LATVIAN JOURNAL OF PHYSICS AND TECHNICAL SCIENCES
2018, N 1

DOI: 10.2478/lpts-2018-0002

OPTIMISATION OF COMBINED CYCLE GAS TURBINE POWER PLANT IN INTRADAY MARKET: RIGA CHP-2 EXAMPLE

P. Ivanova, E. Grebesh, O. Linkevics
Riga Technical University
12/1 Azenes Street, Riga, LV-1048, LATVIA
e-mail: polina-ivanova@inbox.lv

In the research, the influence of optimised combined cycle gas turbine unit – according to the previously developed *EM & OM* approach with its use in the intraday market – is evaluated on the generation portfolio. It consists of the two combined cycle gas turbine units. The introduced evaluation algorithm saves the power and heat balance before and after the performance of *EM & OM* approach by making changes in the generation profile of units. The aim of this algorithm is profit maximisation of the generation portfolio. The evaluation algorithm is implemented in multi-paradigm numerical computing environment *MATLab* on the example of Riga CHP-2. The results show that the use of *EM & OM* approach in the intraday market can be profitable or unprofitable. It depends on the initial state of generation units in the intraday market and on the content of the generation portfolio.

Keywords: *conventional generation, EM & OM approach, generation portfolio, intraday market*

1. INTRODUCTION

Nowadays problems of conventional generation are discovered in many literature sources [1], [2], [3], [4], [5], i.e., the shifting from the base load operation to the cycling operation. Combined cycle gas turbine (CCGT) technology is partly adapted to new running conditions [6], [7]. There are a lot of measures [8] to increase the flexibility of power plants from expensive [9], [10] to cost-neutral, for example, by applying the *EM & OM* (evaluation model & optimisation model) approach developed and presented by the authors in [11] to optimise the cycling operation of CCGT power plants.

In brief, the EM & OM approach consists of the two models, i.e., EM and OM. The first processes the production data of power plant and consequently determines the cycling characteristics of power plant and inputs for OM. The second ensures the extension of cycling operation range by shifting shutdown “forward” and start-up “backward” and, hence, the added electricity is produced, the numbers of cycling periods are reduced and start-ups are replaced with less adverse ones. In [11], the authors proposed that the EM & OM approach could be used in different Nord Pool physical markets: day-ahead, intraday or real time/balance market, but its performance changes depending on the type of physical market (Table 1).

Table 1

The Performance of *EM & OM* Approach in Different Nord Pool Physical Markets

Parameter	Type of market		
	Day-ahead market	Intraday market	Balancing market
Benefits of using the *EM & OM* approach	The integration of approach in power plant optimisation models to prepare the bids for submission in the market. The accuracy of optimisation models is increased and the planning of conventional generation operation becomes more precise and profitable because the features of start-ups and proposed principles of cycling operation improvement are taken into consideration.	The observation of cycling operation features and the proposed principles of its improvement provide more profitable operation of conventional generation, when bids are approved	The consideration of start-up features and the proposed principles of cycling operation improvement ensure the possibility to evaluate the production of additional energy in areas with power deficit.
The necessity of added calculations	The forecast of input data (ambient temperature, heat load, electricity price, etc.)	Investigating the impact on other generation units (portfolio)	Investigating the impact on other generation units (portfolio)

In [11], the developed *EM & OM* approach was verified on the example of CCGT-2/1 of Riga CHP-2 (the detailed information about this power plant is available in [11], [12]) on the principles of Nord Pool intraday physical market. It is when the results of unit commitment (UC) and electricity price are known, i.e., the dashed box in Fig. 1. Y'^1 denotes the first cogeneration unit and Y'^2 – the second cogeneration unit of generation portfolio *Y'*, which is Riga CHP-2.

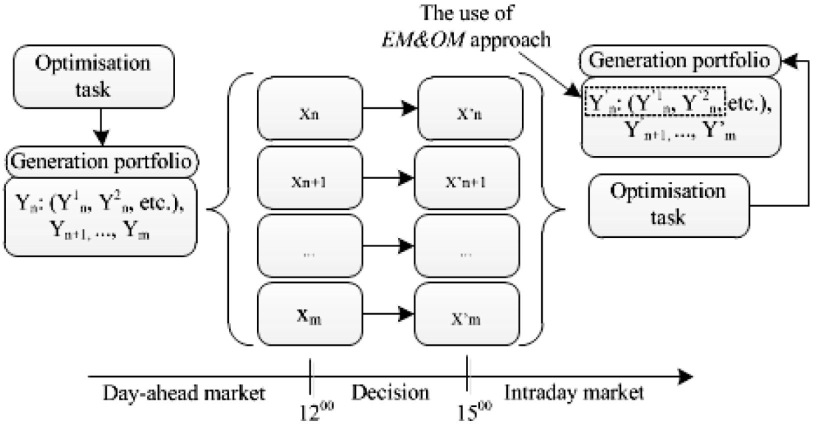

Fig. 1. The example of use of the *EM & OM* approach in [11].

(Y_n, Y_{n+1}, Y_m denote the generation portfolio before bid submission to the Nord Pool market; x_n, x_{n+1}, x_m – the submitted bids to the market; x'_n, x'_{n+1}, x'_m – the approved bids on the Nord Pool market; Y'_n, Y'_{n+1}, Y'_m – the generation portfolio after bid approval on the Nord Pool market and optimisation provision in line with the approved bids)

According to Table 1, if the *EM & OM* approach is used in the intraday market, then the added calculations are needed, which are presented in this paper. The influence of the optimised generation unit should be investigated on other generation units or portfolio.

In [11], the impact of optimised CCGT-2/1 cogeneration unit on the generation portfolio, i.e., Riga CHP-2, was omitted. That is why in this article the authors assess this impact by introducing the evaluation algorithm, which consists of the CCGT-2/2 optimisation according to the *EM & OM* approach and changes of cogeneration units' (CCGT-2/1 and CCGT-2/2) generation portfolio in multi-paradigm numerical computing environment *MATLab.*

The remaining part of this paper is organised as follows: in Section 2 the assessment algorithm is presented; in Section 3 the results of assessment are provided; in Section 4 the main conclusions are made.

2. THE EVALUATION ALGORITHM

The evaluation algorithm is created for thermal power plants, which consist of the two CCGT units (Fig. 2).

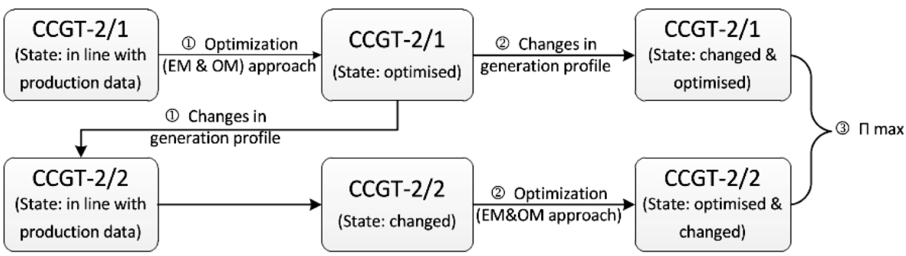

Fig. 2. The block scheme of the evaluation algorithm.

Initially, the operation of CCGT-2/1 unit is optimised in line with the *EM & OM* approach. Additionally, the produced power and heat energy by the first cogeneration unit are compensated by CCGT-2/2 unit, i.e., the changes in CCGT-2/2 generation profile are observed. Then the *"changed"* generation profile of CCGT-2/2 unit is optimised by the *EM & OM* approach making changes in CCGT-2/1 optimised profile. As both units are identical, the obtained characteristics of CCGT-2/1 in [11] are used to provide the calculation with CCGT-2/2.

The optimisation of CCGT-2/2 unit in line with the *EM & OM* approach is provided and/or changes in the generation portfolio of CCGT-2/1 are implemented, if it is possible to ensure them. For example, the second unit is operated in parallel with the first unit, the load of cogeneration units is enough to make changes in the generation portfolio, it is possible to save the power and heat balance, etc.

The objective function of the evaluation algorithm is profit (Π) maximisation of Riga CHP-2:

$$\sum_{i=1}^{i=k} (\Pi'_{CCTG-2/1_i} - \Pi_{CCGT-2/1_i}) + (\Pi'_{CCTG-2/2_i} - \Pi_{CCGT-2/2_i}) \to \max \Pi$$

Subjected to

$i = 1,...k\ ;\ i \in Z_+$

$P_{CCGT-2/1}^{\min} < P_{CCGT-2/1} \le P_{CCGT-2/1}^{\max}$

$Q_{CCGT-2/1}^{\min} < Q_{CCGT-2/1} \le Q_{CCGT-2/1}^{\max}$

$P_{CCGT-2/2}^{\min} < P_{CCGT-2/2} \le P_{CCGT-2/2}^{\max}$

$Q_{CCGT-2/2}^{\min} < Q_{CCGT-2/2} \le Q_{CCGT-2/2}^{\max}$

$\sum_{i=1}^{i=k} P_{1i} = \sum_{i=1}^{i=k} P_{2i}$ Electrical power balance. P_1 is the sum of CCGT-2/1 and CCGT-2/2 electrical power in line with the production data. P_2 is the sum of CCGT-2/1 and CCGT-2/2 electrical power in the changed and optimised states, respectively.

$\sum_{i=1}^{i=k} Q_{1i} = \sum_{i=1}^{i=k} Q_{2i}$ Heat power balance. Q_1 is the sum of CCGT-2/1 and CCGT-2/2 heat power according to the production data. Q_2 is the sum of CCGT-2/1 and CCGT-2/2 heat power in the changed and optimised states, respectively.

where

$\Pi_{CCGT-2/1_i}$ profit of the first cogeneration unit according to the production data, [€];

$\Pi'_{CCTG-2/1_i}$ profit of the first cogeneration unit in the changed state, [€];

$\Pi_{CCTG-2/2_i}$ profit of the second cogeneration unit in line with the production data, [€];

$\Pi'_{CCTG-2/2_i}$ profit of the second cogeneration unit in the optimised state, [€];

i number of cycling operation ranges, [number];

P electrical power, [MW];

Q heat power, [MW].

The profit of cogeneration units is calculated taking into account the marginal costs of cogeneration units, which hold on two components: natural gas and carbon dioxide.

3. RESULTS OF EVALUATION ALGORITHM

Figure 3 presents the example of evaluation algorithm performance results. In line with the *EM&OM* approach, the start-up of CCGT-2/1 was shifting to 15 hours backward. The start-up time was at 0.00 instead of 15.00. Due to high electricity price, in this period (from 0.00 to 15.00) the electrical power of CCGT-2/1 was higher by 50 MW then after 15.00. To save the power and heat balance of Riga CHP-2, the power of the CCGT-2/2 was reduced until the technical minimum, i.e., 149 MW.

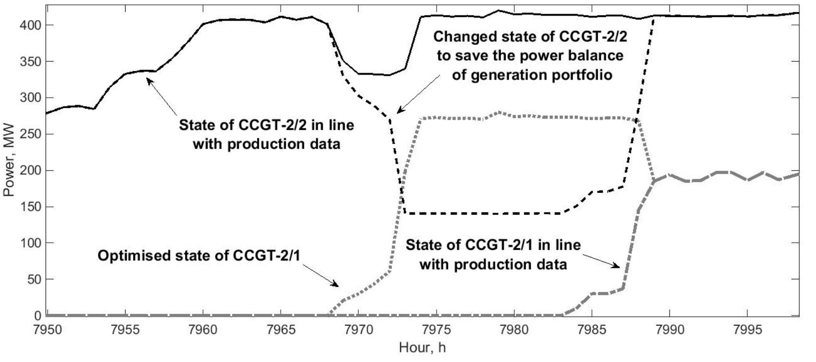

Fig. 3. The example of evaluation algorithm performance results.

In line with the evaluation algorithm (Fig. 2) after the optimisation of CCGT-2/1 and changes of CCGT-2/2 generation profile, the optimisation of CCGT-2/2 and changes in the optimised CCGT-2/1 profile should be performed. According to the reflected situation in Fig. 3, they were not done because there were not any possibilities.

In [11], the *EM & OM* approach was performed simultaneously for start-ups and shutdowns. In the present research, this approach is divided into the three scenarios:

- Scenario No. 1: Start-ups are shifted *"backward"*;
- Scenario No. 2: Shutdowns are shifted *"forward"*;
- Scenario No. 3: Start-ups are shifted *"backward"* and shutdowns – *"forward"*.

The results of the three scenarios of the *EM & OM* approach in line with the evaluated algorithm in Fig. 3 are presented in Table 2. The positive result is obtained in Scenario No. 1, i.e., additional profit at the value of 23 800 € for added 24 operation hours. The last two scenarios (Scenarios No. 2 and No. 3) ensure an increase in operation hours by 29 and 59 hours, but provide a negative profit in monetary terms by - 102 600 € and - 78 600 €, respectively.

Table 2

Interpretation of Optimisation Results

Parameters & Scenarios	The value of parameter before optimisation	The value of parameter after optimisation	Additional profit
Scenario No. 1:	**Start-ups are shifted *"backward"***		
Gain/Losses, [€]	$17{,}2537 \cdot 10^6$	$17{,}2775 \cdot 10^6$	23 800
Operation hours of both cogeneration units, [h]	5 744	5 768	24
Scenario No. 2:	**Shutdowns are shifted *"forward"***		
Gain/Losses, [€]	$17{,}2537 \cdot 10^6$	$17{,}1511 \cdot 10^6$	- 102 600
Operation hours of both cogeneration units, [h]	5 744	5773	29
Scenario No. 3:	**Start-ups are shifted *"backward"* and shutdowns – *"forward"***		
Gain/Losses, [€]	$17{,}2537 \cdot 10^6$	$17{,}1751 \cdot 10^6$	- 78 600
Operation hours of both cogeneration units, [h]	5 744	5803	59

In case of Scenario No. 1, the additional profit is obtained due to the reduction of time spent in warm state preservation. This has resulted in more efficient start-up. In their turn, Scenarios No. 2 and No. 3 provide a negative profit because the optimisation of CCGT-2/1 has led to the CCGT-2/2 power reduction to the technical minimum. The specific natural gas consumption of the second cogeneration unit has increased. As a result, the efficiency of CCGT-2/2 has decreased.

4. DISCUSSION

In the present research, the authors have evaluated the impact of the optimised CCGT unit running condition in line with the *EM & OM* approach in intraday market on the generation portfolio. For this reason, the evaluation algorithm has been introduced with the optimisation task: profit maximisation of the generation portfolio. The *EM & OM* approach has been implemented according to the evaluation algorithm by saving the power and heat balance of the generation portfolio, i.e., making changes in the generation profile of units.

The evaluation algorithm has been implemented on the example of Riga CHP-2. In line with the obtained results, it can be concluded that the use of the *EM & OM* approach in the intraday market can be both efficient and inefficient, i.e., with additional profit or losses, respectively. The authors consider that the positive result (additionally gained profit) of the *EM & OM* approach use in the intraday market can be achieved by extending the generation portfolio and adding a different generation unit, for example, natural gas and hydropower units.

ACKNOWLEDGEMENTS

The research has been supported by the Latvian National Research Programme LATENERGI.

REFERENCES

1. Ludge, S. (2017). The value of flexibility for fossil-fired power plants under the conditions of the Strommarkt 2.0. *International Journal for Electricity and Heat Generation VGB Powertech*, *3*, 21–24.
2. Honkasalo, N. (2015). Future role for thermal generation [Blog post]. Retrieved 4 September 2016, from http://www.powerengineeringint.com/articles/print/volume-23/issue-5/opinion/the-future-role-for-thermal-generation.html
3. Richter, M., Mollenbruck, F., Obermuller, F., Knaut, A., Weiser, F., & Lehmann D. (2016). Flexibilization of steam power plants as partners for renewable energy systems. In *Power Systems Computation Conference*, 20–24 August 2016 (pp. 1–8). Genoa, Italy: IEEE. DOI: 10.1109/PSCC.2016.7540840
4. Chen, X., Kang, C., O'Malley, M., Xia, Q., Bai, J., Liu, C., Sun, R., Wang, W., & Li, H. (2015). Increasing the Flexibility of Combined heat and power for wind power integration in China: Modeling and Implications. *IEEE Transactions on Power Systems*, *30* (4), 1848–1857. DOI: 10.1109/TPWRS.2014.2356723
5. Keatley, P., Shibli, A., & Hewitt, N. (2013). Estimating power plant start costs in cyclic operation. *Applied Energy*, *111*, 550–557. DOI: 10.1016/j.apenergy.2013.05.033

6. International Energy Agency. (2014). *Energy Technology Perspectives 2014*. France: IEA.
7. VGB Powertech. (2017). *Electricity Generation. Facts and Figures. 2017/2018.* Germany: VGB Powertech.
8. Ivanova, P., Sauhats, A., Linkevics, O., & Balodis, M. (2016). Combined heat and power plants towards efficient and flexible operation. In *IEEE 16th International Conference on Environmental and Electrical Engineering (EEEIC),* 7–10 June 2016 (pp. 1 – 6). Florence Italy: IEEE. DOI:10.1109/EEEIC.2016.7555874
9. Linkevičs, O. (2017). VGB darba grupas "Elektrostaciju koncepcijas" sanāksme Bušēnas termoelektrostacijā. *Enerģijas un Pasaule, 3/104*, 90–94.
10. Varley, J. (2016). Fortuna: Demonstrating a role for flexible CCGT with cogeneration. *Modern Power Systems, 36*(5), 27–34.
11. Ivanova, P., Grebesh, E., Mutule, A., & Linkevics, O. (2017). An approach to optimise the cycling operation of conventional combined heat power plants. *Energetika. 64*(4), 1–19.
12. About the Riga combined heat and power plants. (n.d.). Retrieved 3 December 2017, from https://www.latvenergo.lv/eng/about_us/generation/chpps/

KOMBINĒTĀ CIKLA GĀZES TURBĪNAS ELEKTROSTACIJU DARBĪBAS REŽĪMU OPTIMIZĀCIJA TEKOŠĀ DIENAS TIRGŪ: RĪGAS TEC-2 PIEMĒRS

P. Ivanova, E. Grebešs, O. Linkevičs

Kopsavilkums

Šajā darbā tiek apskatīta optimizētās – pēc iepriekš izstrādātās *EM & OM* pieejas tekošās dienas tirgū – TEC-2 divu energobloku (katrs no tiem sastāv no divām kombinētā cikla gāzes un tvaika turbīnām) ietekme uz ražošanas portfeli. Piedāvātais vērtēšanas algoritms saglabā elektriskās un siltuma jaudas bilanci pirms un pēc *EM & OM* pieejas pielietošanas, mainot energobloku ražošanas profilu. Vērtēšanas algoritma mērķis ir ģenerācijas portfeļa peļņas palielināšana. Tas tiek realizēts uz objektu orientētas programmēšanas valodas – *MATLab* - uz Rīgas TEC-2 piemēra. Iegūtie rezultāti atspoguļo, ka *EM & OM* pieejas pielietošana tekošā dienas tirgū varbūt efektīva, neitrālā vai neefektīva. Iegūtā rezultāta vērtība ir atkarīga no ražošanas iekārtu sākotnēja stāvokļa tekošā dienas tirgū un apskatītā ģenerācijas portfeļa sastāva.

14.01.2018.