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Methodology to analyze combined heat and power plant operation considering electricity reserve market opportunities

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ABSTRACT

This paper presents a methodology to promote the operation of combined heat and power (CHP) power plant in the liberalized energy markets. The methodology considers a combination of marketplaces available to the power plant for its end products heat and electrical power, with a special reference to electricity reserve market opportunities. A result of the paper is a daily operation sequence to analyze the hourly operation in the heat and electricity markets. The proposed methodology is tested with price data of the respective energy and power markets between years 2013 and 2015.

1. Introduction

Electrical power markets are facing major changes in many countries. Reasons for this are the rapid increase [1] in renewable power generation boosted by green energy policies [2], subsidies for the renewables, and changes in people's attitudes and electricity consumption habits [3].

The increasing amount of solar and wind power production [2,4,5], typically leads to a situation where the power balance may fluctuate significantly over a short period of time. This can be problematic for the electrical power system if the power production or demand cannot be controlled. Thus, the electrical system has to contain reserve power capacity and/or demand response, which is able to respond to a deficiency in power production or overproduction. Power balancing can be arranged by using power plants that can be adjusted according to the power demand. Moreover, to be able to quickly increase the power production, the power plant cannot initially be driven with full electrical power. These conditions can be met by CHP plants, which have an ability to increase flexibility, for instance, by controlling the power-to-heat ratio. Flexible power production is essential from the perspective of power system balancing [6].

The output power of the CHP power plants is typically determined by the heat demand in the heat system [7], which can be, for instance, a district heating (DH) network or a large-scale industrial operator. Thus, the electricity production is determined based on the boiler power required for the heat production. It would also be possible to operate the power plant based on the electricity production, but the present low electricity wholesale price does not encourage this operation.

Optimization of CHP plant operation has been described for instance in Refs. [5,8,9]. These research reports discuss the optimal operation in liberalized power markets. However, the studies do not consider short-term electricity markets such as intraday market or electricity reserve markets. In Refs. [10,11], the opportunity to use a CHP power plant in reserve market operation is considered, and thus, these papers serve as an introduction to this paper.

In this paper, the objective is to develop a methodology to analyze the operation of a CHP power plant in liberalized energy markets covering the heat energy market, the day-ahead electricity market, the intraday electricity market, and the electricity reserve power markets.

2. Electrical energy system

The basic function of an electrical energy system is to produce and deliver electricity to electricity end-users without interruptions and with good quality. The electrical power system has to be operated so that production and demand are always in balance to keep the system frequency stable at the desired value, such as 50 Hz. Therefore, it would be beneficial for the system if both the production and demand were stable. In reality, demand is not

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stable, and thus, production has to follow the demand. If production and demand are in imbalance, the system frequency starts to decrease or increase depending on the imbalance. If demand is higher than production, the frequency starts to fall. The opposite situation, when the production is higher, indicates a rising frequency. When the change in frequency reaches a certain level, the stability of the system is lost and the system will collapse causing a blackout. Therefore, the system has to contain regulating production capacity to ensure stability of the system. An example of the system frequency is presented in Fig. 1.

The figure shows a dead band, which is the frequency band where the frequency is not regulated in the Nordic countries [12]. It can be seen that the frequency has to be regulated many times within an hour. The same issue is illustrated for the years 2008–2016 in Table 1, which presents the percentage of hours in a year during which the frequency deviates from the frequency limits. For instance, in the year 2014, 81% of the hours contained an instant when the frequency was below 49.95 Hz. Similarly, 82% of the hours contained an instant when the frequency was above 50.05 Hz. Further, it seems that the percentage of instants when the frequency falls outside the limits has increased year by year. For instance, when the frequency fell below 49.9 Hz in 23% of the hours in 2008, the percentage was 33% in 2015.

The frequency statistics indicate that the power system is under continuous control, and thus, the frequency containment reserves play an important role in system balancing. As the statistics show, the role of reserves is increasing even further in the future.

3. Energy markets

Energy markets can be divided into heat and electrical energy markets. The heat energy market is typically a local and limited regional district heating system, whereas electrical energy markets can be cross-border multinational markets.

3.1. District heat market

Local district heat markets are often operated by a dominant operator, which usually owns both the heat production capacity and the district heating network. Thus, the market is often inflexible, and the consumer prices are closely related to the pricing of the dominant operator. However, pricing is not free of regulations.

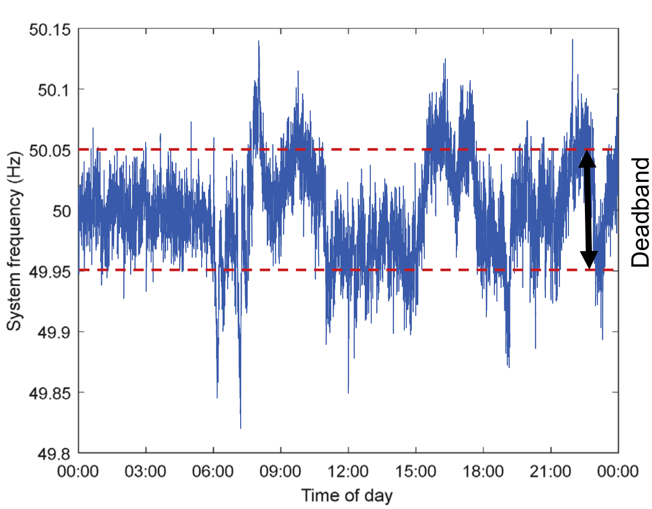

Fig. 1. Frequency of the electrical power system in the Nordic countries on 4 February 2013.

Table 1
Hourly deviation from the frequency limits between the years 2008 and 2016. The statistics of 2016 are for the period of January–July.

	$f < 49.5$ Hz	$f < 49.9$ Hz	$f < 49.95$ Hz	$f > 50.05$ Hz
2008	0%	23%	74%	75%
2009	0%	26%	75%	75%
2010	0%	29%	78%	77%
2011	0%	31%	81%	78%
2012	0%	31%	79%	79%
2013	0%	31%	82%	80%
2014	0%	30%	81%	82%
2015	0%	33%	84%	83%
2016	0%	41%	85%	85%

For instance, according to the Finnish competition legislation [13], the district heating operator is in the dominant market position and the abuse of the dominant market position is prohibited. For the DH industry this means that prices are reasonable and cost-reflective, similar customers are treated equally, and different products are not pulled together in the total energy delivery.

3.2. Electrical energy markets

Electrical energy markets in Europe have evolved rapidly since their opening in the 1990s [14]– [15]. The markets are divided into segments. In the Nordic Electricity markets, the main wholesale market is the day-ahead market Elspot, which defines the hourly prices for the produced and consumed energy. The intraday market supplements the day-ahead market by giving an opportunity, for instance, to fix the energy balance of the market actor.

In addition to the day-ahead and intraday markets, the electricity markets contain electricity reserve markets, which play a key role in stabilizing the system production and demand. Electricity reserve markets, in particular, are interesting from the perspective of CHP operators, because in some reserve market products the compensation is based on power, not on energy.

3.2.1. Day-ahead markets

The day-ahead market Elspot is the main wholesale market in the Nordic power market Nord Pool. The trade in the market closes on the previous day before the supply at 1:00 p.m. East European Time (EET). Nord Pool publishes the prices around 2:00 p.m. [16]–[17]. The day-ahead market is also the main market for the CHP operators.

Over the past few years, hourly Elspot prices have typically varied between 10 and 100 €/MWh,h, even though prices of single hours may have been lower or significantly higher. However, the statistics show that prices have been relatively low since 2011; this can be seen in Fig. 2. This is a challenge for the electricity producers, including the CHP operators, because a significant proportion of their income is based on electricity, the production cost of which can be close to the average market price or even less.

3.2.2. Intraday markets

The intraday market provides an option for the market parties to adjust their power balance if required. In Nord Pool, the intraday market is a continuous market, where the trading ends each day 1 h before the delivery [19]. The trade unit is similar (€/MWh,h) as in the day-ahead market. The difference between the day-ahead and intraday markets in Nord Pool is that when all the hourly trading in the day-ahead market gets the same price, in the intraday market all sales are independent and agreed with the sale parties. From the perspective of CHP operators, the intraday market provides an option to balance their production.