Challenges in Integrating Wind and Solar Power in the EU Electricity Grid

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BIOGRAPHY - Henrik Lund is Professor of Energy Planning at Aalborg University and Editor-in-Chief of Elsevier International journal ENERGY. He was head of department from 1996 to 2002 and holds a PhD in Implementation of Sustainable Energy Systems (1990) and a Senior Doctoral degree in Choice Awareness and Renewable Energy Systems (2009). For more than 25 years, his area of expertise has been energy system analysis, energy planning and energy economics. The International Energy Foundation (IEF) gave him a gold medal for Best Research Paper Award within the area Energy Policies & Economics in 1998. In 2005-2007, he headed an international research project (www.project-desire.org) on the integration of wind and CHP and he is now the coordinator of a research project on 100% renewable energy systems involving most Danish universities (www.CEESA.dk). Moreover, HL is the architect behind the energy system analysis model EnergyPLAN (www.EnergyPLAN.eu).

ABSTRACT - The challenge of integrating wind and solar power in the EU electricity grid cannot be looked at as an isolated issue but should be seen as one out of various means and challenges of approaching sustainable energy systems in Europe. Therefore, the integration of wind and solar power must be coordinated with the utilisation of other kinds of renewable energy including biomass as well as energy conservation and efficiency improvements, such as CHP and improved efficiencies e.g. in the form of fuel cells. All such measures have the potential to replace fossil fuels or improve the fuel efficiency of the system. However, they also add to the electricity balancing problem and contribute to the excess electricity production. The point is that renewable power production should not be regarded as the only measure when conducting analyses of large-scale integration. The long-term relevant systems are those in which such measures are combined with energy conservation and system efficiency improvements. This paper emphasises the inclusion of flexible CHP production in the electricity balancing and grid stabilisation and highlights some recent developments in the Danish electricity market operation.

Keywords: *Large-scale integration of wind and solar, electricity market, flexible Combined Heat and Power production (CHP)*

1. INTRODUCTION

The challenge of integration of wind and solar power as well as similar fluctuating renewable energy depends strongly on the share of the input. The following three phases of implementing renewable energy technologies can be defined[1]:

The introduction phase: This phase represents a situation in which there is no or only a small share of renewable energy in the existing energy system. The phase is characterised by marginal proposals for the introduction of renewable energy: E.g. wind turbines integrated into a system without or with only a small share of wind power. The system will respond in the same way during all hours of the year and the technical influence of the integration on the system is easy to identify in terms of saved fuel on an annual basis.

The large-scale integration phase: This phase represents a situation in which there is already a major share of renewable energy in the system; e.g. when more wind turbines are added to a system which already has a high share of wind power. The phase is defined by the fact that further increases in renewable energy will have an influence on the system and this will vary from one hour to another, e.g. depending on whether a heat storage is full or not or whether the electricity demand is high or low during the given hour. The integration of wind and solar power in the system becomes complex and requires the inclusion of grid stabilisation.

The 100 per cent renewable energy phase: This phase represents a situation in which the energy system is or is being transformed into a system based 100 per cent on renewable energy. The system is characterised by the fact that new investments in renewable energy will have to be compared not to nuclear or fossil fuels but to other sorts of renewable energy system technologies, including conservation, efficiency improvements and storage and conversion technologies, e.g. wind turbines introduced to replace the need for biomass resources. The influence on the system is complex not only with regard to differences from one hour to another but also with regard to the identification of a suitable combination of changes in conversion and storage technologies.

On average the integration of wind and solar power in the EU electricity grid is in the first phase, i.e. the introduction phase. However, in general EU will soon go into the next phase and in many local areas this is already the case. Consequently, this paper addresses the challenge of large-scale integration of renewable energy sources into existing energy systems in which one must meet the challenge of coordinating fluctuating and intermittent renewable energy production with the rest of the energy system. Especially with regard to electricity production, meeting this challenge is essential since electricity systems depend on an exact balance between demand and supply at any time.

2. LARGE-SCALE INTEGRATION OF WIND AND SOLAR POWER

Given the nature of solar and wind power as well as wave and tidal power, only little can be gained by regulating the renewable source itself. Large hydropower producers make up an exception, since such units are typically well suited for electricity balancing. The possibilities of achieving a suitable integration are to be found within the surrounding system, i.e. the power and CHP stations which constitute the rest of the supply system. The regulation in supply may be facilitated by flexible demands, such as e.g. heat pumps, consumers' demand, and electric boilers. Moreover, the integration can be helped by the use of different energy storage technologies.

The issue has been analysed carefully in the book Renewable Energy Systems – the choice and modeling of 100% Renewable Solutions[1]. The book refers to and deduces the essence from a series of studies applied to the analysis of large-scale integration of renewable energy sources (RES) into the Danish energy system. At present, the Danish energy system already includes a relatively high share of renewable energy and is therefore suitable for the analysis of further large-scale integration.

Additionally, the book presents a method for comparing different energy systems in terms of their ability to integrate RES on a large scale. The question in focus is how to design energy systems with a high capability of utilising intermittent RES. The method addresses the comparison of different systems in terms of this capability, including the problem that the fluctuations and intermittence of e.g. wind power differ from one year to another. Such challenge is met by analysing and illustrating different energy systems in so-called excess electricity diagrams. In these diagrams, a curve represents the system in all years regardless of the fact that the fluctuations of RES differ from one year to another.

A number of studies of large-scale integration of RES are presented and, finally, some reflections and conclusions sum up the chapter with regard to the methodologies and principles as well as the technical measures involved. This leads to a series of recommendations concerning the most feasible technical measures; how to combine the measures, and when to use them considering the share of RES in the system. With regard to large-scale integration of renewable energy, the following general recommendations can be made:

The large-scale integration of renewable energy should be seen as a way of approaching renewable energy systems. The integration of RES must be coordinated with energy conservation and efficiency improvements, such as CHP and improved efficiencies e.g. in the form of fuel cells. All such measures improve the fuel efficiency of the system. However, they also add to the electricity balancing problem and contribute to the excess electricity production.

The point is that RES should not be regarded as the only measure when conducting analyses of large-scale integration. The long-term relevant systems are those in which such measures are combined with energy conservation and system efficiency improvements. In that respect, the Danish energy system with a high share of CHP can be regarded as a front runner and a system well suited for the analysis of large-scale integration of renewable energy. In such systems with a high share of CHP, excess electricity production can best be dealt with by giving priority to the following technologies:

1. The CHP stations should be operated in such a way that they produce less when the RES input is high and more when the RES input is low. When including heat storage capacity, such measures are likely to integrate fluctuating RES up to 10-20 per cent of the demand without losing fuel efficiency in the overall system. After this point, the system will begin to lose efficiency as heat production from CHP units is replaced by thermal or electric boilers.

2. Heat pumps and any additional heat storage capacity should be added to the CHP stations and operated in such a way that further RES can be efficiently integrated. Such measures will allow for the integration of up to 40 per cent of fluctuating RES into the electricity supply without losing overall system efficiency. The economic feasibility of the investments in heat pumps proves very high for Danish society. Moreover, the investment in wind power is substantially improved.

3. Electricity should be utilised in the transport sector, preferably in electric vehicles. Such measures will serve as an efficient improvement of the integration of fluctuating RES.

4. In general, it is not beneficial to include electricity storage capacity in the above-mentioned steps. Such storage capacity is both inefficient and expensive compared to the benefits which may be achieved. Moreover, the nature of fluctuating RES dictates the need for high capacities of both conversion units and storage capacities in combination with a low number of full load hours. Thus, the electricity storage technologies call for high investments in combination with low utilisation. If such technologies are to be competitive, they should provide further benefits such as saving power station capacity and/or involving security of grid stability.

5. It is not important to include flexible consumer demands in the regulation. The use of such measure raises the same problems as for electricity storage technologies. The nature of fluctuating RES calls for energy amounts of such extent to be relocated in a time span so long that a realistic flexible consumer demand would not be sufficient.

6. It is very important to involve the new flexible technologies such as CHP, heat pumps and the electrification of transport (batteries and electrolysers) in the grid stabilisation tasks, i.e. to secure and maintain voltage and frequency in the electricity supply. Such involvement becomes increasingly important along with an acceleration of the share of RES.

3. THE CASE OF FLEXIBLE OPERATION OF SKAGEN CHP PLANT

As described above, the integration of wind and solar power in EU electricity grids has to be seen in connection with parallel transformations of the European energy system including energy conservation and efficiency improvements such as expansion of CHP. Seen in this light, some of the most efficient ways of facilitating the large-scale integration of wind and solar power are to be found in the operation and regulation of CHP plants, which can be furthered by adding large-scale heat pumps and involving flexible CHP plants in the task of securing the stabilisation of the electric grid.

The case of flexible operation of Skagen CHP plant illustrates the significance of including distributed CHP and renewable power production units in the task of grid stabilisation, i.e. securing voltage and frequency stability of the electricity supply. Today, in most countries, electricity is produced either from hydro power or by large steam turbines on the basis of fossil fuels or nuclear power. Electricity from distributed generation constitutes only a small part of the production. Until now, the tasks of balancing supply and demand and securing frequency and voltage on the grid have been managed only by such large production units. However, the large-scale integration of wind and solar in EU electricity supply as well as the expansion of CHP is necessary to secure future renewable energy systems. Consequently, sooner or later such distributed production units need to contribute to the task of securing a balance between electricity production and consumer demands. The case of Skagen presents technical designs of potential future flexible energy systems which will be able to both balance production and demand and to fulfill voltage and frequency stability requirements to the grid and it illustrates how such operation has already been implemented in a few places in Denmark. The Skagen CHP plant is located in northern Jutland in Denmark as illustrated in Figure 1.

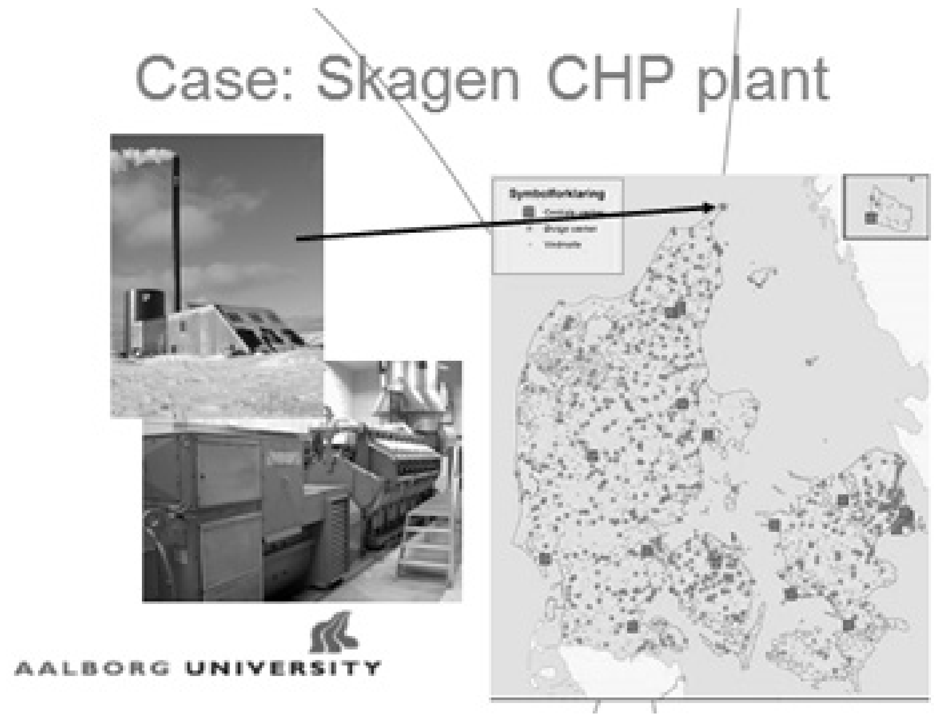

Figure 1: SKAGEN CHP plant located in the north of Denmark

Skagen CHP Plant has three gas engines, heat storage, a gas peak load boiler and an electric boiler as listed in Figure 2. Moreover, Skagen CHP plant has considered investing in a large-scale heat pump.

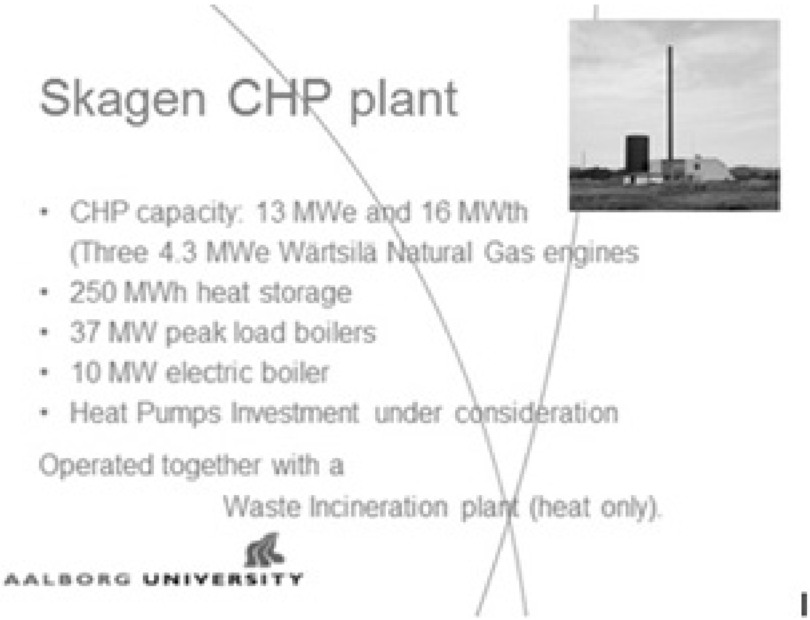

Figure 2: Technical specifications of Skagen CHP Plant.

The organisation of the Danish electricity markets - being part of the Nordic system – is shown in Figure 3. As shown, the market is divided into a day-ahead spot market and a number of regulating power markets. The specific organisation varies from one European system to another, but the principle shown in Figure 3 is typical for most countries.

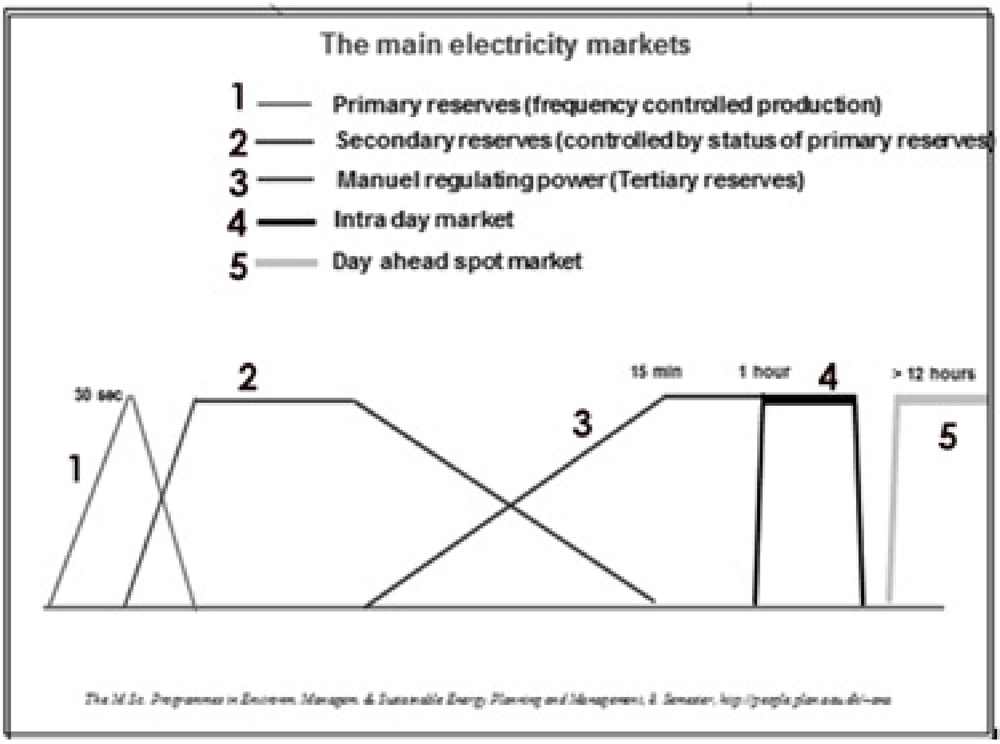

Figure 3: The main electricity markets (typical for many European systems)

Access to the different markets was made possible for a small CHP plant like the one in Skagen along the time line shown in Table 1.

Table 1: The opening dates of the different markets for small CHP plants in Denmark.

January 2005	Day ahead spot market
Approx. 2006	Regulating power market
November 2009	Automatic primary reserve market

Skagen has been operated at the day ahead spot market for several years and was one of the first small CHP plants to enter the regulating power market. Recently, Skagen also entered the automatic primary reserve market and has been operated at this market since November 2009.

The simultaneous operation of the plant at all these markets is done in the following sequence: Bets are given day-ahead on the spot market. Bets of electricity production from the CHP units are given on the basis of alternative costs of supplying heat from the gas boiler or the electric boiler. In the calculation of the bets, the heat storage option is carefully taken into account. How the bets are calculated is described in (Andersen and Lund)[2] and considerations on optimising the heat storage investment are described in (Lund and Andersen)[3]. The CHP units can be operated at the regulating power market in the following two ways: If operation at the spot market is won, a downward regulation can be offered while if the unit is not operated at the spot market, an upward regulation can be offered. The same (i.e. the reversed situation) applies for the electric boiler. Additionally, the CHP units can be operated at the automatic primary reserve market. This is done by offering the CHP plants to the spot market on a full capacity minus 10% offer.

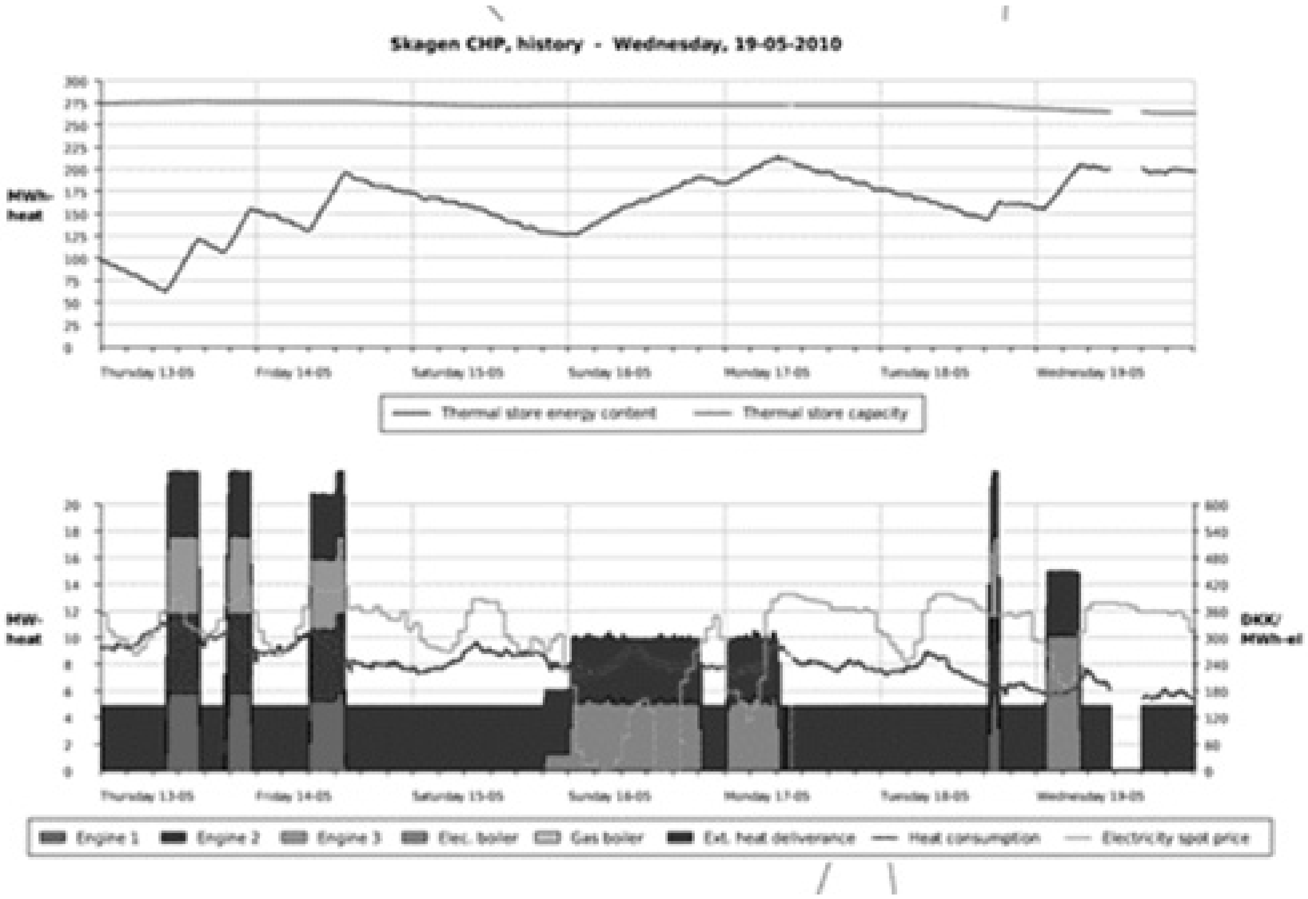

Figure 5: The operation of the Skagen CHP plant at the spot market, the regulating power market and the primary reserve market.

If the offer is won, the same unit can be offered for a plus minus 10% operation at the primary automatic reserve market. The same principle can be applied to the electric boiler. Figure 5 illustrates the operation of the plant in a day in May 2010.

Figure 5 shows that on Thursday May 13, the three CHP units were traded full load into the spot market during the well paid hours in the middle of the day and in the evening. On Friday May 14, the three CHP units were traded into the spot market during the well paid hours in the middle of the day - however not full load - the remaining capacity was traded into the primary reserve market. On Sunday May 16, the electric boiler was run half load - allowing it to be offered both as positive primary reserve (reducing consumption) and as negative primary reserve (increasing consumption). On Tuesday May 18, all three CHP units were activated at the regulating power market for an upward regulation. The following day, the 10 MW electric boiler was activated at the regulating power market for a downward regulation (the online operation of Skagen and the prices at the spot market and the balancing market can be seen at www.emd.dk/desire/Skagen).

The investment cost of making it possible for Skagen CHP plant to be involved in the primary reserve market has been surprisingly low. The cost of equipping the existing CHP units, i.e. making it possible to offer plus minus 1.4 MW has been only 27,000 EUR and the cost of the 10 MW electric boiler has been 0.7 million EUR.

4. CONCLUSION

The challenge of integrating wind and solar power in the EU electricity grid cannot be looked at as an isolated issue but should be seen as one out of various means and challenges of approaching sustainable energy systems in Europe. Therefore, the integration of wind and solar power must be coordinated with the utilisation of other kinds of renewable energy including biomass as well as energy conservation and efficiency improvements, such as CHP and improved efficiencies e.g. in the form of fuel cells.

Seen in this light, this analysis comes to the result that some of the most efficient ways of facilitating the large-scale integration of wind and solar power are to be found in the operation and regulation of CHP plants including involving them in the stabilisation of the electric grid.

The case of flexible operation of Skagen CHP plant illustrates the significance of including distributed CHP and renewable power production units in the task of grid stabilisation, i.e. securing voltage and frequency stability of the electricity supply. Today, in most countries, electricity is produced either from hydro power or by large steam turbines on the basis of fossil fuels or nuclear power. Electricity from distributed generation constitutes only a small part of the production. Until now, the tasks of balancing supply and demand and securing frequency and voltage on the grid have been managed only by such large production units. However, the opening of the spot market and later on both the regulating power market and the primary reserve market has made it possible for small distributed CHP plants to enter such markets. The case of Skagen CHP plant equipped with CHP units, heat storage and electric boilers illustrates how such small plants can provide valuable grid stabilisation at very low additional investment and operating costs.

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