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Simulation of the Accumulator Tank Coupled with the Power Unit of Power Plant under the Conditions of Open Electricity Market

Anna Volkova*, Aleksandr Hlebnikov, Andres Siirde

Department of Thermal Engineering, Tallinn University of Technology, Kopli 116, Tallinn, Estonia, 11712
anna volkova@ttu.ee

The simulation model created in the environment of EnergyPro software is used to evaluate the influence of an accumulator tank used with 215 MW power unit in the Balti Power Plant, which can operate in cogeneration mode. The plant supplies heat to the city district heating system. Production of heat reduces the electricity generation in the power unit and the highest electricity capacity can be reached without heat being produced. The electricity sale prices are variable, changing hourly. After installation of the heat accumulator tank, the power unit can operate in cogeneration mode with charging the accumulator tank when electricity prices are lower and delivering district heat during the period when the unit operates in condensation mode (electricity only). The real input data on the operation of district heating system; heat and electricity generation and ambient temperature have been used for simulation.

1. Introduction

The Estonian electricity market is among the smallest in the EU and up to now has lacked effective competition due to few alternative supply options as the market is dominated by oil shale based electricity. As Roos et al. (2011) have reported, in Estonia the opening of electricity market has been slower than in most other EU countries where all the electricity consumers can already choose their electricity provider as of July 2007. Starting from 1 April, 2010 the Estonian electricity sector is a part of the Nord Pool Spot Market, which signed an agreement with the Estonian national grid company Elering to create the Nord Pool Spot Estlink bidding area. The state-owned company Eesti Energia AS is the main participant of the Estonian electricity sector engaged in power generation and sales throughout the country. This company owns the world's largest oil shale-fired power plants – the Eesti and Balti Power Plants located in Narva, Estonia. Some power units of these power plants have been renovated 7 years ago. As Hlebnikov et al. (2009) have reported that after renovation the fluidized-bed power unit No. 11 of the Balti Power Plant can operate in cogeneration mode to provide heat to the district heating system of Narva City.

The main purpose of the research was to evaluate the influence of the accumulator tank on the performance of a power unit of Balti Power Plant, which can operate both in cogeneration and condensation mode under the conditions of open electricity market. The accumulator tank will be installed to provide economic benefit. It will be possible to produce more electricity when the spot market price is higher when working in condensation mode, but heat will be released from recharging the heat accumulator tank. When, electricity price is low, power plant can operate in cogeneration mode, charging the heat accumulator and producing less electricity.

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2. Problem definition

The use of thermal energy storage as an option to increase the efficiency of cogeneration performance was discussed and analysed in the papers by Haeseldonckx et al. (2007), Pagliarinia and Rainieri (2010), Volkova and Siirde (2011). The use of thermal storage coupled with power units in big power plants was investigated by Bogdan and Kopjar (2006). According to their research, it was possible to gain economic benefits by charging the accumulator during the daytime when the electricity price is high and when the cogeneration plant could be run at full capacity generating more electricity and by releasing the district heat during the cheap night hours when other parts of the equipment could be shut down. This approach is appropriate in case the technology is designed such that with the increase of heat production the electricity production will increase too. In case of the Balti Power Plant, the maximum amount of electricity can be produced when no heat is produced; increasing of heat production will decrease electricity production.

The power unit Nr. 11 with a steam condensing extraction turbine of Balti Power plant produces heat and electricity. The turbine can work both in cogeneration and condensation mode. The electrical capacity of a steam turbine operating in condensation mode is always higher than in cogeneration mode, because the steam for heat supply to the district heating system can do additional work in the turbine and the capacity of steam turbine will increase.

The steam for heating comes mainly from the steam pipeline between the medium- and low-pressure cylinders of the turbine. The highest thermal output capacity of the given steam makes 120 MW. The steam goes to the networks horizontal heat exchanger, which has the maximum capacity of 120 MW with the maximum output water temperature of 110 °C. If the heat load exceeds 120 MW, the additional steam output for heating up to 40-60 MW can be reached in the steam pipeline between the high- and medium-pressure cylinders of the turbine through the steam pressure/temperature reduction unit. The steam pressure and temperature after the reduction unit are 15 bars (decreasing from 25 to 15 bar) and 300 °C (decreasing from 535 to 300 °C), respectively. The maximum heat capacity makes 160-180 MW. In the operating mode with the maximum steam output for heating, the capacity on the generator plugs makes 192.5 MW. The nominal electric capacity in condensation mode without the steam output for heating makes 215 MW. It is assumed that the accumulator tank will be installed for increasing the electricity generation during time when the electricity price is higher. It can be possible when the power plant operates in cogeneration mode with the maximum heat capacity and the accumulator tank is charged when the electricity prices are low. Vice a versa, when the electricity prices are high, the power plant starts to operate in condensation mode with no heat generated, but the heat is recharged from the accumulator tank.

3. Simulation model and input data

EnergyPro software can be used for creating simulation models. The units used for the simulation model in this paper are shown in Table 1.

The power unit of a power plant is given in two dependent model units: a power plant operating in cogeneration mode and power plant operating in condensation mode. Each unit can operate when the second is not operating. The division of power units into two parts for the model is required for the implementation of operation strategy, which supposes, that the power plant operates in condensation mode when the electricity price is high.

An additional peak boiler is required for the cases where the heat capacity of power plant is not sufficient to supply heat to the district heating system. To evaluate the impact of the installation of an accumulator tank on the performance of the power plant, the accumulator tank was included in the model. The storage loss in the accumulator tank was taken into account too. Various data and assumptions were used for the simulation. During one year (2011) the hourly data were collected about the heat production, electricity generation, ambient temperature, return water temperature.

The data about electricity and heat production were required for defining the dependence of electricity generation from heat production. As it was mentioned before, with increasing the heat production the electricity production will decrease and this dependence can be expressed by Eq.1:

$$P_i = -0.2388 \cdot Q_i + 202 \tag{1}$$

where

P_i - electricity generation in the power plant during *i* hour, MWh

Q_i - heat production in the power plant during *i* hour, MWh

Table 1: The units used for the EnergyPro simulation model

Energy conversion units	
Power plant operating in cogeneration mode	Maximum heat capacity 160 MW, minimum heat capacity 10 MW, the operation depending on another unit: allowed only with no production from the power plant operating in condensation mode. Fuel: the fuel mix (oil shale and wood chips), min. operation time 8 hours.
Power plant operating in condensation mode	Electrical capacity 200 MW, the operation depending on another unit: allowed only with no production from the power plant operating in cogeneration mode. Fuel: the fuel mix (oil shale and wood chips), minimum operation time 0 hours.
The peak boiler	Heat capacity 80 MW, minimum operation time 2 hours. The operation independent of other units. Fuel : natural gas
Demands	
Heat demand	Heat demand 452 GWh/y, the maximum heat load 183 MW.
The electricity spot market	Nord Pool Spot's market (2011, EE)
Heat storage	
An accumulator tank	Temperature at the top 95 °C, temperature in the bottom 42-63 °C, depending on the ambient temperature, volume 12,000 m^3, height 22 m, insulation thickness 300 mm, thermal conductivity 0.0370, utilization 100 %,

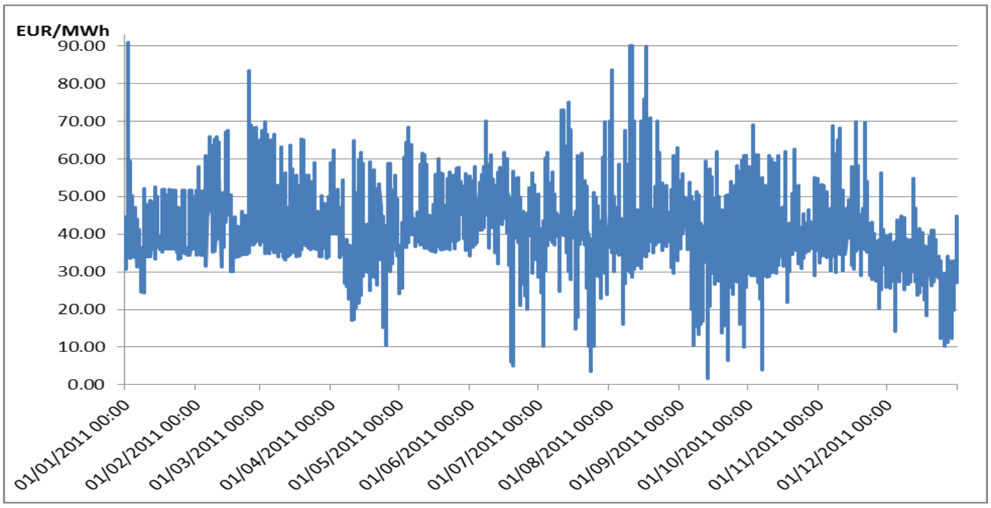

Figure 1: The Nord Pool Spot's market price dynamics for the bidding area in Estonia

For evaluating the economic benefits, the hourly spot market prices (the Nord Pool Spot) were used in the simulation model. The Nord Pool Spot's market price dynamics for the bidding area in Estonia are shown in

Figure ***1***.
The Nord Pool spot market prices were split into 4 groups before the simulation (Table 2): the peak prices, high prices, low prices and low peak prices.
The peak prices and high prices are usual for working days from 7 am to 2 pm. The low prices and low peak prices are typical for the night time. The operation strategy for each energy conversion unit, included in the model, is shown in Table 2. The operation strategy is expressed by coefficients 1, 2, 3 where coefficient equal to 1 shows that this energy unit has the highest priority and should be chosen for the operation during simulation. Coefficient, equal to 2 illustrates the medium priority and coefficient equal to 3 the lowest priority.

Table 2: The operation strategy for energy conversion units

	Peak prices	High prices	Low prices	Low peak prices
	<52 EUR/MWh	45…52 EUR/MWh	30…45 EUR/MWh	>30 EUR/MWh
Power plant in cogeneration mode	3	1	1	1
Power plant in condensation mode	1	1	2	3
Peak boiler	3	1	2	2

According to Table 2, it is preferable that the power plant operates in condensation mode when the prices are higher than 45 EUR/MWh, but in case the prices are lower than that, the cogeneration mode is the highest priority.
To evaluate the influence of an accumulator tank on the amount of generated electricity, it is important to compare the indicators of the system with and without an accumulator tank. The following indicators were used for the evaluation: heat production by the power plant, heat production by the peak boiler, total electricity production by the power plant, sale of electricity, net cash from running the energy system.

4. Results

The results of simulation for the energy system with an installed accumulator tank are shown in Figures 2-4.

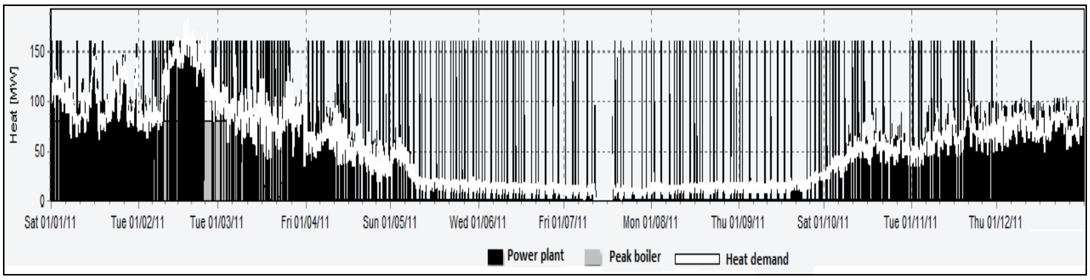

Figure 2: Heat supply by the Balti Power plant and peak boiler

Figure ***2*** presents a solution for the heat production during a year. The power plant operates in cogeneration mode when the electricity prices are not high. When the heat demand is lower than amount of generated heat, the accumulator is charged with the heat surplus.
Heat from accumulator tank is used when prices become higher and power plant operates in condensation mode as shown in Figure 3. As it can be seen from the figure, the Balti Power Plant operates mostly in cogeneration mode when the heat load is high, but in condensation mode when the heat demand is lower and electricity prices are higher.

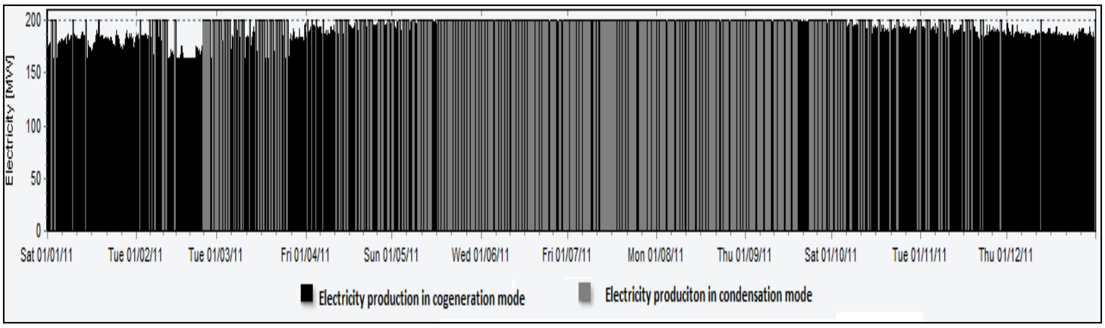

Figure 3: Electricity production in the Balti Power Plant

Figure 4 shows the changes in the capacity of heat accumulation tank and how the accumulator can be charged and recharged during a year.

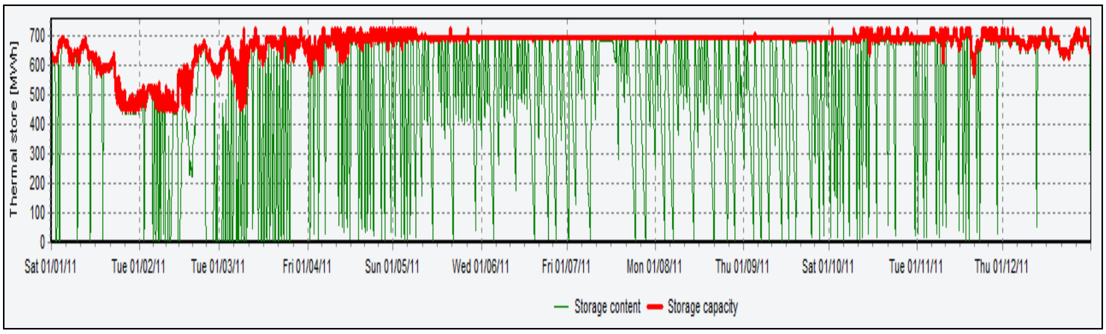

Figure 4: Charging and recharging of accumulator tank

It can be seen that the capacity of accumulator tank varies during the heating period. It can be explained by the variation of ambient temperature and return water temperature in the district heating system. The capacity of accumulator tank varies from about 550 MWh to 700 MWh. The accumulator tank is charged only from the Balti Power Plant and it can be charged when power plant is operating in cogeneration mode. The accumulator is rarely charged during cold months, because then the heat demand is higher than heat production by Balti Power plant. The accumulator tank is not often fully recharged during the summer months. The heat loss per year of accumulator tank is not higher than 200 MWh.
Comparison of the main indicators for the simulation of energy system operation with and without heat the accumulator tank is presented in Table 3.

Table 3: Comparison of energy systems with and without the heat accumulator tank

Indicator	Without the heat accumulator tank	With the heat accumulator tank
Heat production, the power plant, GWh/y	440	423
Heat production, the peak boiler, GWh/y	12	29
Electricity production, GWh/y	1455	1660
Sale of electricity, thousands EUR	63627	72241
Net cash from the operation, thousands EUR	22209	24786

The table shows that it is possible to increase the electricity production by 205 GWh/y and income for electricity can be increased by more than 8.6 mil EUR/y

5. Conclusion

Installation of the heat accumulator tank may positively influence the economic performance of power plant in the conditions of open electricity market when electricity prices vary during the day. A simulation model created in the EnergyPro Software showed that it is possible to generate more electricity per year (by 205 GWh). The net cash from the operation of Balti Power Plant in the case with the heat accumulator tank can be increased by 2.56 million EUR/y.

It is achieved mainly by operating in cogeneration mode and charging the heat accumulator when electricity prices are lower, and operating in condensation mode, generating more electricity and recharging the heat accumulator when electricity prices are higher.

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