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COMBINED HEAT AND POWER PLANTS BALANCING WIND POWER

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Wind power (WP) is the most developing area in the Estonian renewable energy sector, but there are technical limitations on its integration. At a certain capacity some balancing measures are required to handle large amounts of WP. This could be achieved by introducing combined heat and power plants (CHP) at regional level. The use of gas engine allows quick response to load changes and therefore is suitable for regulating activities. As for principles of distributed power generation, the aim is to locally minimise the shortfall and surplus of electricity. By this additional costs of rebuilding power lines and building new balancing generation units can be avoided. In this paper possibility of balancing WP with CHP is analysed. The investigation is carried out with the help of energyPRO software, which allows simulating the cooperation of WP and CHP. Also the essence of building heat storage is analysed, to add flexibility into the plant operation.

Introduction

The wind resources in Estonia are excellent, but there are different technical limitations on their utilization, such as transmission capacity bounds of electrical network and lack of regulating reserves to compensate the fluctuations in wind power [1]. WP has currently only a small share in Estonian electricity production. In the year 2007, 91 GWh electricity was generated by wind turbines corresponding to 0.7% of electricity production [2]. WP will have a bigger importance in the future as there are several hundred MW projects under development. The total capacity of planned wind power projects in Estonia reaches 4000 MW, which is more than two times higher than the maximum consumption of the whole country. Most probably all these projects will not be implemented, but at least 200 MW by 2010 and 400 MW by 2012 will be in operation. As there are no fast start-up

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production capacities in Estonia, some balancing measures are necessary if the capacity of WP exceeds 200 MW [3].

Currently the Estonian electricity network is not suitable for large-scale integration of WP. The best wind resources can be found along the coastline and on islands, but the electric grids in these areas are very weak and cannot transmit large amounts of electricity. Another problem related to WP is its unpredictability. Wind energy is a fluctuating weather-dependent energy source where wind speed varies rapidly and frequently within wide range. This will have an influence to production as power output from WP is a function of the wind speed in the third power [1]. A wind power plant must foresee its power generation. The accuracy of wind power generation forecast models currently available allows predicting the WP production up to 72 hours ahead with preciseness between 10 and 20% [4]. There are many options for balancing the WP, like using hydro power plants, gas turbines, gas engines, condensation power plants, connections to neighbouring countries etc. In this paper the focus is on small-scale CHP plant operation for balancing the supply and demand in a system with fluctuating WP generation.

Cogeneration plants are commonly found in Estonian district-heating systems of bigger towns, department stores, paper mills, wastewater treatment plants and industrial plants with large heating needs. In the year 2007, 869 GWh of electricity and 2777 GWh of heat was produced using cogeneration, corresponding to 7.1% of electricity and 27.4% of heat production [2]. The whole potential for cogeneration is not utilized in Estonia. According to the long-term development plans 20% of electricity production would come from CHP-s by the end of 2020. Currently many new CHP plants are planned and some of them are already under construction. By the year 2011 three new CHP-s will start operating with capacity of 75 MW of electricity and 150 MW of heat [3].

The use of CHP plants balancing the WP production supports the principles of distributed generation. Distributed generation (also decentralised generation) comprises all generation installations that are connected to the distribution network and are based on the use of renewable energy sources or technologies for CHP with a maximum size of approximately 10 MW of electricity. This means that electricity is generated close to the point of use to match the load requirement of the customer reducing the necessity to build power lines and improving the reliability of the power supply [5].

The operation of CHP according to the availability of WP is complicated, as it is necessary to take into account the heat consumption. A normal operation of a CHP plant is determined by thermal load. In the case of balancing activities, CHP plants would produce within these hours when electricity is needed *i.e.* at low WP production. At hours when WP covers the electricity demand, the CHP plant avoids producing, and heat demand could be covered through the use of boilers. Additionally, if heat storage is applied, heat produced by CHP could either be used to cover the demand directly or be stored and used later on [6].

Modeling the operation of wind turbines and CHP plant

The aim of the study is to investigate at which level a CHP plant could compensate the fluctuating WP and how it would affect the operation of the CHP plant. Also the essence of building heat storage is analysed, to add flexibility into the plant operation.

The key assumptions are summarized in Table 1.

Table 1. **Key assumptions**

Temperature	Daily temperature data of Estonia
Heat demand	Annual demand 27.5 GWh 70% temperature-dependent from September to May Reference temperature 15 °C Daytime demand/night-time demand 10/6
Electricity demand	Annual demand 25.0 GWh 50% temperature-dependent Reference temperature 25 °C Daytime demand/peak/night-time demand 11/12/9
Production units:	
Wind park	Annual production 42.8 GWh , different shares are used
Gas engine	Electrical capacity 3.0 MW Thermal capacity 3.0 MW Minimum load 30%
Boiler	Thermal capacity 10.0 MW
Fuel	Natural gas Heat value 9.35 kWh/Nm3
Thermal store	Capacity 50 m^3 – 500 m^3, different capacities are used Temperature difference 30 °C Utilization 90%
Planning period	1 year

The investigation is based on the example of Pakri wind park. The park consists of 8 Nordex N-90 wind turbines with a capacity of 2.3 MW each. The total capacity of the park is 18.4 MW and is currently the second largest in Estonia. Eight wind turbines situated in the coastline, 52 km west of Tallinn, began to operate in spring 2005 [7]. Pakri wind park was chosen as an example, as hourly production data for the year 2006 was available for this site. The production during the year 2006 was 42.8 GWh.

The aim of local CHP-s compensating WP production is to avoid additional costs of rebuilding power lines and building new generation units performing balancing. Typically a weak electricity grid in areas with best wind resources would require extensive investments, which could be thereby avoided or reduced. For the investigation purpose it is therefore assumed that, due to limited capacity of power lines, the system operator requires balancing activities to reduce the need for transmitting large quantities of wind power to the transmission network.

The balance in Estonia's electricity system is currently regulated by oil-shale power plants, which are not designed for that purpose [4]. Therefore the system operator is planning to build a new gas turbine for balancing activities [3]. This investment could be avoided or postponed if these duties would be carried out by local CHP-s. Therefore, second assumption is that the balancing activities will be carried out by an existing small-scale CHP plant, situated in the same distribution network as the wind park.

As there is currently no CHP-s near Pakri wind park, it was taken as an example that the balancing CHP could be placed in Paldiski as it is the nearest town to Pakri wind park. In Paldiski, there are approximately 4200 inhabitants who live mainly in apartment houses and consume district heating. Additionally there are some industrial consumers nearby like harbour, saw mill, etc, of which some are not connected to the district heating network, but could be possible electricity consumers [8]. The annual heat demand is approximately 27.5 GWh, and electricity consumption is estimated to be 25.0 GWh. It is assumed that Paldiski would have an existing cogeneration unit, which would be used to balance locally the WP. Based on estimated electricity and heat demand, the optimal size of CHP would be a Jenbacher gas engine with a capacity of 3.0 MW electricity and 3.0 MW of heat. For heat production, there is a boiler with a thermal output of 10.0 MW. It is assumed that the plant uses natural gas as a fuel, which used in gas engines allows quick response to load changes and therefore is suitable for regulating activities.

The principle idea of balancing WP locally by a CHP is visualised in Fig. 1.

Figure 1 shows that wind park and CHP generate electricity to the network to satisfy the local demand of domestic and industrial consumers. The aim is to minimise the need for additional electricity import from outside this area and also to minimise electricity production which could not be consumed locally and therefore would be considered as export. This means that the following power balance equation will be guaranteed for every hour of the whole year:

$$P_{cons} + P_{eks} = P_{WT} + P_{CHP}(Q_{CHP}) + P_{imp}. \qquad (1)$$

The goal is to minimize the following objective function:

$$\min(P_{eks}, P_{imp}) \qquad (2)$$

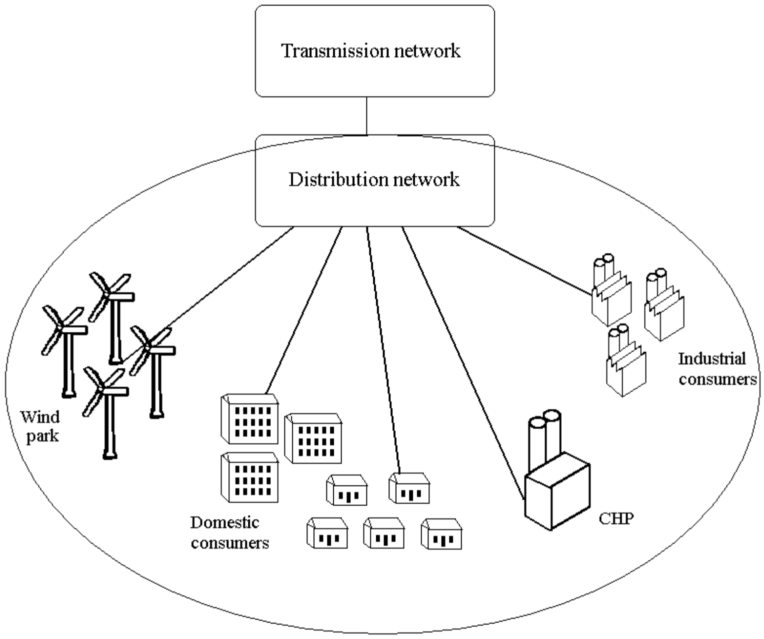

Fig. 1. Distributed generation network.

Also the heat balance equation must be fulfilled:

$$Q_{cons} = Q_{CHP} + Q_B\,, \tag{3}$$

where P_{cons} – electric power demand;
P_{eks} – electricity export;
P_{WT} – power output from wind turbines;
$P_{CHP}(Q_{CHP})$ – power output from CHP; produces simultaneously heat;
P_{imp} – electricity import;
Q_{cons} – heat demand;
Q_{CHP} – thermal output of CHP;
Q_B – thermal output of boiler.

WP is renewable energy source and its production is nonpredictable, therefore the whole balancing is made by CHP. In case the power balance is carried out perfectly, there would not be any electricity directed into and no electricity needed from the transmission network. In the system operator's point of view, this would be a positive effect, as the WP fluctuations would not reach the transmission network and therefore no WP regulation would be necessary. Also the investment into raising the transmission capacity of electricity network would not be needed.

For the simulation and optimisation a software package energyPRO is used, which is a Windows-based software package for design, optimisation, and analysis of energy projects developed by Danish company Energi- and

Miljødata. The user is able to input a wide range of data on different energy plant types, external conditions such as demands, operating strategies, tariff structures, revenues and operating costs, investments and finance arrangements. Based on the inputs, the energyPRO optimises the operation of the plant against technical and financial parameters and provides a graphical overview. Software also provides the user with the operating results and a detailed financial plan in a standard format accepted by the World Bank [9].

EnergyPRO is an input/output model for calculating annual production in steps of one hour. In the current project the inputs are capacities, efficiencies, fuel data, hourly outdoor temperature and hourly WP production. For the optimisation it is necessary to define hourly demand for electricity and second curve for heat. For this purpose annual demand, its dependency on outdoor temperatures, hourly variation of demand during a day and period of heating were modeled.

The optimisation in energyPRO is based on calculation periods and is dependent on operational strategy. Based on user-defined data, the model constructs for the whole planning period (in this case for one year) hourly time series for electricity demand and similar curves for heat. The production units (wind park, CHP and boiler) are given priorities, and additionally it is defined whether the partial load, production to heat storage and restrictions to electricity demand are allowed or not.

As for principles of distributed power generation, it was assumed that a CHP plant would be operated to balance the WP production and to meet the electricity and heat demand of the area. For this purpose demand profile for electricity and heat were modeled. The WP production is prioritized, which means that electricity demand, which is not covered by WP, will be covered by CHP plant. In balancing activities the CHP plant is not allowed to produce more electricity than needed locally, but for wind turbines it is assumed that the surplus is transmitted to consumers outside the given area. Based on these criteria's energyPRO models the annual production of wind park, CHP and boiler. The operation is based on priorities of production units, which are defined by the modeller. Firstly, as WP is prioritized, the hourly time caps for electricity demand are filled with wind energy production. The remaining electricity demand is covered with CHP. As simultaneously CHP produces heat, the time series for heat consumption is covered. If the CHP produces more heat than the actual heat consumption, the excess heat is stored in the accumulator (if available). In case the storage is full, the unit can only produce as much as needed to cover the heat demand. If after these two steps there will be caps under the electricity demand not filled, this demand will be covered with electricity import.

After filling the electricity demand, the model continues with heat demand. The remaining caps, which have not been covered by CHP, will be now covered with heat from accumulator (if available). The remaining heat demand will be covered with boiler. The graphical overview of electricity and heat production during one week in winter is presented in Fig. 2, where

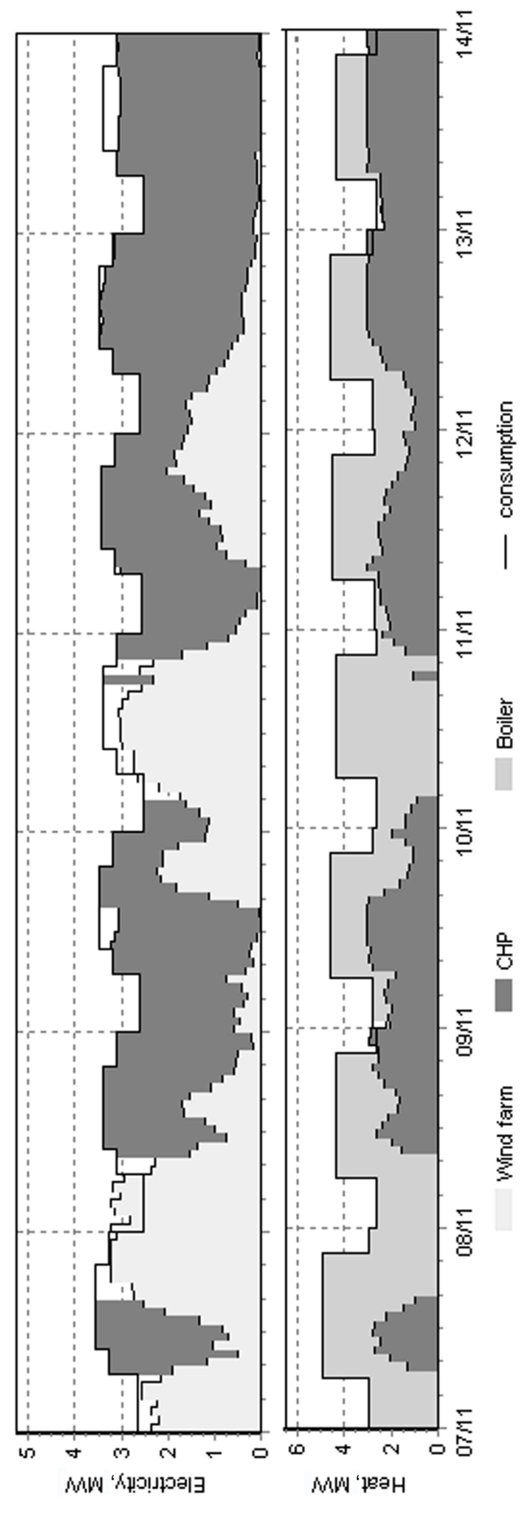

Fig. 2. Production of electricity and heat.

the operation of CHP is restricted taking into account the wind power production and the demand for electricity and heat.

As seen from Fig. 2, energyPRO manages to operate WP, CHP and boiler to meet the local electricity and heat demand. There are different operational cases, which are shown in Fig. 2:

1. During some hours on the 7th, 8th and 10th November the WP production covers the whole electricity demand and as there is enough of WP to meet the whole demand, operation of CHP plant is restricted. Hence it is necessary to cover the heat demand and as the CHP is restricted to operate, the heat demand will be covered by boiler. During some hours the WP production is even greater than the demand, therefore electricity surplus is directed to the transmission network.
2. On the 9th, 11th and 12th November wind turbines produce electricity, but their production is not sufficient to meet the whole demand. Therefore additional electricity demand is covered by CHP. As the production of CHP is limited due to WP, the additional heat demand is covered with the boiler.
3. On the 13th and some hours on 9th and 11th November there is no WP production, and therefore the whole electricity demand is covered by CHP. As thermal capacity of CHP is 3 MW, but the heat demand exceeds 4 MW, the remaining heat demand is covered by the boiler.

Balancing activities

The energyPRO models were constructed to investigate the balancing ability of CHP. As a basic model, a model of conventional operation of CHP plant was constructed, in which case the production of CHP is dependent only on heat demand. Secondly the operation of CHP was restricted, taking into account wind power production, electricity consumption and heat consumption. To estimate the optimal size of WP, which CHP would be able to balance, different shares of actual electricity generation of Pakri wind park were considered in the model (from 5%, 10%, 15%... to 100%). Finally availability of heat storage was included in the model and different accumulator capacities were simulated.

Based on simulation of all these models in energyPRO, the results of annual electricity and heat production, import and export are presented in Table 2. Only some examples of WP capacities (percentages of actual production of Pakri wind park) were chosen to be presented in this table. The results of a model with heat storage will be analyzed later, and the results presented in Fig. 4.

From Table 2 it is seen that in the basic model, there is no need to balance WP production, *e.g.* CHP is producing regardless the electricity demand and availability of WP, the total annual electricity production is 61.4 GWh, of which production of CHP is 18.7 GWh and the rest is WP. As

Table 2. **Annual production of electricity and heat**

Windpower, MW	18.4	1.8	3.7	9.2	18.4
% of actual Pakri WP generation	100	10	20	50	100
CHP restrictions	no	yes	yes	yes	yes
Electricity production, GWh					
Wind	42.8	4.3	8.6	21.4	42.8
CHP	18.7	16.4	12.8	7.8	5.3
Total production	**61.4**	**20.6**	**21.4**	**29.2**	**48.1**
Import	1.7	4.4	3.8	2.7	2.0
Total balance	**63.1**	**25.0**	**25.2**	**31.8**	**50.1**
Export	38.1	0.0	0.2	6.8	25.1
Consumption	25.0	25.0	25.0	25.0	25.0
Heat production, GWh					
CHP	18.5	16.2	12.7	7.7	5.3
Boiler	9.0	11.3	14.8	19.8	22.2
Total production	**27.5**	**27.5**	**27.5**	**27.5**	**27.5**

the electricity consumption is 25.0 GWh, this means that 60% of produced electricity will not be consumed by locally. Hence of large amounts of excess electricity, there is also a small need for import, which is 3% of the total power balance. Import is necessary mainly in the summer period, where there is no WP production and the heat consumption and therefore also the electricity production from CHP are very low. Therefore, in a conventional operation of WP and CHP, large amounts of export will not satisfy the aim of distributed generation.

If it is necessary to balance 10% of the production from Pakri wind park (equals WP capacity of 1.8 MW and production 4.3 GWh) with CHP, the annual total electricity production is reduced to 20.6 GWh. Electricity production from CHP is 16 4 GWh, meaning that CHP will have to reduce its production by 12% in case it is necessary to take part in balancing. There is practically no export required and import is 4.4 GWh, which is 17% of the total balance. The increased import quantities are due to the fact that the maximum local electricity demand is 5.0 MW, but the maximum output of CHP is only 3.0 MW, and therefore there is a considerable need for import on hours with high electricity demand and low WP production.

Higher share of WP will reduce the need for import and introduce some amounts of export. If it is necessary to balance 20% of the production from Pakri wind park (equals WP capacity of 3.7 MW and production 8.6 GWh), the annual total electricity production is increased by 4% to 21.4 GWh. The production from CHP has decreased by 32% (compared to no balancing operation) to 12.8 GWh, export is 0.2 GWh (1%) and import 3.8 GWh (15%).

Balancing of 50% of the production from wind park (WP capacity 9.2 MW and production 21.4 GWh) will mean that the annual total electricity production is increased to 29.2 GWh. The production from CHP is only 7.8 GWh, export has sharply increased to 6.8 GWh (21%) and import reduced to 2.7 GWh (8%).

The inclusion of the total Pakri wind park (capacity 18.4 MW and production 42.8 GWh) will result in a situation where the CHP produces only 29% (5.3 GWh) of what it should normally produce when no balancing is necessary. Export will be 25.1 GWh (50%) and import 2.0 GWh (4%).

As the main idea of distributed generation is to limit the export into and import from outside the given area, the best indicators for evaluation are the quantities of exported and imported electricity. Figure 3 presents the export and import quantities in case it is necessary to balance the WP production at different shares from 0% (0 MW) to 100% (18.4 MW). Also the calculated regulating price from CHP is visualised on the same graph, which will be analysed later on.

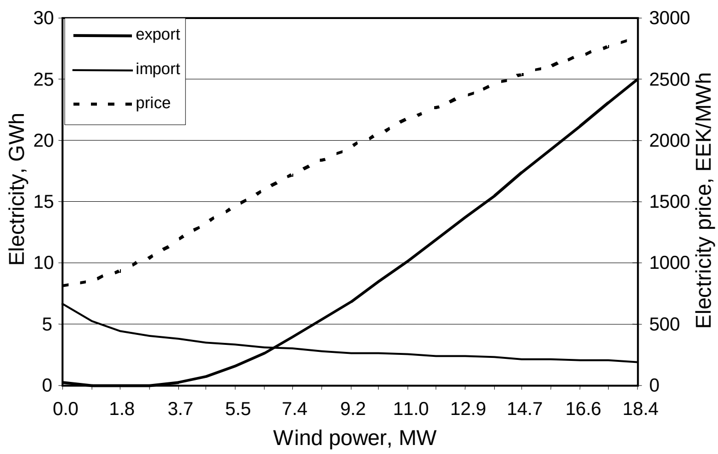

Fig. 3. Export and import quantities and balancing price.

As seen from Fig. 3, the need for import is decreasing from 6.6 GWh, when there is no wind power to be balanced, to 2.0 GWh, when it is required balancing the whole Pakri wind park. Regarding export quantities remarkable changes are observable. At first, there is no electricity surplus, meaning that the total produced electricity will be consumed near the point of generation. Export quantities will start to increase if it is necessary to balance more than 20% (3.7 MW) of the total wind park production and will sharply rise to 25.1 GWh. If the electricity consumption is 25.0 GWh and it is needed to balance the whole wind park, the export quantities equal the consumption. It results in a situation where CHP and wind turbines produce so much electricity that it covers nearly twice as large area as the current example. This means that most of the WP will not be consumed locally and is therefore sent to the transmission grid. So, looking from the point of view of distributed generation, it is reasonable to balance up to 20% of the total WP generation or a wind park with a capacity of 3.7 MW. Therefore the CHP, with an electrical output of 3 MW, is suitable to balance the maximum 20% forecasting faults from 18.4 MW Pakri wind park or production from any wind park which is about the same size as the CHP.

Also the heat production of CHP will be affected in balancing activities, as electricity and heat are produced simultaneously. In non-balancing activities CHP produces 18.5 GWh and boiler 9.0 GWh of heat. In balancing activities the production from CHP decreases and uncovered heat demand will be fulfilled by boiler. As already seen in the electricity production analysis, the CHP has to reduce its production dramatically. In case it is needed to balance the whole Pakri wind park, the heat production will be only 5.3 GWh, and 81% (22.2 GWh) of heat will be produced in boiler.

Economical aspect

In order to motivate CHP plants to balance the fluctuating WP production, some incentives are necessary. From Table 2 it was seen, that in case the operation of CHP plant is dependent on WP generation, the total CHP electricity production will be reduced, in this case even to only one third of what it would normally be. This will result in lower incomes from electricity sale and leads us to a state where it is not economically feasible to operate the CHP plants in conjunction with WP. Therefore electricity price must provide an incentive in order to regulate power at certain hours. Possible measures could be electricity sale in competitive electricity market or introducing tariffs with a hourly variation.

Normally, if no balancing is required, the total electricity production from CHP is 18.7 GWh. For the sold electricity a small CHP plant in Estonia would receive, according to the Energy Market Act, a fixed tariff 810 EEK per sold MWh of electricity (52 €/MWh) [10]. This price will be received independent from the time when electricity is generated. Thus, the incomes from electricity sale would be approximately 15 million EEK. In balancing duties the plant would receive less, in the worst case only 4.3 million EEK, if paid the current fixed price. Therefore the CHP would not be interested to regulate WP production to meet the whole electricity demand. They would be interested only in case their operation is financially sufficient. Considering that incomes from electricity sale should be at the same level (15 million EEK) as in non-balancing activities, the calculated fixed price for balancing energy units is shown in Fig. 3. From this figure it is seen that this calculated balancing price increases from 810 EEK/MWh to 2800 EEK/MWh, which is extremely high.

As a comparison, the spot-market price in Nordpool market has been changing during the year 2008 between 30 and 70 €/MWh. If taken into account that the balancing price should be at highest 70 €/MWh (1100 EEK/MWh), then it is possible to balance up to 20% of the total WP generation or a wind park which is about the same size as the CHP. This means that, if it is needed to balance more than 3.7 MW of WP, it would be economically reasonable to use the connection to Nordpool to balance the fluctuating WP production and not to force the local CHP to reduce its production.

The essence of heat storage

One task of the paper is to analyse the essence of heat accumulator. Currently CHP-s and boiler houses in Estonia do not have any heat accumulators, but Danish examples [6] have shown that they could be very useful for concentrating the production of CHP-s on certain hours.

From the graphical results from energyPRO, like the one presented in Fig. 2, it was seen that in certain hours some part of electricity demand is not covered (white area between demand and production from wind turbines and CHP). One reason for this is restrictions on CHP production. In this time the CHP is not allowed to produce more, because this would result in excess heat, as the heat demand is already met. This is due to the fact that CHP is not allowed to produce more heat than necessary. In this case, the availability of heat storage could improve the operation, as CHP could then produce as much as needed to cover the electricity demand, and the heat surplus would be stored in the accumulator. Therefore, the availability of heat storage was simulated in energyPRO.

As it was found out above, it is reasonable to balance up to 20% of total production from Pakri wind park without any export quantities, and also at this level the electricity sale price for CHP would be kept at a reasonable level. Therefore it was assumed that it is necessary to balance 20% of the WP production building a heat accumulator at the CHP plant, and capacity from 50 to 500 m^3 was considered. The resulting export and import quantities and electricity price can be seen in Fig. 4, as they are best indicators for evaluation.

Figure 4 shows that if the CHP plant balances 20% of WP production and has no heat storage (capacity 0 m^3), the import is 3.8 GWh, export 0.2 GWh, and the previously calculated electricity price is 1180 EEK/MWh. Regarding different sizes of heat accumulator, the export will stay at the same level, as it is necessary to balance the same amount of WP and CHP is not allowed to produce more electricity than locally needed. Changes are seen in regarding import quantities, which will decrease by 30% from 3.8 GWh to 2.7 GWh. The biggest effects of having a heat storage will be accomplished with the smallest storages. A storage with a size of 50 m^3 will reduce the import by 17%, and 100 m^3 – an additional 5% to 3.0 GWh. Beyond that capacity, larger storages will reduce the need for import only in smaller amounts and therefore could not be very feasible. Also the balancing price will be affected as the CHP is now allowed to produce more. Figure 4 shows that the price will be reduced by 8% to 1088 EEK/MWh.

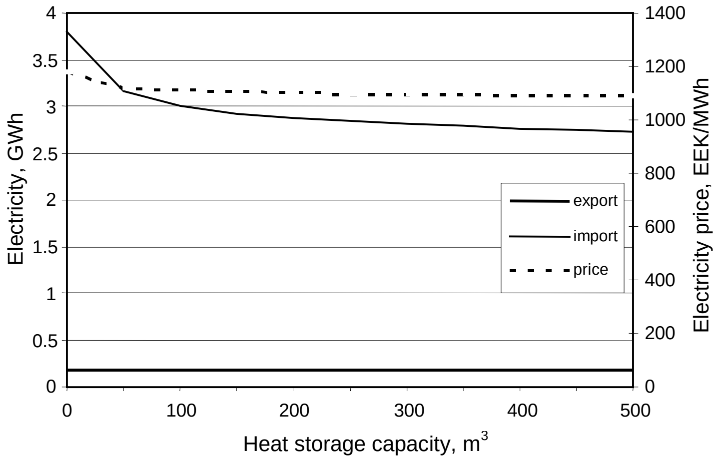

Fig. 4. Export and import quantities and electricity price.

At analyzing heat storages it was discovered that, during a certain period (from November to March) accumulator is used rarely and only at a very low level. The rare use of heat storage is due to the fact that there is no excess heat during the period of high heat demand, as it is consumed simultaneously. This is also caused due to the fact that, for this specific CHP technology, the gas engine produces equal amounts of electricity and heat (power ratio 1 to 1). In the case of different production technology with a heat and power ratios for example, 1 to 2 or 1 to 3, more heat is produced for the same amount of electricity, and this will result in a wider use of storage. However, for this certain technology the effects of heat storage can be mainly seen in the period from April to October when the heat demand is lower. In this case CHP will run on a maximum load or as high as the electricity demand allows storing surplus heat in the accumulator to be used later when CHP is restricted to operate (e.g. at high WP production).

To calculate the economic benefits of building an accumulator, it is necessary to estimate the cost of heat storage, which, based on Danish examples, can be taken as 200 €/m^3 [11]. This means that the cost of 100 m^3 storage is 310 000 EEK (20 000 €). By comparing the CHP electricity production between energyPRO models with storage and without, it is possible to calculate how much the CHP plant could benefit through having heat storage. If CHP has no heat accumulator, the electricity production is 12.8 GWh and the availability of storage will increase the production to 13.6 GWh. So CHP plant could gain additional incomes from the sale of

0.8 GWh electricity. Calculations show that the costs of storage is paid back in four years, and the balancing price would be 6% lower.

Conclusions

The data presented in figures and tables demonstrate that it is possible to balance the WP production locally with a small-scale cogeneration plant. CHP with electricity output of 3 MW is suitable to balance the maximum 20% forecasting fault of 18.4 MW Pakri wind park or production of a wind park which is about the same size as the CHP. In this case there would be no electricity surplus, also import quantities and balancing price are kept at a reasonable level. However, as a result CHP will have to reduce its production by one third of the normal operation level. In order to motivate CHP to regulate its production at certain hours, the electricity sale price must provide an incentive for CHP. To guarantee the same income for the enterprise, the current fixed price has to be higher, in this case 1180 EEK/MWh.

Based on calculations it was seen that if it is required to balance larger amounts of WP than the electrical output of the CHP, it would be economically feasible to use the connection to Nordpool to balance the WP production and not to force the local CHP-s to reduce its production. Larger amounts of WP will reduce the need for import, but export quantities will sharply rise up to double of the local consumption, and the calculated balancing price would be even 3.5 times higher. Also boiler will gain a greater importance in the heat production as less electricity and heat will be produced by CHP.

In spite of the fact that CHP plant can manage the production optimization according to the WP without using the accumulator, the building of heat storage will improve the CHP operation and reduce the need for electricity import. The biggest effect of having heat storage will be accomplished with the smallest storages. Calculations show that the cost of a 100-m^3 storage is paid back in four years, and the balancing price would be 6% lower.

Heat storage is rarely used during the period of high heat demand, as there is no excess heat from CHP. One reason for that is the use of specific gas engine. Technology with a different heat and power ratio could result in different usefulness of storage. Currently the benefit of using the heat storage is seen mainly in summer, but also in situations in which the heat demand is only slightly higher than the heat production.

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