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*international sales or hydrogen production*

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# Excess wind power; international sales or hydrogen production

Poul Alberg Østergaard

**Abstract**--Expansion of wind power is an important element in Danish climate change abatement policy. Starting from a high penetration of approx 20% however, momentary excess production will become an important issue in the future. Through energy systems analyses using the EnergyPLAN model and economic analyses it is analysed how excess productions are better utilised; through conversion into hydrogen of through expansion of export connections thereby enabling sales. The results demonstrate that particularly hydrogen production is unviable under current costs but transmission expansion could be profitable particularly if transmission and dispatch companies operate under a feed-in tariff system.

**Index Terms**-- cogeneration, hydrogen, electrochemical processes, power transmission, wind power generation

## I. INTRODUCTION

Electricity systems throughout the world are facing a number of challenges these years. Market liberalisation and ensuing organizational restructurings occur at the same time as climate change mitigation and environmental compliance are driving forces for expansion of the exploitation of renewable energy sources.

Denmark has for a long period of time had a very complex energy systems with many interdependencies and in spite of its modest size, ranks 4<sup>th</sup> globally in terms of installed wind power capacity as of January 1<sup>st</sup> 2004 [1] and 5<sup>th</sup> within OECD member countries in 1998 in terms of installed CHP (Cogeneration of heat and power) capacity [2]. In both areas, Denmark has by far the highest relative electricity production on these technologies making the Danish electricity system extraordinarily complex to operate due to the dependency on both wind velocities and on temperature levels. Fig. 1 demonstrates some of the issues relevant in Denmark in the current situation where the production share on centrally dispatchable power stations attain increasingly lower production shares.

With continuously lower production shares controllable by the central load dispatch, problems with excess productions and required stand-by reserve capacity will become graver.

Transmission grids are also impacted by both the opening of markets and the shift towards distributed generation technologies. On one side, trans-national electricity transfers are furthered by market places such as the Nordpool of the Nordic countries and the newer Leipzig Power Exchange for

Central Europe. On the other side does the exploitation of freely fluctuating energy resources such as wind power also stress transmission systems as wind parks often are located in areas with relatively weak grids and as long-distance transmission is relied upon for power balancing from a merely technical perspective.

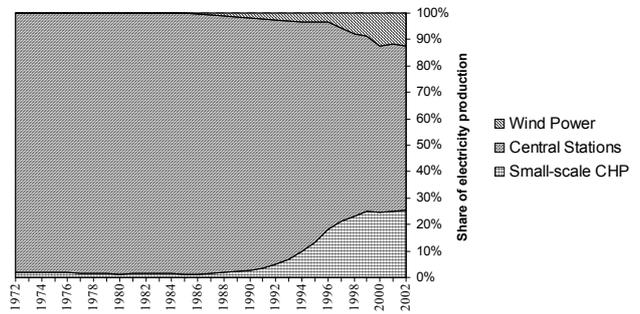


Fig. 1. Electricity production in Denmark. Source: [3] with data from [4].

Integration and transmission of particularly wind power is therefore also very important issues in research communities particularly in countries with high wind penetrations as Germany (see e.g. [5]) and Denmark (see e.g. [3], [6] & [7]). With exploitation of wind power growing in most countries and with potentially costly grid expansions as consequences, needs for alternatives are required and grid expansions must definitely be weighed economically in a cost benefit analysis.

One means of integrating wind power is by means of producing hydrogen for vehicles which has the added benefit of enabling the use of renewable energy sources for transportation. Transportation accounted for 157 PJ of a total Danish final demand of 635 PJ or approximately 25% in 2003 [4] of which no renewable source was significant enough to even enter the statistics. Hydrogen can thus play a role in lowering carbon dioxide emissions from transportation; an area hitherto neglected in Danish CO<sub>2</sub> abatement policies and in abatement policies of most other Kyoto-protocol signing nations.

## II. SCOPE OF THE ARTICLE

The article focuses on Western Denmark which has the highest wind penetration of Denmark. This area is electrically separated from Eastern Denmark but connected to Germany through AC lines and Norway and Sweden through HVDC lines. With a high penetration of wind power in Northern Germany, export in this direction is not always possible whereas export towards the Scandinavian Peninsula is more feasible.

The scope of this article is to compare the two options for using excess wind power; a) expanding transmission lines – particularly international connections – to the extent that excess productions may be sold on the Nordpool power market in Scandinavia or b) producing hydrogen using electrolytic converters or reversible fuel cells for use in individual means of transportation.

Both the alternatives will serve the same purpose i.e. help integrate a fluctuating electricity source, but outcomes are different as one will replace fossil fuels for transportation while the other rather will play against Scandinavian hydroelectric power systems thus ultimately saving fossil

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fuels for power generation. Such secondary impacts are not included in these analyses; they would require a more holistic view on the energy system.

It is analysed how much electricity from wind power may not be utilized in the energy system at high penetrations and thus constitutes a potential that may or may not be utilized depending on the economy of the alternative utilizations. The degree to which this potential is utilised depends on the installed capacities of added transmission capacity or electrolytic converters. These capacities however depend solely on economic viabilities.

The analyses are conducted at high penetrations of wind power in Western Denmark ranging from 60 to 100% of the annual demand.

### III. SCENARIO ANALYSES

The scenario analyses take their point of departure in scenario analyses from the Danish Energy Agency [8]. This scenario details a year 2020 situation with the anticipated energy demands and installed production capacities in Western Denmark. The system parameters are listed in table 1. The capacity of central stations in condensing mode operation is merely included in sufficient quantity to cover any required demand. In reality, minimizing this would of course be of importance to minimize cost of reserve capacity in high wind energy systems. This is not addressed in this article though.

TABLE 1  
Energy system scenario parameters. Heat pumps are only used in one power balancing strategy

Consumption [TWh]	Generating capacity [MW]	
24.87 Electricity	2750	Cogeneration of heat and power (CHP)
20.00 District heat	5000	Central stations – Condensing operation
	2500	On-shore wind
	2100	Minimum off-shore wind
	4455	Maximum off-shore wind
	350	Heat pumps

The demands are modelled for using hourly distribution data for both electricity demand and heat demand. The electricity demand has an immediate impact on the power balance whereas the district heating demand has a derived impact as it is produced on CHP plants producing heat and electricity in conjunction. The hourly annual distributions are from a constructed year based on empirical data.

The installed wind power capacities correspond to production ranging from 60% to 100% of demand in Western Denmark. These percentages, however, assume all electricity is utilized and no turbines' productions actively decreased to avoid excess generation.

The wind turbine stock is split on inland turbines as well as off-shore turbines. The inland stock is kept constant due to constraints on new locations whereas off-shore is less constrained in terms of potential sitings, so expansions are modelled off-shore. Inland and off-shore turbines are modelled group-wise with hourly production distributions for one year. The distributions stem from a factual distribution from an average year with higher generation off-shore than on inland locations.

Typically, when operating a complex system with substantial non-controllable fluctuating power sources such as

wind power, an excess regulation strategy must be applied. In the Danish case, this is for instances when the combined production on wind turbines, CHP plants and condensation plants exceeds the demand plus export capacity. One possible strategy is to actively make changes in the energy system through e.g. the following sequence of steps: 1: Shift from CHP to boilers and 2: Shift from CHP to electric heaters. Both of these steps reduce heat-tied electricity production on CHP plants thereby reducing excess generation and both are applied in the modellings here.

Next step in the sequence applied here splits in two for the two cases analysed: Either still existing excess is a) used in electrolytic converters or b) international connections are strengthened to take the added export.

Economically, the two options for removing excess power generation are:

- HVDC cables to Norway and Sweden at 2.25 million DKK / MW or 0.11 million DKK/MW annually based on a price of 1350 million DKK for one 600 MW connection [3] The international lines are modelled with a continuous expansion
- Electrolytic converters at 10 MDKK/MW or 0.51 MDKK/MW annually [3]

In both cases, annual values are calculated with a discount factor of 3% over 30 years.

Not included in the grid expansion is domestic expansions estimated at no less than 10% of the HVDC costs adding to a total of 0.13 million DKK per MW annually. This is based on scenario modellings carried out in connection with the Mosaic Project [3].

The energy system is modelled using the EnergyPlan model [9] which was developed for making scenario analyses of energy systems with high penetrations of renewable energy sources with focus on balancing production and demand. With a good description of the temporal characteristics of power sources and demands and the requirements for system stability, it is a model well suited for these analyses. The models also assures the supply of adequate ancillary services by matching stipulated demands with the characteristics of the different production technologies.

### IV. RESULTS OF THE SCENARIO ANALYSES

With increasing wind production in Western Denmark, there comes a point around 20% wind share (5 TWh wind power) where the electricity system cannot accommodate more wind power and excess situations occur. This is demonstrated in Fig. 2. The different steps taken to reduce excess generation in the modelling are also shown indicating how shifts from CHP to boilers and on to electric heating is applied to reduce imbalances between demand and production.

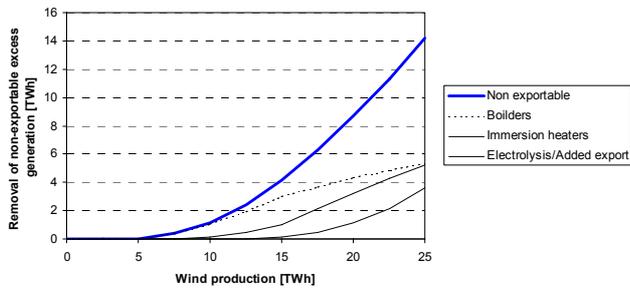


Fig. 2. Non-exportable excess power generation as a function of wind production corresponding to 0 to 100%.

One observation must be made at this point which is that the figure is based on aggregate annual data. Data for shorter periods' of time – months – weeks – hours – may show a more momentous use of excess reducing measures just as Fig. 1 would show a much more narrow free range certain periods of the year.

The non-removable excess generation which need export or conversion into hydrogen only becomes relevant at even higher penetrations; mainly above 60% wind penetration (15 TWh) as indicated also in Fig. 2.

The amount of electricity that may be exported or used for hydrogen production purposes annually depend on the installed capacity of the device – electrolytic converter or transmission lines – installed to pick up the excess. This is demonstrated in Fig. 3. The higher the penetration of wind power, the higher the required capacity to exploit the wind resource fully.

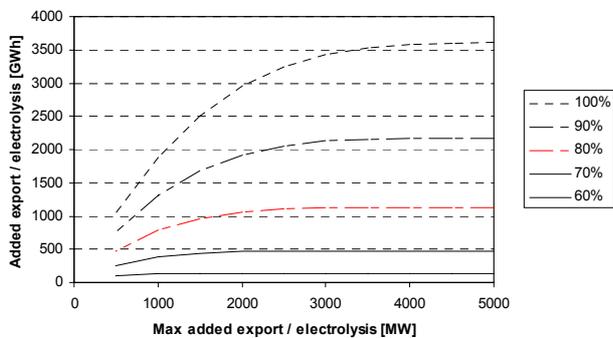


Fig. 3. Added export or electrolysis production as a function of the maximum required capacity and annual wind penetration shares.

It is naturally also clear from Fig. 3 that the higher the level of wind penetration, the later the curve attains its maximum level. The share of the excess production to be harnessed by electrolytic converters or exported through added transmission capacity is thus a matter of economic optimisation.

Applying the costs of added transmission capacity domestically and internationally to Sweden and Norway listed previously and calculating the cost per kWh added electricity export gives the results in Fig. 4. Also included is a line indicating an average level on the Nordpool power exchange. For curve segments higher than this indicative Nordpool price level, it would be economically feasible to invest in the transmission capacity. It should be noted that there is not a strong correlation between wind power excesses and the Nordpool spot-market price though this might become the case at higher wind penetrations.

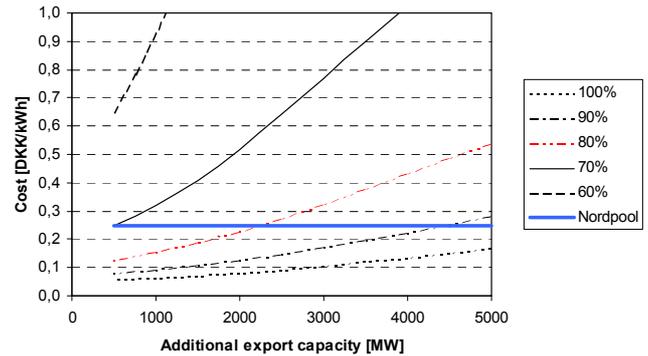


Fig. 4. Cost of electricity delivered abroad

Not included in the cost are other elements such as tariffs to electricity producers. It would thus not necessarily be economically attractive for the transmission and dispatch company to purchase power to export. However, in countries with an obligation to pick up productions from renewable energy sources regardless of momentary power needs at a fixed rate (feed-in tariffs), it will be economically attractive to have the added export capacity.

For the highest penetrations it would under these circumstances be economically feasible to have very strong international connections. At more modest wind power penetrations – if 60% can be labelled such – however, it would not be economically attractive expanding the export capacity at the modelled Nordpool price level. Even at 60%, prices need be unrealistically 0.68 DKK/kWh before the line is economically feasible. Lines would thus not be feasible from a purely economic perspective.

Alternatively, excess may be converted into hydrogen. Rather than stating the kWh price, the cost has been converted to DKK per litre petrol and compared to a retail price of 9 DKK per litre petrol. Even compared to this price inflated with taxes, only few of the scenarios show any economic viability as indicated in Fig. 5.

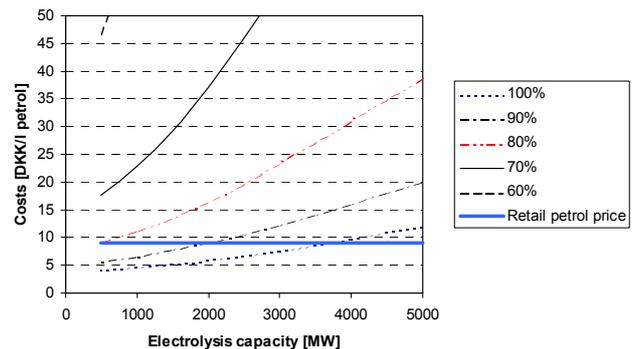


Fig. 5. Production cost of hydrogen given as DKK/l ordinary petrol.

As with transmission lines however, this price does not even leave space to cover production costs through the tariff.

In general, only the combination of high wind penetrations and low installed capacity on either transmission capacity or hydrogen producing facilities give sufficiently high annual operating hours for it to give reasonably modest costs. Fig. 6 shows the annual operating hours

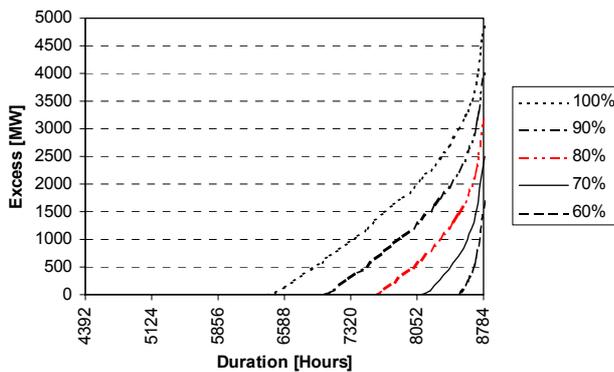


Fig. 6. Duration curves for added transmission capacity and electrolytic converters.

It is clear, that regardless of excess reducing measure there will be a limited number of annual full-load hours thereby giving the poor economic performance.

## V. CONCLUSIONS

In countries pursuing carbon dioxide emission reduction goals through the exploitation of fluctuating energy sources, two issues are pertinent. Reserve capacity minimisation for low power situation and excess power regulation strategies for surplus situations. This article has analysed two options for excess power regulation strategies that are both additional to also implemented measures lowering CHP production. The two – added transmission capacity to Norway/Sweden and hydrogen production are not favourable under current economic settings. Using excess for hydrogen production is prohibitively expensive at current technology costs. The situation may change if more emphasis is put on shifting fuel supply for individual means of transportation.

Export however may be attractive particularly if power generation from wind turbines has to be picked up by the transmission and dispatch company regardless of momentary system needs. Potential incomes will not be sufficient to cover tariffs for producers however.

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## VI. BIOGRAPHY



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