5th International Conference on Power Engineering, Energy and Electrical Drives (POWERENG)*, 11–13 May 2015 (pp. 548–553). Piscataway, NJ: IEEE.
5. Balodis, M., Krickis, O., and Ivanova, P. (2016). The realization of n-ergie heat storage tank project in nuremberg district heating system. *Enerģija un Pasaule*. No. 3, 40–44.
6. Zigurs, A., Kunickis, M., Linkevics, O., Stuklis, I., Ivanova, P., and Balodis, M. (2015). Evaluation of exhaust gas condensing economizer installation at riga chp plants. *REHVA Annual Conference 2015*, 6–9 May 2015 (pp. 149–154). Riga, LV: RTU Press.
7. International Energy Agency (IEA). (2014). *Energy technology perspectives 2014. Harnessing electricity's potential.* France: OECD/IEA.
8. GE Energy (2011). *OpFlex Reserve*. pp. 1–2.
9. GKM presentation (2016). *Grosskraftwerk Mannheim AG. VGB TG power plant concepts*.
10. Emberger, H., Schmid, E., and Gobrecht, E. (2005). *Fast cycling for new plants and upgrade opportunities.* Siemens AG.
11. Kehlhofer, R., Rukes, B., and Hannemann, F. (2009). *Combined-cycle gas & steam turbine power plants*. Tusla: PennWell Corp.
12. Stockmans, P.-J., and Peter, O. (2015). *Presentation about start-ups benchmarking and flexibility improvements levels.*
13. GE Power materials (2015). *Latvenergo AS budgetary proposal for OpFlex LVP and Purge Credit*.

ELEKTROENERĢIJAS TIRGUS LIBERALIZĀCIJA UN KONVENCIONĀLĀS ĢENERĀCIJAS ELASTĪGUMA LĪMEŅA UZLABOŠANA ATJAUNĪGO ENERGORESURSU BALANSĒŠANAI – VAI IESPĒJAMS PALIKT KONKURĒTSPĒJĪGAM?

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K o p s a v i l k u m s

Atjaunīgo energoresursu (saules un vēja enerģija) integrācija enerģijas ražošanas procesā un elektroenerģijas cenas svārstības izmainīja konvencionālo elektrostaciju darbības režīmus, t.i., pāreja no bāzes režīmiem uz cikliskajiem darbības režīmiem. Konvencionālās elektrostacijas nav pielāgotas jauniem darbības režīmiem, tādējādi ir nepieciešams uzlabot to elastīguma līmeni, lai strādātu efektīvi no tehniskā un izmantota kurināmā viedokļa un iegūstu papildu peļņu. Ir pieejamās dažādas metodes, lai palielinātu elektrostaciju elastīguma līmeni. Pirms ievest elastīguma uzlabošanas pasākumus, jāizpēta situācija elektrostacijā un vājas vietas jāidentificē. Šajā publikācija sekojošie pasākumi apskatīti uz Rīgas TEC-2 piemēra: siltumenerģijas akumulācijas sistēmas izmantošana; koģenerācijas iekārtas darbības diapazona paplašināšana un palaišanas režīmu paātrināšana.

27.10.2016.