

The transport sectors potential contribution to the flexibility in the power sector required by large-scale wind power integration

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Abstract — In 2006, the Danish Society of Engineers developed a visionary plan for the Danish energy system in 2030. The paper presents and qualifies selected part of the analyses, illustrating the transport sectors potential to contribute to the flexibility in the power sector, necessary for large-scale integration of renewable energy in the power system – in specific wind power. In the plan, 20 % of the road transport is based on electricity and 20 % on bio-fuels. This, together with other initiatives allows for up to 55-60 % wind power penetration in the power system. A fleet of 0.5 mio electrical vehicles in Denmark in 2030 connected to the grid 50 % of the time represents an aggregated flexible power capacity of 1-1.5 GW and an energy capacity of 10-150 GWh.

Index Terms — Energy system, energy plan, electrical transport, renewable energy, wind energy, sustainable development.

1. INTRODUCTION

The IDA Energy Plan 2030ⁱ – a visionary energy plan for the Danish energy system – was developed as part of The Danish Society of Engineers' (IDA) project 'Energy Year 2006' – a project involving more than 1600 professionals at 40 workshops during 2006 (Ref [1], [2], [3]).

The aim of the IDA Energy Plan 2030 was threefold:

- to maintain the security of energy supply;
- to reduce the CO₂-emission; and
- to extend the energy technology business opportunities.

The analysis results indicate that the Danish society can meet all three targets even with a positive economic result

(Figure 1, Figure 2, Figure 3, Figure 4). The targets can however only be met by long-term investments in energy savings, energy efficiencies and new energy technologies – investments that are paid back over time. The IDA-results are compared to a 'business-as-usual' 2030 reference scenario based on a scenario developed by the Danish Energy Authority (Ref [5]).

The Danish energy system has been modelled and analysed using the computer model for energy system analysis, EnergyPLANⁱⁱ, developed at Aalborg University, Denmark (Ref [9]). The energy system has been analysed on hourly basis for power and energy balance analyses, however with no indication of potential distribution bottlenecks.

The robustness of the results has been tested by sensitivity analyses on the investment costs (including the discount rate used) and the energy market prices. The robustness of the recommendations for the system development has been tested by a projection of the system development to 100 % renewable energy based (in year 2050)

1.1. CO₂ emission

One of the aims of the IDA study was to identify solutions to reduce the energy sectors CO₂ emission by 50 %, without reducing the service levels. All means in all sectors were investigated, evaluated and utilised – including increasing the energy efficiency, decreasing the energy needs and shifting towards renewable energy resources. The recommended

Primary energy supply

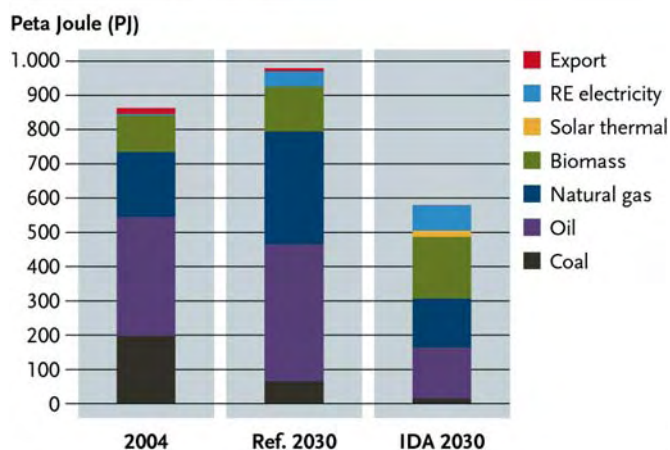


Figure 1: The primary energy supply for the Danish energy system in 2004, for the 2030 reference scenario and for the IDA 2030 scenario. (Source: Ref [1])

CO₂ emissions

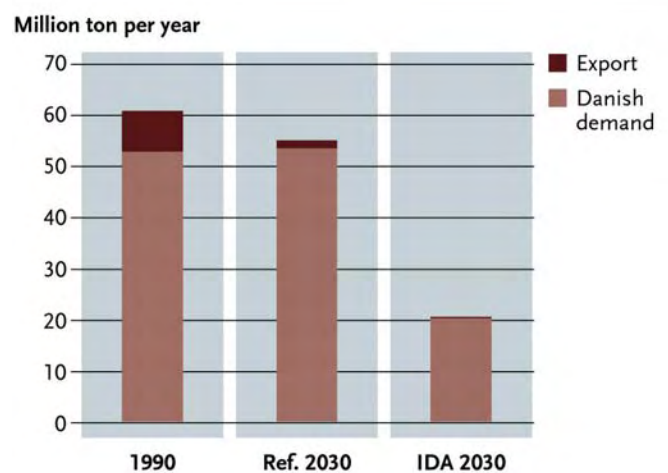


Figure 2: The CO₂ emission from the Danish energy sector in 1990 (the Kyoto reference year), for the 2030 reference scenario and for the 2030 IDA scenario. (Source: Ref [1])

Business potential

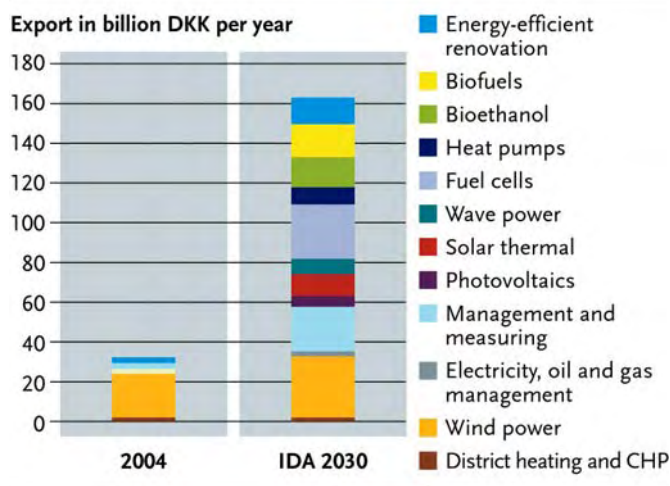


Figure 3: The estimated business potential in the Danish energy sector in 2004 and for the 2030 IDA scenario. (Source: Ref [1])

solution requires a large share of wind power in the power system, which again requires a high degree of flexibility in the power system in order to be able to optimise the system operation and the wind power integration. Several means were introduced to provide the necessary flexibility – including flexible bio-refineries producing bio fuels and the flexible power buffering provided by electrical vehicles, while connected to the grid.

In the IDA Energy Plan 2030, 20 % of the energy for road transport is based on electricity and 20 % is based on bio-fuels. This, together with other initiatives to increase the flexibility in the power system, allows for up to 55-60 % of the electricity consumption covered by wind power. The present paper qualifies these numbers.

The batteries in the electrical driven vehicles act as intelligent electrical buffers, whenever connected to the grid – charging the batteries when abundant generation capacity in the power system (and thus low electricity prices), and supplying power and other system services to the power system when needed by the system (expressed by high market prices). The vehicles intelligent controllers ensure that the vehicles are able to provide the requested transport work when needed by the user – specified by the user when connecting the vehicle to the grid in terms of required operating distance at specified time.

The bio-fuels for the transport sector are produced at flexible, multi-product bio-refineries, e.g. producing a mix of syngas, transport fuels, power plant fuels, power, heat (for district heating), animal feed, fertilization, fibre materials and other chemical products – with a flexibility of adjusting the actual product mix depending on the varying market prices. These multi-product plants are able to switch between e.g. production of power and production of liquid fuels (based on the syngas) for the transport sector.

2. SUSTAINABLE TRANSPORT DEVELOPMENT

In the IDA Energy Plan, a wide range of measures towards a sustainable transport development has been proposed and analysed. The measures are different from other suggestions related to transport policy because the plan involves a wide range of technologies and includes both the demand and

Economic costs

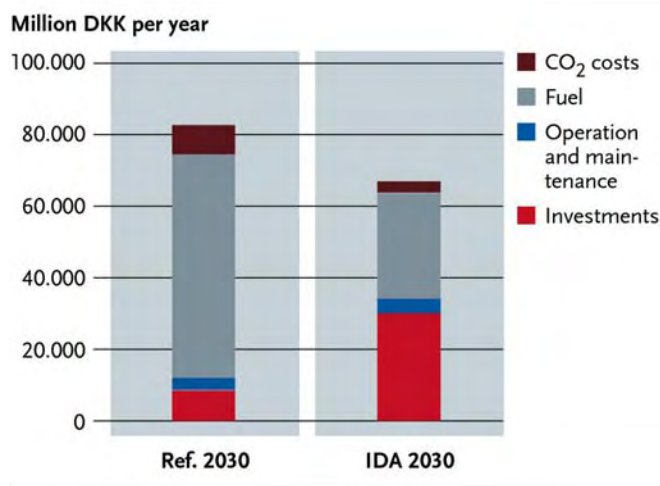


Figure 4: The estimated additional economic cost for the 2030 reference scenario and for the 2030 IDA scenario. (Source: Ref [1])

supply side. Also, it differs from other analyses as its measures have been analysed both in the context of the surrounding energy system and in relation to economics.

The following proposals have been used in the analysis as part of the transport theme for Denmark:

- Passenger transport work (person km) in 2030 in vehicles, trains and bicycles is stabilised at the 2004 level.
- The rate of increase in passenger air transport is limited to 30 % (instead of 50 %) in the period from 2004 to 2030.
- 20 % of the passenger road transport is transferred to trains, ships and bicycles in 2030:
- 5 % transport of goods (ton km) transferred from roads to trains and 5 % to ships
- 5 % passenger transport is transferred to trains and 5 % to bicycles.
- 30 % more energy efficiency in the transport sector compared to the reference situation in 2030 with stable passenger transport at the 2004 level and with a lower increase in air transport.
- 20 % biofuels and 20 % battery electric vehicles in road transport in 2030.

Some of the results of the analysis are shown in Table 1 and in Figure 5.

2.1. Electrical vehicles

Although electrical vehicles have been on the market for

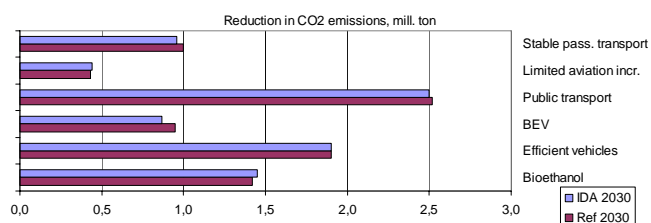


Figure 5: The estimated CO₂ emission reduction for the 2030 reference scenario and the 2030 IDA scenario. (Source: Ref [7])

TWh/year	Reference 2030	IDA 2030
JP4 (for aviation)	13,25	11,63
Diesel	27,50	18,82
Petrol	28,46	6,33
Biomass for ethanol		7,98
Electricity	0,24	2,10
Sum	69,45	46,85

Table 1: The estimated fuel consumption for the transport work in Denmark. (Source: Ref [7])

decades, they have never real materialised. The weak part has been the lack of sufficiently robust, energy compact and cheap batteries (Ref [10]).

However, the recent and the expected development in battery technology, power electronic and electrical drives in terms of robustness, energy efficiency, energy density, reliability, long life and low cost provides new potentials for the deployment of electrical driven vehicles.

The state-of-the-art capacities of the Lithium-based battery types are 0.2 kWh/kg. The Lithium-type batteries allows extended dynamic operation with many, rapid and heavy charging/discharging cycles, while preserving their high energy efficiency and long lifetime. Electrical vehicles typical have an energy consumption of 0.15 kWh/km (compared to typically 0.5 kWh/km for traditional, efficient internal combustion engine based vehicles and 0.4 kWh/km for hybrid vehicles). A battery package of 200 kg with an energy capacity of 40 kWh corresponds thus to a driving range of up to 250 km.

The deployment of electrical driven vehicles is supported by the potential step-by-step development from the presently introduced 'hybrid vehicle concept' (already mass-produced by several of the large car manufactures) over the so called 'plug-in hybrid' to the dedicated electrical vehicles. The hybrid concept consists of a combination of an internal combustion engine (ICE), an electrical motor/generator and a battery, and provides only increased fuel efficiency by a combination of picking-up and utilising the braking energy and optimising the operation of the ICE. The plug-in concept has typically a larger battery capacity, can drive solely on the electrical drive for short distances and has the option of charging the battery from the grid – while parked and connected to the grid. The dedicated electrical vehicle concept has a pure electrical drive train, but the operation range may be extended by an on-board fuel based battery charger – e.g. based on fuel cell technology.

The ultimate electrical vehicle concept is the so called 'vehicle-to-grid' (V2G), enabling the power between the grid and the battery to flow in both directions, and with the potential through intelligent control of the inverter for the vehicle to provide system services to the power grid. The concept requires a fully controllable bi-directional inverter between the grid and the battery, an possibility for on-line power trading with the power distribution company while connected to the grid and an intelligent controller that can optimise both the system services and the battery charging. The system services provided by the grid connected electrical vehicles may contribute to the flexibility in the power system needed for the optimisation of large-scale wind power integration. The concept is not expected to materialise within

	CO2/km	Reference
Standard gasoline car	160 g	Danish Transport Agency
Hybrid car	100 g	Toyota
Electrical car	70 g	Danish Energy Association
Electrical car on renewable power	0 g	

Table 2: Typical CO2-emission figures for various vehicle concepts. (Ref [11])

the first 5-10 years, but the concept forms the basis for the analyses of the 2030-potential presented in the present paper.

In addition, the development of electrical drive platforms for vehicles is further pushed by their potentials for reducing the transport sectors dependency of fossil fuels, CO2-emission (Table 2), local air pollution and noise emission, as well as their potentials for 'smart' drives with the electrical engines integrated in the wheels, providing true all-wheels-drive, turning support etc.

2.2. The Danish transport sector

The transport sector in Denmark (as well as in EU) is 98 % (2006) dependant on fossil oil products (gasoline and diesel). The annual grow in number of person vehicles in Denmark is 3-5 %, with 2 mio in 2006, in average driving 15-20 000 km annually and in average in use less than 90 % of the time.

A fleet of 0.5 mio electrical vehicles (corresponding to 20 % of the expected vehicles in 2030 with the present grow rate), each having a battery capacity of 50 kWh and a 5 kW inverter, and in average connected to the grid in 50 % of the time represents a power capacity of 1.2 GW and an energy capacity of 12 GWh – corresponding to the maximum power generation from 250 × 5 MW wind turbines in 10 hours. 50 kWh battery capacity is expected to be realistic for vehicles within the next 10 years. The price and size of 5 kW inverters expects to be pressed by the competition on the expected increasing PV market, also within the next 10 years. The development of a market for trading of large number of small-scale system services is driven by the household's potentials for power demand response and other power system services, and is also expected to materialise within the next 10 years.

The implementation of the necessary infrastructure for grid connection of the vehicles is highly dependent of standardisation of power level, communication between grid and vehicle, and the control of the power flow, of registration of the power trading and of the development power system

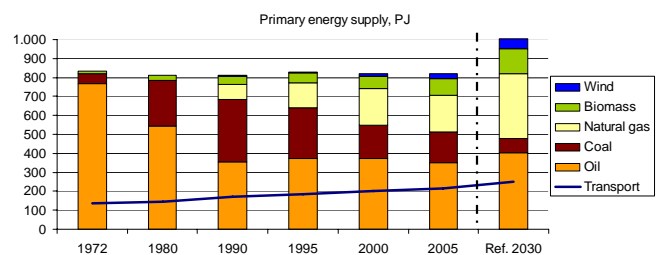


Figure 6: The Danish primary energy supply and fuel supply for transport from 1972 to 2005 and for the 2030 reference scenario. (Source: Ref [7])

service markets. It is therefore important to initiate pilot project that can test, demonstrate and characterise these topics, and thereby form the basis for standardisations. The infrastructure is not expected to materialise until standards has been established.

3. CONCLUSION

The technologies required for the manufacturing of electrical vehicles (especially the battery technology) have developed at lot during the last years in terms of reliability, performance and price, and the developments are expected to continue. The electrical vehicle concepts provide interesting and valuable potentials regarding environmental impact, fossil fuel dependency, energy system flexibility, and driving characteristics. And the electrical vehicles may be introduced through a step-by-step development from the present hybrid vehicles, over plug-in to the vehicle-to-grid, providing the full potential. This in combination leads to an expected deployment of electrical vehicles within the next 10 years.

In a visionary energy plan for the Danish energy system in 2030, developed by the Danish Society of Engineers in 2006, 20 % of the road transport is based on electricity and 20 % is based on bio-fuels. This, together with other initiatives to increase the flexibility in the power system, allows for up to 55-60 % of the electricity consumption covered by wind power.

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<http://ida.dk/Netvaerk/Energiaar+2006>

ⁱⁱ EnergyPLAN web: www.energyplan.eu

Analysis of electric networks in island operation with a large penetration of wind power

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Abstract — The percentages of wind power penetration in some areas of the electric distribution system are reaching rather high levels. Due to the intermittent nature of wind power, the voltage and frequency quality could be seriously compromised especially in case of island operation of such an area of the grid. In this paper the impact of wind power in island distribution systems has been analysed with respect to voltage and frequency. Possible measures for controlling both voltage and frequency are suggested and have been analysed. The suggested measures are static voltage controller (SVC), dump loads, kinetic energy storage systems, and load shedding. It is shown that the measures effectively can bring voltage and frequency quality within the normal operation range.

Index Terms — Dump load, Flicker, Island operation, Kinetic energy storage system, Load shedding, SVC, Wind power.

1. INTRODUCTION

For many years the power consumption has relied on the production of centralized power plants interconnected through transmission lines and thereby accomplishing a rather stable power system. Nowadays this philosophy is changing due to the increase of the embedded generation of small combined heat and power (CHP) plants and wind farms. This configuration leads to some drawbacks but also to advantages. Considering the fact that the electric power has to flow through distribution lines instead of transmission lines, the losses will be increased in many cases. In addition, in the case of wind turbines, the nature of the energy source and the use of power electronics in the generation process can affect the power quality. Nevertheless, wherever the embedded generation capability is able to fulfil the consumption, in cases of e.g. disturbances in the grid or imminent blackout, the network could be split in autonomous grid cells working independent from each other as shown in Figure 1.

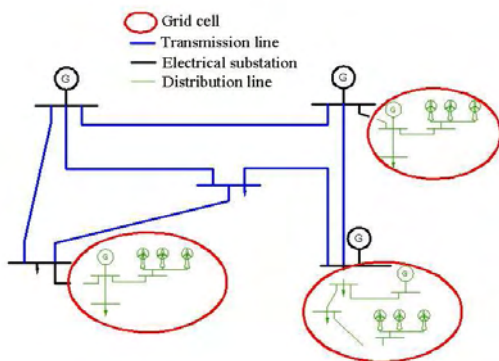


Figure 1. Split network.

The arising problem is the possible instability in terms of voltage and frequency due to the weakness of such a small electric network operated in island. Regarding the frequency, the problems are caused mainly because of the rather low inertia (H) of the system. As it is shown in the network electromechanical equation (1) a mismatch between produced power (P_{mech}) and consumed power (P_{elec}) generates variations in the angular frequency ω of the generators and thereby the frequency of the system. These variations are dumped by the inertia of the system, and since the inertia, in this case, is much smaller than in non isolated operation, the frequency will be more affected.

$$\omega \frac{\partial \omega}{\partial t} = \frac{P_{mech} - P_{elec}}{2H} \quad (1)$$

In the case of the voltage, the reactive power variations of the demand and wind generation have a more significant impact on the total reactive power balance of the system compared with interconnected operation. Considering that the excitation systems of the synchronous generators are not fast enough to compensate such variations, the voltage will be affected.

Considering the objections of the isolated operation, this paper presents the results of a study on the dynamic behaviour of a typical Danish electric distribution network in island operation. The study has been realized by use of the power systems simulation program *PowerFactory* by *DigSilent* based on a quite simple grid. The considered power system includes a variable demand, a CHP plant and a wind farm with variable production.

The wind power is going to be considered as wind turbines of the *Danish concept* type and without any power control capability, i.e. they are fixed speed wind turbines and do not have active stall or pitching systems for controlling the power output. Under these conditions, the power output of the wind turbine will depend mainly on the wind speed; hence the wind power production is an uncontrollable energy source which, as in the case of the variable demand, might generate disturbances in the grid.

The fluctuating wind power and its penetration percentage present a key issue in a grid cell. In order to outbalance the frequency disturbances from the wind power in a grid cell, the use of dump loads, kinetic energy storage systems and load shedding is considered, and in the case of the voltage, the application of a SVC is considered.