Extension Of Wind Energy Systems And Consequences On The Grid

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Introduction

It is envisaged that the offshore wind energy fraction will increase rapidly in Germany. About 25 GW of installed power in offshore wind farms are expected until 2025/2030.
Provided that all the already approved wind farms and the large number of scheduled wind farms are put into operation in Europe we could achieve about 60 GW of installed wind power along the coastlines in Europe. A large number of studies, published in recent years, were analyzed with focus on increased use of renewable energies minimizing of carbon-dioxide, increased use of combined heat and power and a higher portion of biomass [1]. The results from these studies vary to a large extend and also the target year differs from 2020 via 2030 to 2050. For example in the year 2020 the electricity generated by renewable energies ranges between 59 and 172 TWh/a. By 2030 there is an increase to 88 and 256 TWh/a. Finally for 2050 the energy data are 117 and 434 TWh/a. The biggest portion of energy will be provided by wind energy especially from offshore wind farms. In 2030 about 50 % of electricity will be generated by offshore wind farms in Germany. The variety of assumptions in theses studies leads to the outcome that between 50 and 150 TWh/a will be generated by onshore- and offshore-wind parks.

Background

Over the next 15-20 years, a decent percentage of our domestic electricity supply capacity will have to be retired as the older generation of nuclear and fossil fuelled power stations reach the end of their lives. The EU target of sourcing 20 % of all energy supplies from renewables by 2020 provides a firm deadline. But there is no clear route map for achieving this goal. In particular wind power has the capacity to meet the looming energy gap.
The wind industry is confident that it can install wind power as indicated in Table 1.

Table 1: Wind farms in the North Sea/Germany in the future

Year	**Number of wind farms**	**Total inst. power P_t, inst in GW**
2010	14	15.9
2015	18	21.8
2020	24	24.5

Beside the wind farms under construction there are others which remain in the planning system awaiting determination. Fig. 1 a, b, c shows sections of the North Sea and Baltic Sea with the distribution of the offshore wind farms.
The pioneers in offshore wind farms are Denmark, Germany, Great Britain, and the Netherlands. Because of the high power consumption the governments in these countries are

willing to subsidise the high costs of offshore wind parks. The Renewable Energy Act (EEG) in Germany in 2008 paid 8.03 €ct/kWh for offshore wind energy – too little for expensive projects far out in the North Sea.
The German government has therefore obligated power companies to cover the costs for grid connection offshore. The revised EEG went into force on January 1, 2009. Now in the beginning of the operation of the onshore wind farm 9.2 €ct/kWh will be paid.
For offshore wind farms the initial payment will be 15 €ct/kWh until 2015. Is the wind power system in the position to contribute to system stability an extra bonus of 0.5 €ct/kWh will be paid. Detail can be found in: http//www.eeg-aktuell.de/.
The EEG provides a strong opportunity to ensure that Germany is able to bridge the emerging gap in electricity generation and place sustainability at the heart of the energy policy agenda.
Theoretically, we may see about 25 GW of wind turbine power off the German coast by 2020. Indeed, these projects will be far off the coast to reduce the impact on the wadden sea and keep protests from the tourist sector at a minimum. Table 2 shows that offshore wind power is not growing as fast as onshore.

Table 2: Wind power in Europe (EWEA) in MW

	1992	2006	2020
Onshore	839	47,184	120,000
Offshore	5	878	60,000

For the time being, some 900 MW of wind turbines are in operation off the coasts of Europe, with another 300 MW under construction. At the end of 2009, some 2700 MW will be installed offshore if everything goes as planned. In addition to planning obstacles and a lack of funding, industry simply cannot supply the large turbines any faster. For example, SIEMENS is booked all the way into this year and the other two former German manufacturers of wind turbines, “Repower” and “Multibrid” will launch serial production of their 5 MW turbines this year.

Wind turbine technology

The average installed capacity per wind turbine has now reached 1.9 MW. This is due to the fact that in 2007 eight wind turbines with a rated capacity of more than 5 MW were erected. The share of technology and type groups of installed wind energy systems for 2007 is presented in Table 3.

Table 3: Share of technology and size of installed wind energy converters

Rotordiameter	**45.1-64 m**	**64.1-80 m**	**> 80 m**
Without gearbox	82	262	110
With gearbox	31	92	300
Pitch control	113	353	390
Stall control	0	0	0
Active stall	0	1	20
One fixed rotor speed	0	4	0
Two fixed rotor speeds	0	1	20
Variable speed	113	349	390
Number of wind turbines	113	354	410

A number of repowering projects were also realized in the last years. The following table gives some information related to selected wind energy converter (WEC) locations in order to illustrate the increase of power.

Table 4: Selected locations for repowering (2007)

Location	**WEC's pulled down**	**Power MW**	**WEC repowering**
Fehmarn	170 different WEC's	45	68x-Enercon E70 2006: 73.6 MW 2007: 48.3 MW 2008: 34.5 MW Total 156.4 MW
Wind park Ellhöft	32 different WEC's		4xSIEMENS SWT 2.3 2007: 9.2 MW 3xRepower 2008: 15.0 MW Total 24.2 MW
Wind park Galmsbüll	10xAN Bonus 450 kW 4xEnercon 300 kW	5.2	7xSIEMENS SWT 3.6 2006: 25.2 MW 7xSIEMENS 2007: 16.1 MW Total 41.3 MW

As the data related to the year 2008 are not published in full detail the table above indicates clearly that the repowering potential is quite large [2] [4].
In the beginning of the grid integration of the wind energy converters, the generator was connected to the low voltage grid level of 400 V. As the power level goes up now the higher voltage level of 10 kV is used.
Two basic types of generators are commonly used.
- Doubly fed induction generator
- Synchronous generator.

The development of high-energy permanent magnets helped to improve the design of synchronous generators in order to achieve a good power density. Table 5 gives a comparison of different generator types.

Table 5: WEC-generator –types and power density

Manufacturer	**Type**	**Power MW**	**Nacelle weight t**	**Power density kW/t**
Enercon	E-112, syn.gen. excitation current	4.5	440	10.2
Multibrid	M5000, syn.gen. Permanent magnets	5	199.3	25.09
Repower	5M doubly fed asynchr. gen.	5	290	17.24

The application of permanent magnets as flux source in synchronous generators leads to a reduction in size of about 30 %. This is the main reason for the high power density. As the gearbox is often the origin of a system failure there is a tendency to avoid the gearbox at all or to work with a single-stage gear unit.
The Multibrid for example works with a single-stage planetary gearing and the efficiency is high also at partial load, because there are no excitation losses.
The offshore installations are in a harsh environment and therefore corrosion protection of the permanent magnets has to be done. Aluminium, zinc or nickel coatings are used for the sintered magnets. Depending on the construction of the synchronous machine – surface mounted or buried magnets – also a coating is possible which provides electrical insulation and in doing so, eddy current effects can be suppressed.
All the large generators are variable speed drives and therefore power electronic systems must be used to feed the energy into the grid. Different topologies can be used in wind energy utilization [5, 7]:
- standard back-to-back converter
- tandem converter
- matrix converter
- multilevel converter
- resonant converter.

Fig. 2 shows the classical back-to-back converter which is widely used for the lower MW class generators.
Two multilevel-converter topologies are of interest for the Megawatt generators which are connected to the medium-voltage level. Fig. 3. and Fig. 4 show the “3-level-diode-clamped converter” and the “3-level-flying-capacitor converter” (FLC). The “3-level-diode-clamped converter” is often used and also named neutral point clamped converter (NPC). Output voltage of the converter is around 3 kV and a transformer feds the power into a 30 kV grid.
In order to minimize the losses within a wind park, a number of generators will supply the power into the internal 30 kV wind park grid. Alpha Ventus, a project in the North Sea will operate with a 30 kV wind park grid voltage.

Energy transport

The distance between a number of offshore wind parks and the transformer station onshore is larger than 100 km. Special sea cables are necessary to transport the energy to the consumers. Fig. 5 and Fig. 6 provide an overview about ongoing activities in the North- and Baltic-Sea.
Within the 12 sea-miles zone in the North Sea in Germany we have two offshore projects with the following data:
- Riffgat with 44x5 MW
- Hordergrunde with 25x5 MW and a test facility
- Ems-Emden (Dollart) with 1x5 MW.

A wind park cluster called “Sylt group” is dealing with the following wind parks:
- Butendiek: 80 WEC’s with total power of 240 MW
- Dan-Tysk: 80 WEC’s; P_t = 1500 MW
- Nördlicher Grund: 80 WEC’s; P_t = 2195 MW
- Uthland: P_t = 400 MW
- Sandbank 24: 80 WEC’s; P_t = 4720 MW
- H2-20: P_t = 400 MW.

The „Borkum group“ cluster contains nine wind parks.
- Bard Offshore I: 80 WEC’s; P_t = 1600 MW
- Gode Wind: 80 WEC’s; P_t = 896 MW
- North Sea: 80 WEC’s; P_t = 1250 MW
- Delta Nordsee: 48 WEC’s; P_t = 1255 MW
- Alpha Ventus: 12 WEC’s; P_t = 60 MW
- Globaltech I: 80 WEC’s; P_t = 1440 MW
- Hochseewindpark Nordsee: P_t = 2286 MW
- Hochseewindpark He dreiht: P_t = 536 MW
- Borkum Riffgrund: 77 WEC’s; P_t = 746 MW.

Only for the pilot phase the envisaged number of wind energy converters (WEC’s) is listed above. At the very end of the building activities the total power P_t should be reached [3, 4, 10].
The situation in the Baltic Sea is less complicated, as the boundary conditions, e.g. water depth, are more favourable.
With few exceptions the distance between the wind parks and the shore is larger than 100 km and therefore special sea cables are required for the energy transport. The classical AC-three phase cable is not attractive for these distances. A high-voltage direct current (HVDC) transmission link is the better choice. ABB introduced about ten years ago this novel technology based on insulated-gate-bipolar transistor (IGBT) and named the technology “HVDC Light”.
Having in mind the very large number of offshore wind parks the question arises how many high-voltage cable routes can be laid through the wadden sea. Different concepts are discussed such as separate connections, local clusters and a reduced number of cable routes or even meshed clusters with an even more reduced number of cable routes. Depending on the concept, the total power of the wind parks and the chosen cable voltage level, the number of cables will vary to a large extend. If the focus is only on the sea cables and the cable voltage levels the next table gives an estimation of the demanding projects for the future [3].

Table 6: Number of sea cables in the North Sea section of Germany

Type of wind park connection	**150 kV**	**220 kV**	**380 kV**
Separate	157	110	62
Local cluster	129	88	54
Meshed cluster	126	90	59

Only recently a 580 km underwater power cable has been successfully completed. It connects the Feda converter Station/Norway with the converter station in Eemshaven/Netherlands and is based on HVDC technology with a rated power of 700 MW.
This link is the latest in a series of HVDC connections helping to improve an integrated European power network. Working out the details of multi-national transmission, harmonised grid safety standards, cross-border market access has started but has not been easy [6, 8].
As indicated with Fig. 7 the utilities are focusing on supply safety and reserve capacity, however, wind park owners have high interest in energy yield and energy efficiency. After power generation and the grid became separate entities, grid stability became a grey area. As more and more power generated from the wind is being employed in Europe, new solutions

are needed to make sure the power grid remains stable. The demand for ancillary services is therefore increasing. Individual wind turbines are becoming larger and the power electronic interface between turbine and grid are more advanced and so they can contribute to grid stability. However, when wind power is added to a power system, existing short term reserves are used for balancing; reducing any net imbalance between loading, wind power and other generation units.

At higher levels of wind power penetration about 20 to 50 %, the challenges that it poses require modifications to power system operation and power system structure including also more energy storage facilities [9].

It is unrealistic to identify suitable sites for pumped storage hydro stations but compressed air energy storage and compressed hydrogen at high pressure are good candidates to balance the fluctuating power from wind parks. The energy can be stored in underground salt domes existing in Northern Germany. Expertise is at hand for seasonal storage of natural gas using an underground volume of three Mio m^3.

Although wind power is primarily installed to avoid the need for power generation using fossil fuels, it can also be used to replace existing power plant capacity. The capacity value can be evaluated by performing loss-of-load calculations. These take into account both the probabilities of low generation from wind parks and the probability of forced outages of all generation units during periods of peak demand.

Flexibility in the electrical power system can be increased by adding facilities that offer flexible generation reserves e.g. CHP systems and demand-side management [8]

Summary and conclusions

Beside all the progress in the turbine development there are a number of policy obstacles which are undermining the industry’s ability to deliver large scale wind energy generation.

Firstly, the planning system is not dealing effectively with wind energy. Secondly, the current system of offshore site awards and consent is too length, discouraging investment. Finally, planning for connection to the grid is not closely linked with planning for generation.

The necessary grid extensions are analyzed in detail in the study by DENA (German energy agency) [4]. Also the European Wind Energy Association (EWEA) points out that more coupling station should interconnect different number states of the European Union. There are plans to install a “back-bone-grid” all over Europe. Such a Trans-European Network-Electricity (TEN-E) would help to increase the capacity factor of wind power.

As the prognosis software for wind power becomes more accurate the demand for positive and negative balancing power is affected. For the year 2015 positive balancing power ranges form 3.2 GW up to 7 GW, while negative balancing power is between 2.8 GW and 5.5. GW. These data correspond to 8 % and about 16 % of wind power.

Modern wind energy systems show “fault-ride-through-capability”, but the grid-codes are different from country to country [11]. It is essential to harmonize these regulations in Europe.

Up today decentralised power plants are operated in such a way that they feed in active power only and there is, with few exceptions, no communication between them and the utilities control centres. Advanced control strategies, such as power factor control, voltage control or active power management are necessary [12]. The German Transmission System Operator e.on Netz GmbH has published criteria for fault-ride through behaviour and created a platform for advanced control of wind parks.

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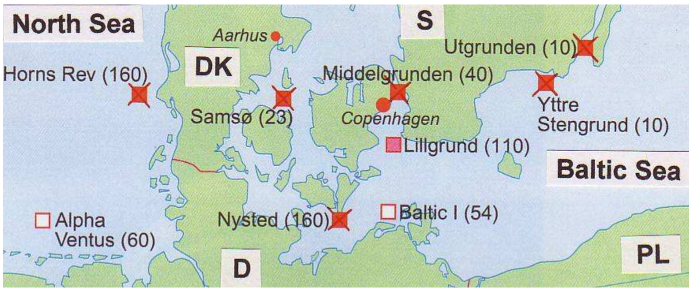
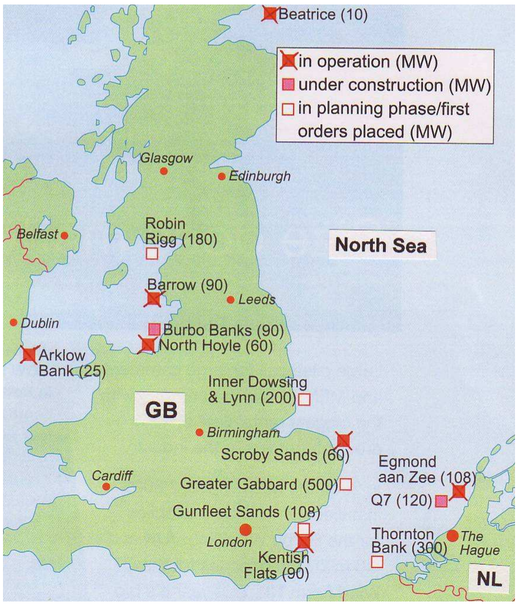
Further information:

European Wind Energy Association (EWEA): www.ewea.org
Multibrid: www.multibrid.de
Repower Systems: www.repower.de
SIEMENS wind power: www.siemens.com/powergeneration/windpower
Wind Energy Agency: www.windenergie-agentur.de



a) Wind farms in the Balic Sea



b) Wind farms along the coast in Great Britain and the Netherlands

c) Wind farms in the North-Sea/Germany

Fig. 1: Selected wind farms in Europe
[Eilers-Media/Koenemann, Sun & Wind Energy 4/2007]

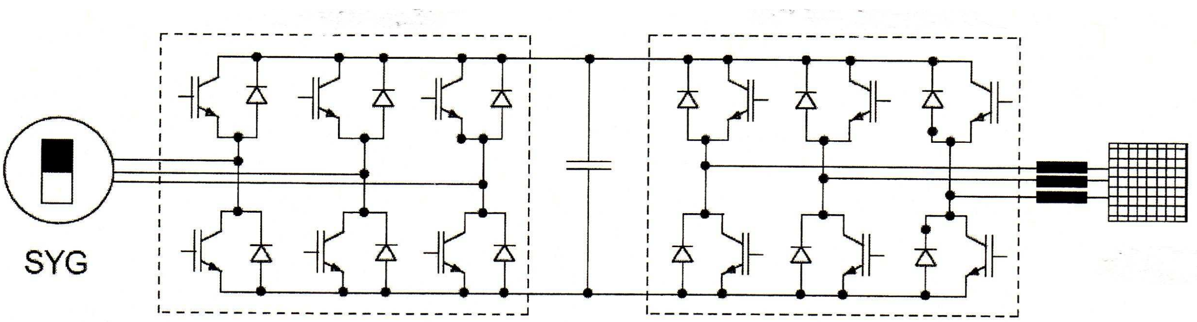


Fig. 2: Back-to-back converter in combination with a permanent magnet excited generator

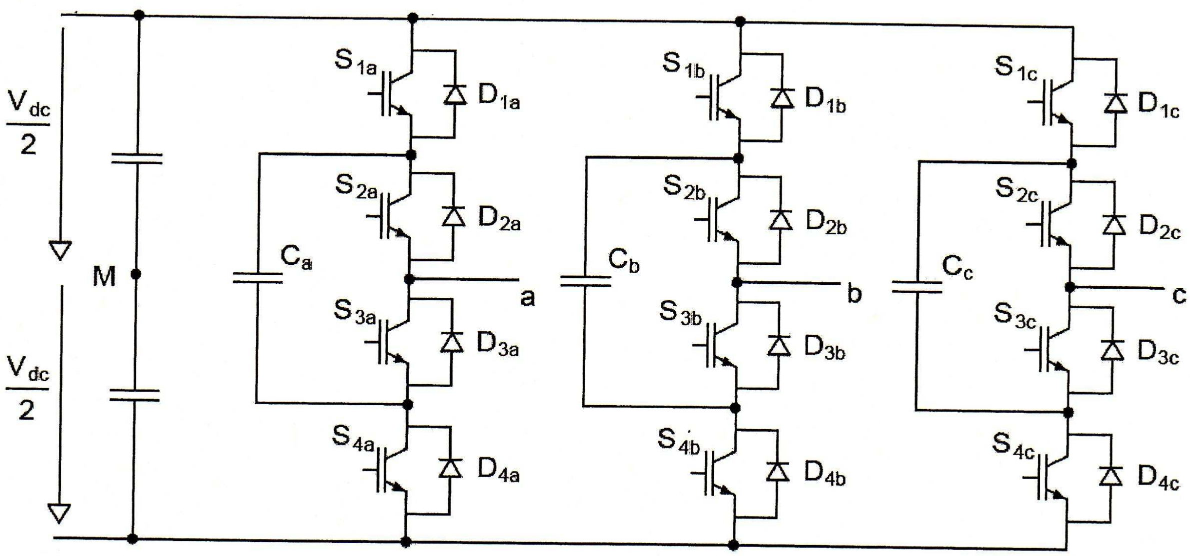


Fig. 3: Three-level-diode-clamped converter

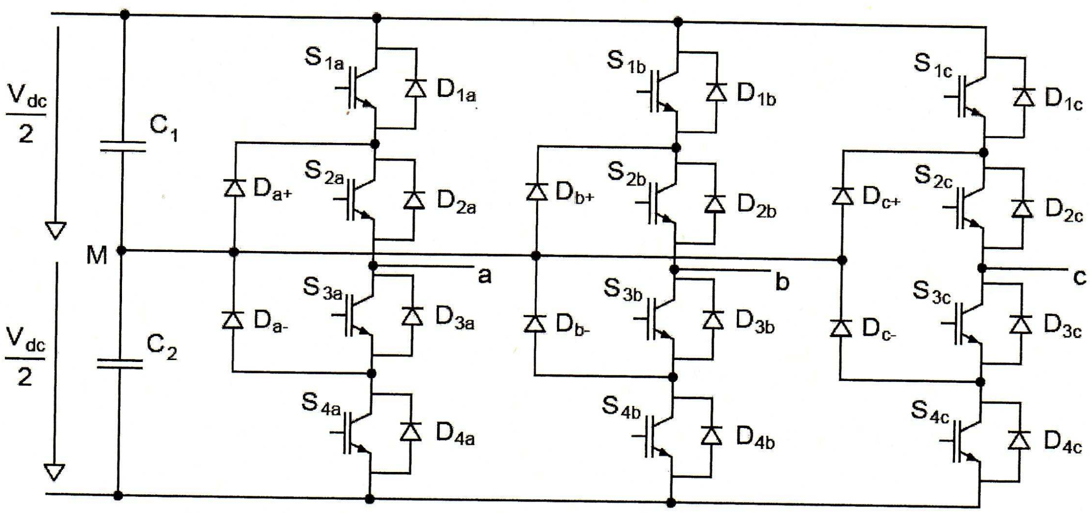


Fig. 4: Three-level-flying-capacitor converter

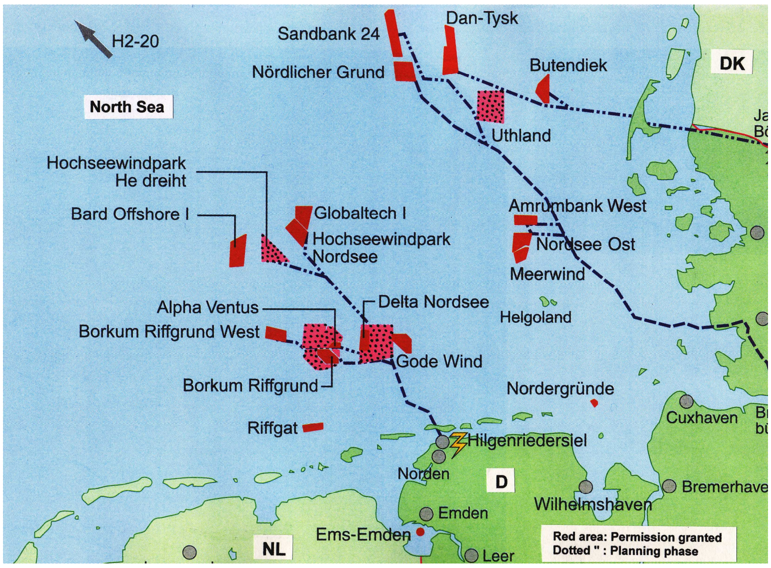


Fig. 5: Selected wind parks in the North Sea [6; Eilers-Media]

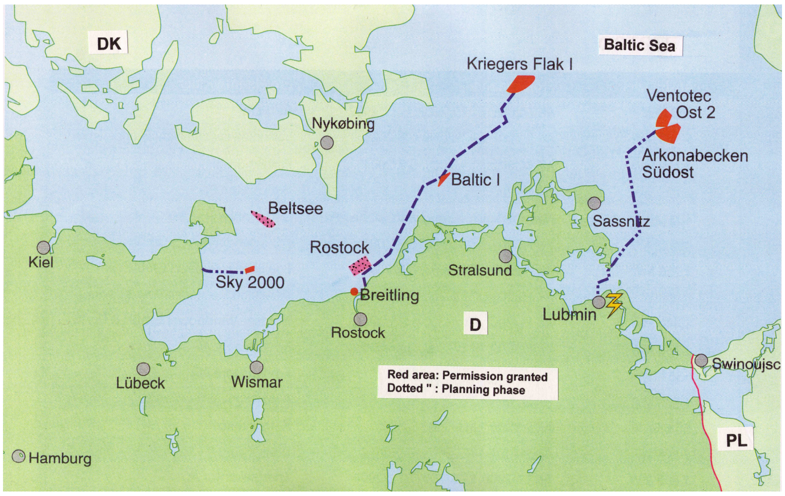


Fig. 6: Wind parks in the Baltic Sea [6; Eilers-Media]

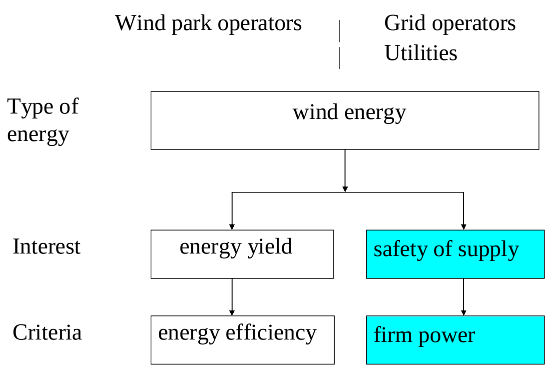


Fig. 7 : Interests of wind park operators and grid operators