Dissemination strategy on Electricity balancing

DESIRE

large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

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Brief abstract / description of dissemination activity	Cogeneration of heat & power and cogeneration of desalinated water and power have similarities from an energy systems perspective. Both introduce limitations in the freedom of action but also introduce possibilities for integrating fluctuating renewable energy sources. Through energy systems analyses, it was demonstrated how storage tanks desalinated water could introduce a buffer corresponding to heat storages for optimising performance of energy systems with respect to integrating fluctuating energy sources.
Audience impact assessment	POWERGEN Middle East is the largest series of power conferences and trade shows in the Middle East with a high attendance. The idea that CPH plants can be used to integrate fluctuating power sources is a novel idea in the Middle East and did generated some interest in the audience causing feed back after the conference session
Dissemination	Included after this form

Renewable energy as a means for climate change mitigation in interconnected transmission grids

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Abstract

Due to readily available and largely inexpensive oil resources, the exploitation of renewable energy resources in the Middle East is largely confined to some solar thermal exploits and 108 MW of wind power mainly in Egypt. Meanwhile electricity consumptions are increasing in the region while at the same time, on the global political agenda, climate change mitigation is gaining momentum particularly after the EU environmental ministers in March 2005 agreed on setting stronger carbon dioxide emission reduction targets.

At modest penetration wind power merely substitutes electricity generated typically at thermal power plants and thereby only giving economic benefits comparable to the saved marginal fuel and O&M costs. At higher penetrations, it becomes increasingly important for the energy system to be able to operate without costly reserve capacity awaiting fluctuations in demand or wind power generation that need be countered.

The Middle East is not generally bestowed with good wind energy resources, however some areas have reasonable resources and future prospects of photo-voltaic cell-based electricity

generation are favourable. Furthermore, transmission grids are only in the process of becoming interconnected in the region. This interconnection is mainly in order to assist in reducing reserve capacity in the existing thermal power generation systems. While indeed relevant in thermal systems, however, this is typically even more so in renewable energy based systems, where fluctuations to a large extent are uncontrollable making interconnected systems prerequisites for proper integration of electricity produced on such energy sources.

Using a European example this article demonstrates how different demand and production patterns in different geographical areas assist in evening out fluctuations and imbalances between demands and productions in systems with high penetrations of renewable energy thereby reducing needs for reserve capacity. Prospects that will also be relevant for the Middle East with interconnected power grids if renewables are to play a large role in this region.

Introduction

The transition from fossil fuel-based power generation to power generation based on fluctuating energy sources such as wind, sun, and wave power introduces challenging demands on the operation of electricity systems. Even without such constraints, other constraints in the form of cogeneration of power and heat, the cogeneration of power and cooling or the cogeneration of power and desalinated water impose problems on the system's load-following capability. Development in the way electricity is being consumed adds another dimension to the issue. Traditional electric engines decrease their power up-take if generators are overloaded thus causing the frequency to drop and thereby relieving the generators of some load. With many electric engines operated through frequency-converters, loads are not relieved but rather kept constant.

The Middle East is only exploiting renewable energy resources to a very modest degree, so any possible problems in load-balancing in the current situation are mainly attributable to the other factors listed. Adding simplicity but thereby also disusing potentials for load balancing is the lack of a transmission grid between Middle Eastern countries or even a lack inside the individual countries.

With the ongoing interconnection project, (The Gulf Electricity Interconnection Grid), a shift has been set in motion regarding changing the electricity from being national or even local affairs to being a regional affair, the latter factor is under change. Through the Gulf Electricity Interconnection Grid, the members of the Cooperation Council for the Arab States of the Gulf will eventually connect to the Mediterranean Middle East and Europe through Turkey as well as through the Arab-Maghreb line to North Africa and Spain. Though such distances are beyond what is readily technically feasible in terms of power exchange it does emphasize the interconnection trend of the larger area.

While the Gulf Electricity Interconnection Grid primarily is in order to reduce reserve capacity requirements as discussed by e.g. Bowen et al. (2002) and illustrated by the interconnection costs being distributed proportional to the individual countries reserve capacity savings, it will also have a positive effect on the exploitation of renewable energy sources. Apart from most notably electricity production based on solid renewable fuels and hydropower, most renewable energy sources are characterised by intermittent natures and therefore an inherent need of either reserve capacity or other means of dealing with the fluctuations. In general, the smaller the system, the fewer the plants, the smaller the variation in energy sources and the smaller the geographic extension of the area in question, the larger the need for reserve capacity.

In line with the European Union’s adoption of a stringent Kyoto-derived carbon dioxide emission reduction target, Denmark has pursued an ambitious energy policy. This has resulted in a complex energy system with many sources of energy being tapped and many interdependencies between sources, demands and conversion systems. In addition, however, Western Denmark has 1200 MW AC capacity to Germany, 1100 MW HVDC capacity to Norway and 700 MW HVDC capacity to Sweden while Eastern Denmark has a total capacity of 1900 MW to Sweden and 600 MW to Germany. Though not mutually connected (see figure 1), the two non-synchronised areas of Denmark thus each have strong ties abroad aiding in power balancing and reducing needs for reserve capacity. The Western Danish connection are summarized in table 1.

Country	Capacity	Type of connection
Germany	1200 MW	Multiple AC lines (400, 220 & 150 kV)
Sweden	600 MW	Underwater HVDC line
Norway	1100 MW	Underwater HVDC line

Table 1: Summary of foreign electric connections from Western Denmark.

Figure 1: The 400 kV transmission grid in Denmark and connections abroad. Western Denmark is AC connected to Germany while Eastern Denmark is AC connected to Sweden and the two areas are not synchronized.

In addition to the issue of mere generating capacity, an added issue is that of ancillary services which is getting increasing attention within utilities and the research community addressing the integration of fluctuating electricity sources. This is increasingly important as these have traditionally been supplied by the large power plants and with stronger reliance on distributed generation technologies or international connections, the systems must maintain resilience against grid disturbances without resorting to the ancillary service providers of the past.

Scope of article

The scope of this article is to analyse how much back-up capacity is required in the Western Danish electricity system in the balancing of this system. The analyses are made under different assumptions regarding the supply of ancillary services, under different assumptions regarding the variation curves of supply and demand as a consequence of areas being interconnected or not and under different assumptions of developments in installed wind power capacity; wind power being he most notable fluctuating power source in Denmark.

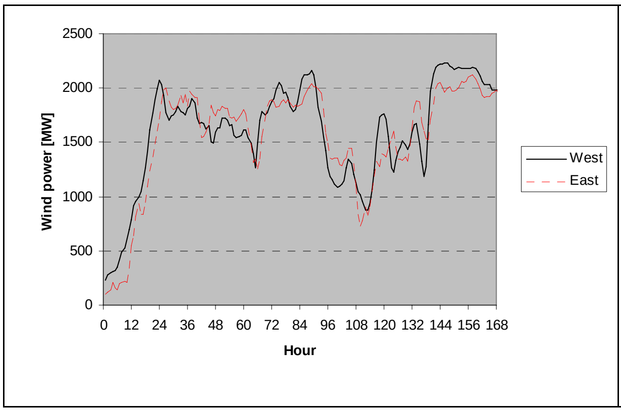
Time variations of demands and productions

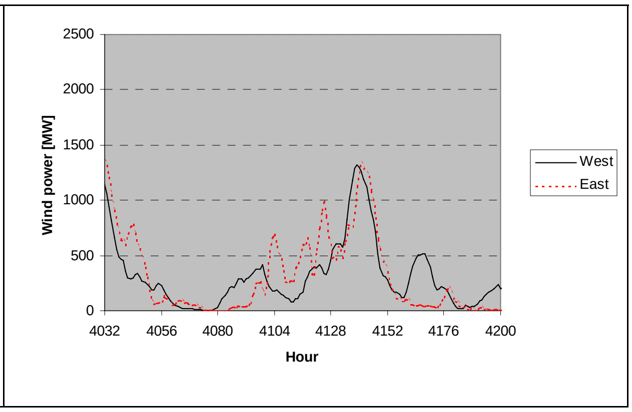
Both production and consumption varies in a diurnal cycle, a weekly cycle and a seasonal cycle. The diurnal cycle of the demand is due to the timing of meal preparation, industrial activity, need for illumination etc. The weekly demand cycle due to the reduced needs of weekend-closed companies, institutions and organisations and the seasonal demand cycle due to changing needs for illumination, heating and cooling.

The production system has to follow the demand variations, so the production should equal the demand curve neglecting international trade. In addition however, in systems exploiting renewable energy sources or cogeneration of heat or cooling and power (CHCP), additional time variations are introduced. The CHCP plant will have a production which is determined by temperature variations which vary in a daily and a seasonal cycle as well as with a stochastic element. The same applies to photo voltaic-based electricity generation where the altitude of the sun varies with the yearly cycle on top of which comes local climatic conditions influencing cloud coverage. The last to be mentioned here is wind power, which probably has the widest addressed fluctuations in power output of any generating technology. Depending on geographical setting, wind power may have a diurnal variation with a tendency of lower production at night than during the day as is the case in Denmark and a seasonal variation with generally higher wind velocities during the winter at the same time as the density of the air is higher thus adding to the power.

All these are factors contributing to the difficulty of designing energy systems with load following capabilities. One factor works against these fluctuations of which some are long-term foreseeable, some are short-term foreseeable and some are not foreseeable: geographic distribution of the production and the demand.

In figures 2 and 3 for instance, hourly wind power inputs for the two non-connected areas of Denmark are shown for a winter and a summer week respectively.

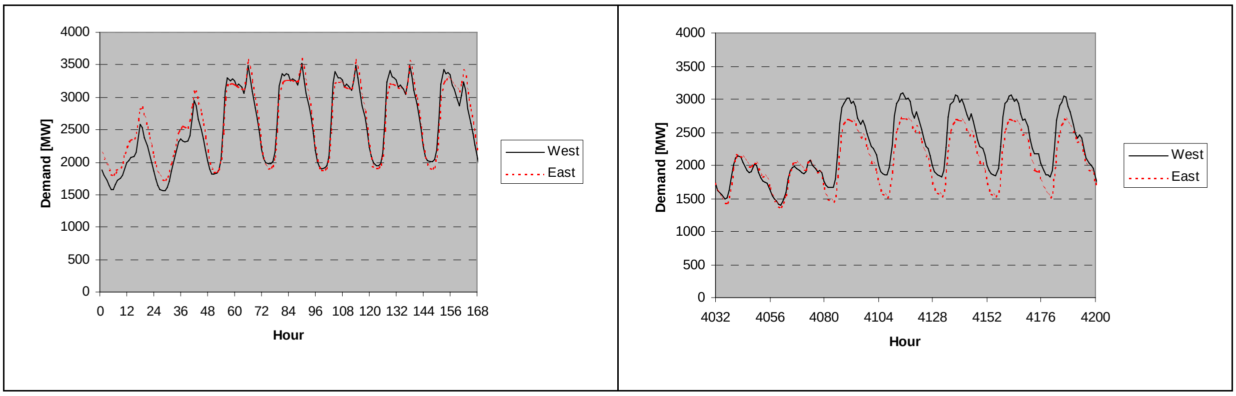




Figures 2 & 3: Wind power generation in Eastern and Western Denmark a winter and a summer week in 2005 respectively. Values for Eastern Denmark have been scaled so the half-year average matches that of Western Denmark. Sources: Eltra (2005) and Elkraft System (2005).

The two individual areas variations are higher than for the two areas combined. For the entire year 2004 for instance, wind input in Western Denmark averaged 555 MW and in Eastern Denmark 195 MW. The average deviation from these averages were 411 and 148 MW respectively indicating the fluctuating nature of wind power. Scaling Eastern Denmark to the Western Danish average the 148 MW would correspond to 411 MW. However, adjoining the two areas and again scaling to the Western Danish average, the average deviation would fall to 400 MW. This is of course not sufficient to render a flat production curve but is does demonstrate how enclosing a larger geographic area adds stability to the production. Particularly when taking into account the relatively modest size of Denmark and the derived situation that the country is usually subjected to the same depressions and high pressures.

Demands in the two parts of Denmark are relatively similar though with a tendency of a lower demand in the Eastern part during the summer as indicated in figures 4 and 5. In order to gain an improved – i.e. more even – diurnal demand curve, larger geographic areas would need be covered. Areas encompassing areas or countries with diverse industrial bases with different mixtures of primary, secondary and tertiary economic sectors would even out demand peaks caused by large single users or clusters of similar and often partly synchronized industries. If it is habitual that certain types of industries work the same shifts in a country, then this aggravates the peaks. Covering more time zones in a demand area will also generate a natural alleviation of larges power surges.



Figures 4 & 5: Electricity demand in Eastern and Western Denmark a winter and a summer week in 2005 respectively. Values for Eastern Denmark have been scaled so the half-year average matches that of Western Denmark. Sources: Eltra (2005) and Elkraft System (2005).

This is of course from an overall system perspective. Technical, economic or organizational bottlenecks may influence the extent to which the effects of geographic dispersion may be utilised.

Energy system scenario

The analyses in this article take their point of departure in an energy system scenario for the year 2020 used in analyses by the Danish Energy Authority (DEA (2001a+b)). Demands are thus the expected with a continuation of present trends and policies. The amount of on-shore and off-shore wind corresponds to the present level although particularly off-shore wind is expected to increase in the future. Going even beyond the current level of approximately 20% wind share in Western Denmark, however would limit the extent to which the analyses and results would be relevant and valid in other countries.

Thermal power plants are modelled as two types; CHP plants supplying electricity to the grid as well as heat to district heating areas and plants operating in condensing mode i.e. only with electricity generation. These latter are merely modelled present in adequate quantities.

Finally, a certain degree of heat humps are include to assist integration of the fluctuating wind resource.

Consumption [TWh]	Generating capacity [MW]	
24.87 Electricity	2750	Cogeneration of heat and power (CHP)
20.00 District heat	5000	Central stations – Condensing operation
	2400	Wind (inland and off-shore)
	350	Heat pumps

Table 1: Energy system scenario parameters.

The core point of the analyses is of course to model the impact of adjoining areas and benefiting from the equalization of diurnal, weekly and seasonal variation curves. However due to a lack of available data, this is limited to the two areas of Denmark that are well-described in terms of publicly available data. As noted regarding figures 4 and 5 however, demand variations are not so large, so mainly the impact of the wind variations are modelled here. This is done by comparing the energy system response to

A) applying the actual wind generation of a year on an hourly basis with
B) applying an artificial wind generation of a year on an hourly basis averaging the actual data from the two areas where the smaller Eastern Area is weighed to match the Western level.

In one analysis, however, demand is modelled applying an artificial demand curve averaging the actual demand curve and the same curve shifted six hours as an indication of the response of the system to a drastic geographic equalisation.

The main analyses are furthermore conducted with two different regulation strategies in which the local CHP plants are operated 1) according to a heat demand and 2) to best help keep overall electricity load balance while also furnishing the required heat.

In order to model the response of systems without the Danish heat-tied production and thus in order to obtain results valid for other climates, the system is then modelled in a situation with and in a situation without the CHP-tied heat demand that is applicable mainly in temperate and cold climates.

Finally, the system is modelled with higher quantities of wind power correspond to levels twice and three times the present level.

The energy system is modelled using the EnergyPLAN model developed by Henrik Lund (Lund et al (2004)) which is a model designed to make analyses of energy systems with high degrees of fluctuating power and heat sources and many interdependencies of the energy systems. The parameter used for assessing the energy system performance is the required level of electricity generation in condensing mode operation as this has the lowest overall thermodynamic efficiency and therefore should be avoided. These are the back-up plants and is the load than can be relieved through interconnection.

Results of energy systems analyses

Modelling the energy system reveals that average production on condensation based power plants is decreasing slightly using the artificial wind distribution compared to using the actual wind distribution. This applies to Regulation Strategy 1 and 2 as well as for the situation without any heat demand and CHP generation as indicated in figure 6. In fact, however, as it also evident from the results in figure 6, differences are small and change over the year.

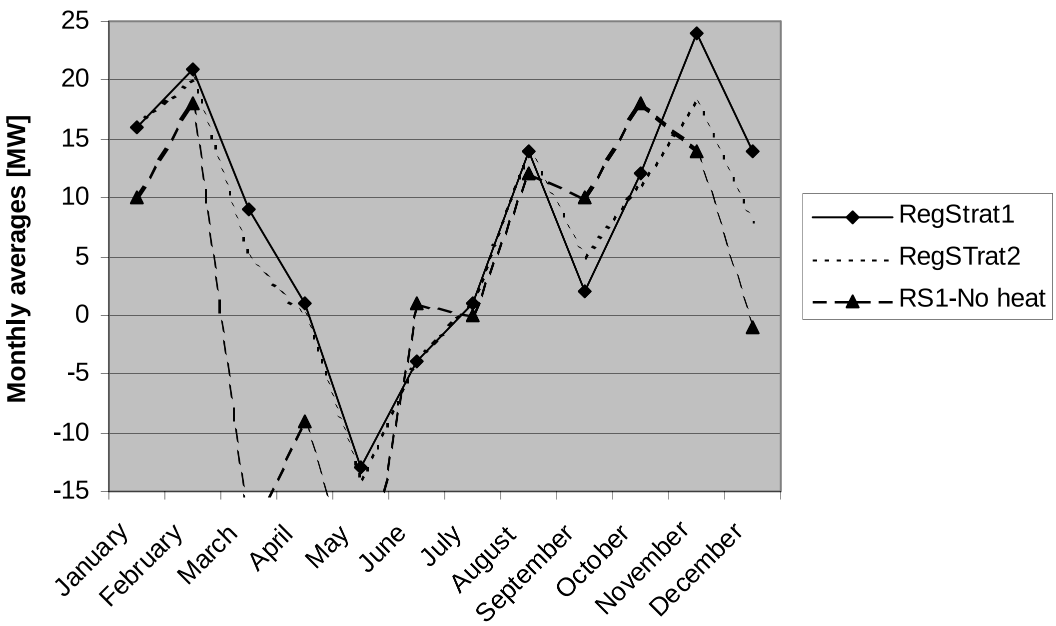


Figure 6: Change in average monthly condensation-based power generation with the artificial yearly wind distribution curve with Regulation Strategies 1 and 2 and in a situation without any heat demand covered by CHP. Positive values indicate reduced condensation-

based power generation compared to the reference scenario with the actual wind distribution.

In some cases - times with negative values in the graphs - the actual wind distribution curve proves better than artificial and equalized wind distribution curve. For the entire year, average condensation-based power generation does nottheless decrease by 7-8 MW by adopting the more levelled wind power distribution curve. Although limited, it does indicate prospects particularly taking into consideration that the marginal electricity production typically is at older and less fuel-efficient plants.

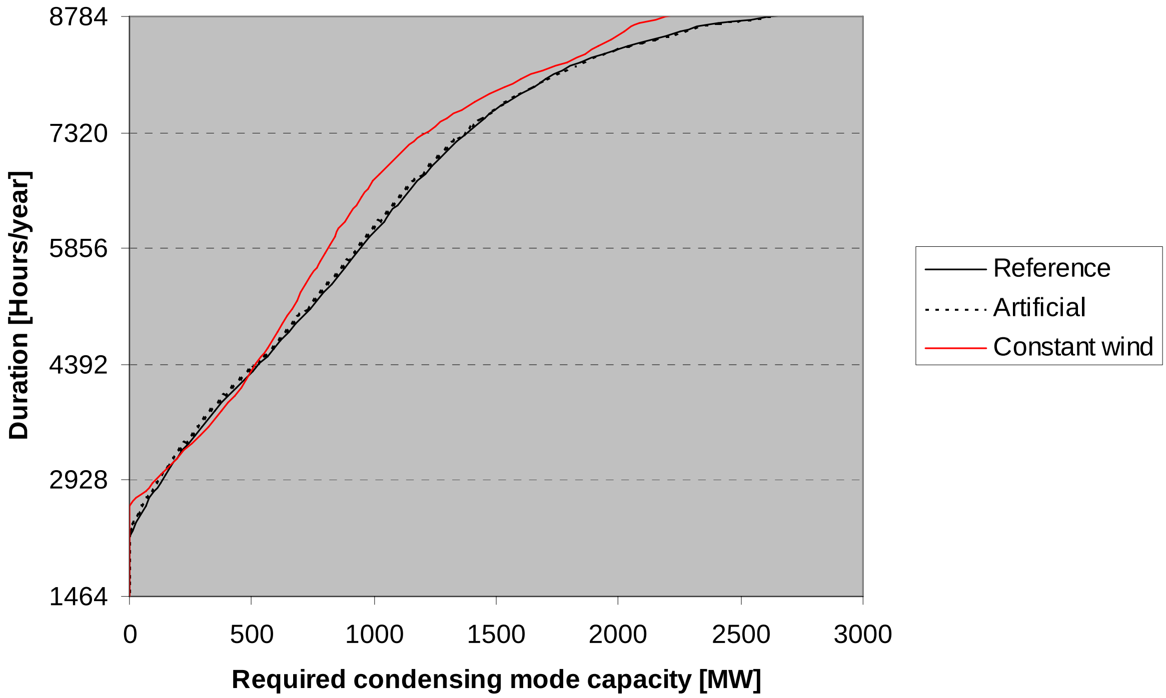


Figure 7: Duration curve for the reference system and for system with artificial annual variation curve for wind power and a system with constant wind power of 550 MW throughout the year.

Showing the results in the form of a duration curve for condensation-based power generation as in figure 7 demonstrates the same marginal shift to the left from applying the constructed wind distribution curve for a larger geographic area. It also shows the duration curve in case wind power gave a fixed input corresponding to evening out wind variation over a very large area. Even in this case, condensation-based power generation would increase at points as was also evident from figure 6. The reason of course being that with stochastic wind power, wind variations will follow demand at times.

Without heat demand tying CHP production and thus electricity generation, condensing mode electricity generation naturally increases as shown in figure 8, and with the levelled variation curve of wind power applied, demands are marginally lower

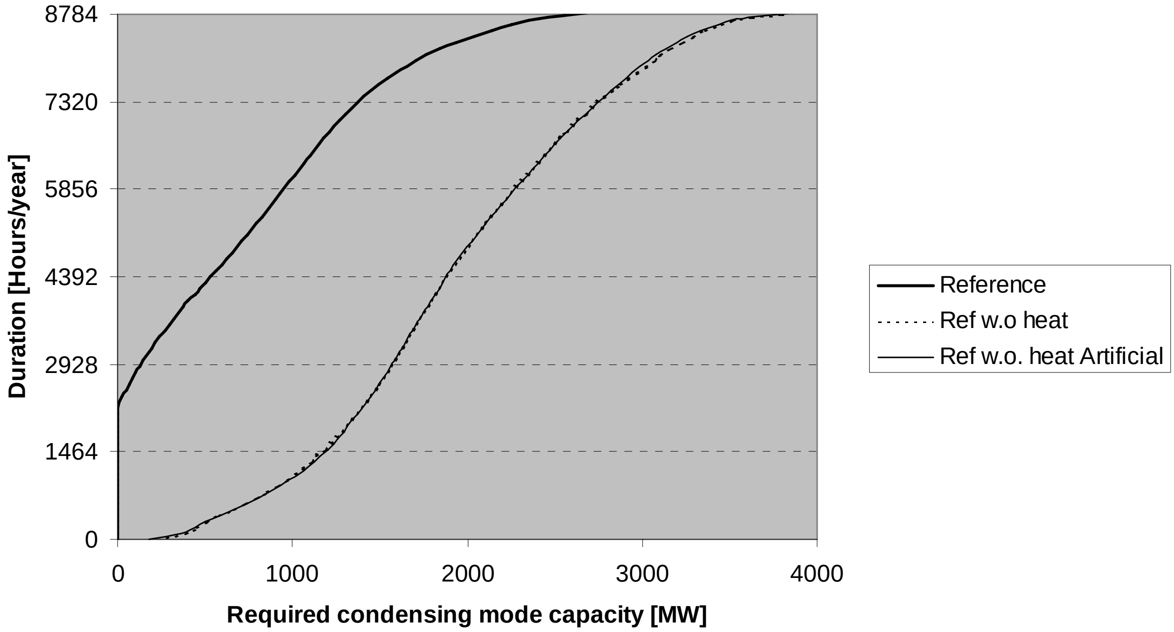


Figure 8: Duration curve for the reference system and for system without heat demand and thus heat-tied CHP generation with 2004 annual wind variation curve and artificial annual variation curve for wind power.

These results are natural as wind power at its present level of approximately 20% of the demand only constitute a modest share. Not in terms of share relative to the shares of wind power based generation in other countries but modest compared to the thermal generation either being in the form of power plants operating in condensing mode to supply solely electricity or CHP plants supplying both heat and electricity to consumers.

Assuming a higher penetration of wind power, results with the actual wind distribution and with the constructed artificial wind distribution diverge more as illustrated in figure 9 showing results for the energy system assuming double and triple the amount of wind power presently available. Here applying the more level wind distribution curve reduces correspondingly higher shares of electricity generation in condensing mode operation.

One apparent element in figure 9 deserving a comment is the fact that high wind (as illustrated by the triple curve) may require a higher level of electricity in condensing mode operation. This is due the present circumstance that wind turbines do no actively assist in maintaining grid stability – i.e. frequency stability, voltage stability and in supplying adequate short-circuit power available. At high levels of instantaneous wind production, thermal power plants – CHP plants or condensing mode plants need to generate a correspondingly higher output to supply the required ancillary services.

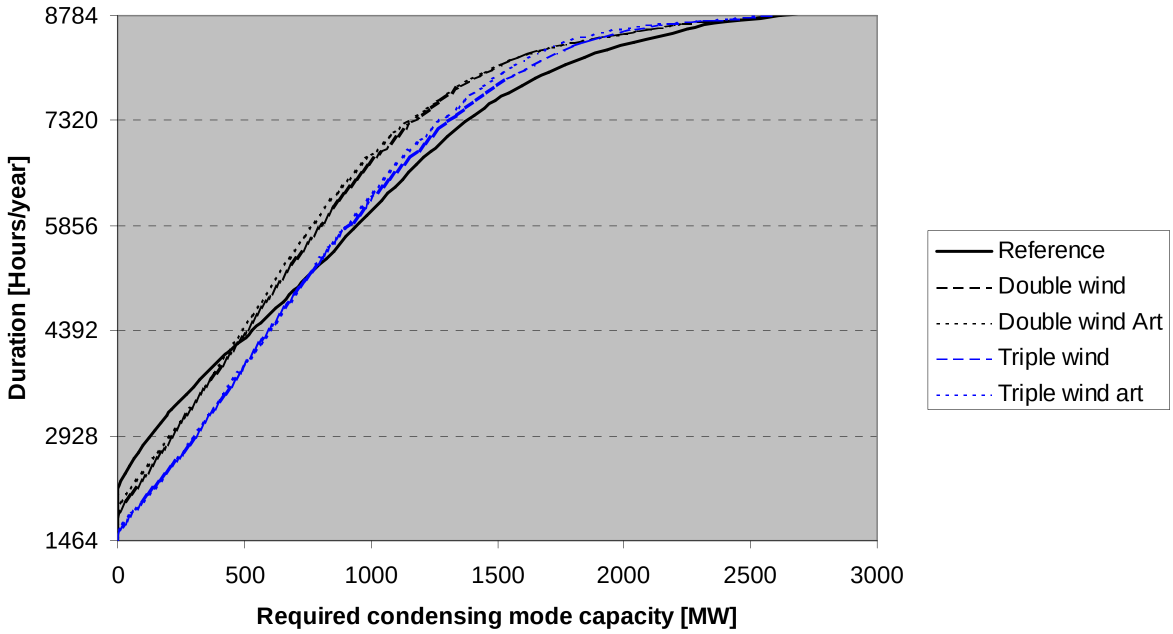


Figure 9: Duration curve for the reference system and for system with double and triple the amount of wind power with 2004 and artificial annual wind variation curves for wind power.

If ancillary services were supplied from wind turbines, the duration curves in figure 9 would shift to the left and have a more gentle inclination.

Conclusions

The results of this paper demonstrate that increasing the geographical extension of the area in which renewable fluctuating energy sources are being exploited reduces the need for stand-by capacity in the form of power plants operating in condensing mode operation. While the analyses have focused on one single source of renewable energy i.e. wind power, the analyses indicate that analyses of energy systems encompassing more unrelated energy sources or areas with larger geographic distributions would lower the demand for stand-by capacity further. This is thus also the result of interconnecting transmission areas with distinct production or consumption patterns.

In terms of integrating renewable energy sources, the result also demonstrate that while it is important encompassing a large area to obtain a stabile production, concern for ancillary services must be a priority as this can otherwise impede transition to renewable energy sources if conventional thermal power plants need to supply these.

Fulfilment of Kyoto-requirements living up to similar standards is thus more easily accomplished in an economically sound fashion in interconnected systems.

Sources

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