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OPTIMISATION CRITERIA OF ENERGY SYSTEMS ANALYSES OF WIND POWER INTEGRATION

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With the utilisation of renewable energy sources gaining momentum world-wide, the issue of integration of these energy sources into the over-all energy system is getting more and more attention. There are, however many approaches to designing the optimal resource mix. The design may be conducted from an economic perspective or from a techno-operational perspective, but within these two pillars, there are several sub-divisions. This article outlines and deliberates a number of criteria applicable for the analysis and design of energy system. These are tested on a model of the energy system in Western Denmark. It is analysed how best to expand wind power from its current level of approximately 20% of the demand to 40% using heat pumps for integration. The optimal design is investigated using different optimisation criteria in order to determine the impact of the applied optimisation criterion on the results of the analyses.

Key words: wind integration, hybrid systems, optimisation

1. INTRODUCTION

There is an increasing attention to the abatement of climate change, to the societal costs of covering an ever growing energy need and to the security of supply. Due to these circumstances there is a growing move towards cities, regions and countries focusing on harnessing locally available renewable energy sources. However, one question is un-answered – what is a renewable energy city? Switching from fossil fuel-based energy supplies to renewable energy supplies has a number of impacts on the energy system. Most renewable energy sources are of a fluctuating nature and are of a use it or lose it nature. In spite of these constraints, systems relying on e.g. wind power still need to have the same load following capabilities as conventionally fuelled energy systems. Many scholars have treated the issue of integrating renewable energy sources into the energy systems without compromising the load following capability of the system (see e.g. [1-6]). However, there is no generally accepted common criterion according to which the systems are analysed and optimised.

2. SCOPE OF THE ARTICLE

This article reviews four optimisation criteria for the design of energy systems with large shares of fluctuating renewable energy sources. The criteria are applied to the case of Western Denmark. This is a region with a very large penetration of wind power at approx 26 % in 2007 (based on hourly production and consumption data from [7]) and where it is expected that wind power will increase even further. In the analyses, the optimal level of installed heat pumps to integrate wind power is pursued.

3. OPTIMISATION CRITERIA

A wide range of criteria exist for the design of optimal energy systems configurations. In the following, a few of these are presented and deliberated.

Within some fields, it is possible to determine a global extreme. In contrast, when analysing e.g. the optimal expansion of wind power and using e.g. fuel use as an optimisation criteria, the likelihood is far higher that the fuel use more or less asymptotically nears some fixed level. Without a clear extreme of the fuel use - installed wind capacity function, it is not so simple using this as an optimisation parameter.

Systems may be analysed in island mode or connected. While it is indeed possible to have high degrees of e.g. fluctuating wind power in an energy system already with present technologies, this is to a high degree due to reliance on the outside world for balancing needs. In a future where neighbouring regions also should switch to exploiting fluctuating energy sources, these regions will probably not have the flexibility to assist other regions in load balancing. Hence, in a future situation with extensive use of fluctuating renewable energy sources, the system may need to be split up into a number of self-reliant subsystems each with appropriate load following capabilities. The line of reasoning for opting to model and design self-reliant energy systems is not unlike Kant's Categorical Imperative [8] or Egner's Cardamom Law [9]. The analyses here are only conducted in island mode for reasons of space.

Reserve capacity requirement

Reserve capacity requirement is a parameter used in e.g. [10] to asses how well a system integrates wind power. Using this parameter, the maximum required generating capacity over a period of time should be minimized. Explicitly or not, there is a strong relationship between reserve capacity considerations and economic costs as capacity naturally has a fixed cost to be covered by the electricity consumers regardless of whether or not the capacity is in fact used.

Related to reserve capacity considerations is the use of import or export in securing a system' load following capability where import and reserve capacity play similar roles in the energy system. Export from the system is not per se a positive or negative quality from a technical perspective and is hence not directly convertible to a design optimisation parameter. Critical import/export – i.e. required import/export beyond the transmission line capacity – must of course be avoided. If not, then added transmission capacity must be considered. An example of analyses aimed at limiting export of electricity is found in [11].

Condensing mode operation (CMO)

In energy systems with cogeneration of heat and power (CHP) plants, electricity generation on condensing mode power plants is usually avoided to the highest extent possible. An example of analyses applying this methodology is found in [4]. While having higher electric efficiencies than back-pressure or extraction CHP plants, condensing mode power plants have far lower total efficiencies as substantial amounts of waste heat is discarded. Regardless of whether the system is exploiting CHP plants or not, fuel use is to be minimised. In non-CHP systems however, there is a more immediate relationship between fluctuating renewable energy input and fuel savings on condensing mode power plants. In systems with CHP, there are more notes to play during the optimisation. There is hence not a simple correlation between fluctuating renewable energy input and fuel savings in such systems.

Primary energy consumption (PEC)

Rather than focusing on condensing mode power generation and the fuel savings that may be realized through the minimisation of this, a wider approach is simply to look at the primary energy consumption (PEC) of the energy system in question. Import/export also plays a role here. Should the system in question be credited fuel savings beyond the system boundary caused by the export of e.g. electricity. Should the system be debited import and how should the fuel equivalence be assessed? One way would be to assume that the alternative to import/export would be running the marginal production facility more or less. This would typically be a condensing mode power plant. It may be argued that the marginal production in complex systems with many production technologies, energy carriers and interdependencies is not always clearly identified. However under the conditions where it is relevant to look deeper into this – i.e. with import or export – the marginal production should be more easily identified.

Carbon dioxide emissions

Optimising the design by quantifying – and minimising – carbon dioxide emissions is a success parameter used in many national energy plans as a consequence of the work in the United Nations Framework Convention on Climate Change and the country-specific targets lined up in the Kyoto-protocol. Carbon dioxide emissions are closely linked to the fuel use with the distinction that different fuels have different carbon dioxide emission factors. So where primary energy consumption is neutral to whether fuels are high or low emission fuels, the distribution of fuels is important here.

The considerations pertaining to import and export are clearly relevant for carbon dioxide emissions too. This has in fact proved to be an obstacle in the internal European Union re-distribution of Kyoto-protocol requirements where countries like Denmark unsuccessfully has advocated that the base-year should be corrected for international electricity trade and for climatic deviations from the long term average, which affects the demand for space heating. The devil is in the detail.

4. Energy systems analyses

Energy system scenario

These analyses are based on an energy system scenario for the year 2020 created by a committee established by the Danish Energy Authority [12]. The main parameters of this scenario are presented in Table 1.

Table 1. Energy system scenario parameters. DH is district heating

Consumption [TWh]		Generating capacity [MW]	
24.87	Electricity	1450	Small CHP
21.21	CHP DH	1300	Large CHP
3.50	Boiler DH	Unlimited	Condensing
		2500	Wind on-shore
		1445	Wind off-shore

In addition to the production plants, the CHP plants are also fitted with 10 GWh of heat storage capacity. The heat pumps are modelled having a coefficient of performance of 3.

The energy systems analyses model

The system is modelled using the EnergyPLAN model, which is a model developed particularly with the intention to enable hour-by-hour analyses of energy systems with many interdependencies and with many fluctuating energy sources – see e.g. [13] and [14].

Energy systems analyses

Three different levels of installed heat pump capacity are modelled to analyse the impact on the various optimisation parameters. Heat pumps are modelled in levels of 0 to 0.6 GW_e installed capacity.

As deliberated in the previous section, it is of large importance whether of not the system is permitted to interact with the surroundings – however for reasons of space, only the island mode is considered. Results of the analyses are listed in Table 2.

Table 2. Optimisation criteria for the energy system. Yearly values. The shaded fields indicate the optimal installed heat pump capacity for each criterion.

Criteria	0 GW_e HP	0.2 GW_e HP	0.4 GW_e HP	0.6 GW_e HP
Reserve capacity	2635 MW	2709 MW	2709 MW	2709 MW
CMO	4.00 TWh	4.22 TWh	4.27 TWh	4.28 TWh
PEC	88.78 TWh	87.37 TWh	86.66 TWh	86.24 TWh
CO_2	15.87 MT	15.45 MT	15.23 MT	15.10 MT

The most favourable technical design varies depending on the optimisation criteria applied as indicated by the shading in table 2. Hence there is no unequivocal best design; i.e. one design that is optimal according to all the optimisation criteria. In addition to this, a few comments should be attached to some of the results.

In general, the higher the degree of heat pumps, the more favourable within the range analysed. Some optimisation criteria show a different profile though. Condensing mode operation increases e.g. with heat pumps. This could be attributed to the circumstance that added heat pump capacity increases the utilisation of wind turbines. However, present wind turbines are not able to supply ancillary services so added wind utilisation requires additional power plant operation in order to secure that ancillary services are being supplied in a correct proportion.

4. CONCLUSION

There are many different assessment criteria that might be applied when designing environmentally benign energy systems. A few of these have been deliberated in this article and have been applied to a case. The case analyses are based on a comprehensive energy system description modelled in a tool tailor-made to investigate how energy systems may be designed with optimal integration of fluctuating energy sources in mind. The question asked, was a fairly simple question regarding selecting between three well-defined cases of installed heat pumps and in spite of the simplicity of the question asked, the different optimisation criteria rendered different results.

This result underlines the fact that there is not an unequivocal answer to how an optimal energy system design is. It also underlines that goals and criteria need to be very well-defined when setting policy ambitions for areas to become renewable energy areas.

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