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New CHP partnerships offering balancing of fluctuating renewable electricity productions

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Abstract

Combined heat and power (CHP) as well as intermittent renewable energy sources (RES) are key elements in future cleaner electricity production systems. This article presents solutions which will integrate fluctuating renewable electricity supplies, such as wind power, into electricity systems using small and medium-sized combined heat and power plants (CHP). Such solutions call for a new organisational setup of partnerships and software tools. The software tools will allow the new partnerships to offer services which are currently only offered by big power plants to electricity markets. The article presents recent results of the development and implementation of such partnerships and focuses on the methodologies and computer tools necessary in order to allow the partnerships to optimise their behaviour on the market. The use of such tools and methodologies makes groups of small CHP plants able to replace large power stations and, at the same time, allows for the integration of a higher share of RES in the electricity supply, resulting in a decrease in both fossil fuels and CO2 emissions.

Keywords: Sustainable energy systems; CHP; Power system modelling; Renewable energy; District heating; Electricity markets; Energy management; Spot market; Regulating power market

1. Introduction

European Energy Policies have given priority to the problem of global warming. Both energy efficiency and the development of new and renewable energy technologies are considered key elements of the solution of this problem. Thus, the replacement of boilers and power stations with CHP units and the integration of an increased share of RES in the energy supply are solutions presented by the European Union. At present, the EU objectives are to increase the share of RES in electricity production from 14% to 22% and the share of CHP from 9% to 18% by year 2010. Small CHP plants play an important role in the achievement of such objectives and their potential has been investigated and discussed in several member countries [1–6].

The implementation of such policies results in an increased share of distributed generation. The generation shares of some areas and regions are likely to be much higher than the average share. The objective of increasing the average share of RES electricity production to 22% is distributed on the EU member states and this results in RES percentages between 6 and 78%. Meanwhile, large-scale integration of RES and distributed generation raises the problem of creating a balance between electricity demand and production. The EU targets for the deployment of CHP and renewable energy will only be achieved if this balance can be created in most, if not all, EU member states, and in the EU accession states. Furthermore, the distribution of renewable sources raises the problem of transmission capacities between different regions on the European electricity grid, which has to be addressed too. Also in this context, the balancing within regions is of significant importance [7–11].

If this integration of renewable electricity is not achieved, it will have a negative effect on the electricity trade across the borders of the EU member states. Proportions of renewable

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electricity rise and electricity inter-connectors with limited capacities are blocked up by the need to transport excess renewable electricity supplies. This is a problem which is already affecting Denmark and Germany, since large excess of wind power are often produced in Jutland and Schleswig Holstein.

2. CHP partnerships

CHP is a very efficient way of transforming fuels into energy services. A number of studies have investigated the methodologies of optimising different CHP technologies in relation to variations in the district heating demand and energy conservation of buildings [12–18]. Such studies have also included the development of models to optimise the use of heat storage capacities into the operation [19,20].

Compared to the conventional approach of producing heat and power in separate plants, CHP plants have the potential of decreasing fuel consumption by 20–30%, while producing exactly the same amount of electricity and heat. Meanwhile, such increase in efficiency can only be achieved when electricity and heat are produced simultaneously at the same location. Consequently, CHP has mainly been used in connection with district heating supply of large urban areas and typically in large steam turbines using fossil fuels. Small CHP plants offer the possibility of distributed generation and thus, give two obvious advantages. First, the CHP efficiency can be used also in small urban areas and industries. Secondly, local biomass resources can replace fossil fuels and ashes can be recycled without major transportation costs [21–23].

The Danish Energy Policy has succeeded in stabilising primary energy supply during a period of 30 years of economic growth. Small CHP plants and different types of renewable energy have been introduced and supported by the government [24–28], and one of the most important successes has been to decrease the fuel consumption for heating in households by 30% in the period from 1972 to 1996. During the same period of time, a 90% oil-based primary energy supply in 1972 has been replaced by a mixture of oil, coal, natural gas, and renewable energy [29].

The success can be explained by the combination of energy conservation mainly achieved by insulation, and the expansion of district heating based on CHP. Insulation of houses has resulted in a 12% decrease in the heat demand from 1972 to 1996, at the same time as heated areas have increased by 46%. In the same period, district heating was expanded by more than 50%, and in general, CHP plants have replaced boilers. Consequently, fuel consumption for heating per square metre decreased by 53% from 1972 to 1996. Approximately 40% of this decrease is caused by energy conservation, while the rest is due to the expansion of CHP.

Initially, CHP in Denmark was expanded in city areas, where power stations were already located. Secondly, during the 1990s, CHP plants were built in towns and even villages. Today, more than 50% of the electricity demand is produced on CHP plants, many of which are small CHP plants. The small Danish CHP plants are typically built in connection with district heating systems in towns and villages. The CHP plants contain one or more CHP units, peak load boilers and heat storage. The CHP units are either engines, gas turbines, or in some cases steam turbines or combined cycle plants.

The CHP plants already have considerable experience in optimising their electricity production against the triple tariff which has existed for almost 10 years. Consequently, the CHP plants know how to organise the production of the CHP units in order to optimise their profit [30]. Meanwhile, Denmark is in the process of replacing such pricing conditions by spot market prices. Consequently, new methodologies and tools for the optimisation of the daily operation of small CHP plants are needed. The new markets include regulating power which meets short-term imbalances and supplies ancillary markets concerned with improving frequency and voltage control. Meanwhile, bidding on the Regulating Power Market requires a minimum capacity of 10 MW. Since many small CHP plants are not able to meet the demanded minimum they need to enter into CHP partnerships in order to be able to benefit from the new opportunities. Moreover, small CHP plants may benefit from the involvement in public-private partnerships in order to finance long-term contracts and gain low interest loans for renewable energy generation [31].

3. Methodology of partnership bidding

When a CHP plant only sells electricity on the spot market, it does not need to join a partnership with other CHP plants. However, it does need tools for the optimisation of its daily operation. The biddings on the Nord Pool spot market for each hour of the following day must be given no later than at 12 a.m. the day before. Subsequently and no later than at 3 p.m., Nord Pool informs all bidders of the result. This means that from 3 p.m., the CHP plant has complete knowledge of how to organise its production until the end of the following day.

A simple example of the bidding strategy on the spot market is shown in Fig. 1. In this example, a CHP plant has only one CHP unit. The strategy is to make the CHP unit produce when the prices on the spot market are expected to be high and in similar manner, to stop the engine when the prices are expected to be low. The figure consists of three curves.

The upper curve shows the expected variations of the spot market electricity prices during one week, and it shows the bidding price at which electricity is offered on the spot market from this CHP unit. In this example, the bidding price on the spot market is equal to the price at which the CHP unit can produce heat at the boiler. The spot prices are expected to be high during daytime hours and low during night hours. The next curve shows the hours when the production from the CHP is planned to be offered. The bottom curve gives the expected content of thermal energy in the heat storage. The content increases when the engine is running and decreases when it is stopped. Thus, the storage is used to make it possible for the engine to produce in the best-paid periods.

When a CHP plant plans to increase its income on the regulating power market, it needs to establish a partnership with