Grid Integration, Energy Supply & Finance

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1. Introduction

1.1. Interaction between production and consumption (EMS)

1.1.1. Production and Consumption patterns

In all electrical systems, the production and the consumption should always be in close conformity as it would otherwise be physically impossible to keep the system frequency within allowable tolerances. This balance is the main reason why continuous production planning is necessary.

In the EU white paper on Renewable energy, 40000 MWe installed capacity is targeted by 2010 (delivering about 80 TWh/y). If 25% should be delivered by 10000 MWe capacity from large wind farms, preferentially offshore, then this would lead to an annual production of over 20 TWh/y. Concentration of such large production capacity could lead to a large penetration in the existing network and the problems of balancing production and consumption becomes then important.

- **Load forecast** aims at an economic and reliable adjustment of the production to the load, from seasonal, daily down to 15 minutes level. Load forecast handles prediction of the load with all stochastic aspects involved. Analysis tools include probabilistic generation simulation and generation costing models and reliability analyses in generation/transmission based on Monte Carlo simulations.

- **The temporal production** from wind parks, with a substantial stochastic character, will require new sophisticated methods to forecast the production capacity, and to mobilise conventional generation capacity to continuously meet the consumption. What is the state of the art in short term resource forecast for offshore wind parks?

- **Prognosis tools**: At European level, an annual wind turbine production of about 20 TWh in 2010 would require a number of changes in the EMS practices and tools. Especially the prognosis tools currently available for this variable production concept need to be further developed and optimised. When the local penetration of wind energy is large, it is very important – technically and financially – to be able to forecast the expected production from such a large installed capacity. In some electricity markets (e.g. the UK NETA balancing market system) it is also very important for individual wind farms. Furthermore, the capacity cannot be equally distributed throughout Europe as the wind resources and the available sites are concentrated in certain areas, e.g. Northern Europe. Experience has demonstrated that the uncertainty of the present prognostic tools is in the vicinity of 30-40% for a 36-hour forecast. The accuracy of the prognostic tools should be improved to less than 10% to reduce the costs for regulating power to an acceptable level. There is another issue related to forecasting periods ('look-ahead' period). In conventional systems, it is relatively easy to forecast generation and demand for periods of a day or more ahead. It may be suspected that look-ahead periods of 24 hours and more are chosen for administrative convenience rather than real need. The costs this imposes on the system or on generators is small in conventional systems, but is much higher when there are variable sources such as wind in the generation mix. There is a need to establish the costs and benefits of longer look-ahead periods, in order to determine the optimum. This optimum is likely to be different for different systems.

1.1.2. Utility operation and energy management systems:

In spite of the improvements made in the prognoses tools, it will remain difficult to forecast the power gradients arising in the wind power production within a quarter of an hour. The Transmission System Operation (TSO)will be under an obligation (i.e. the grid code) to keep the **Area Control Error (ACE)** within limits to avoid penalties for too large imbalances and to ensure that these **power gradients** are compensated for via the secondary control, either by central production facilities or cross-border exchange. This gives rise to a number of important questions, for instance: Who will be establishing and financing data acquisition and remote control facilities as such? Who will be paying for the lost production and other system costs? Who will be refunding the loss if the production margin is lowered before a particular time of operation – resulting in the wind turbine owner being unable to deliver the production offered to the exchange? How will the priority between several wind farms be administered – whose production is going to be restricted? Is this need best met by requiring wind farm operators to install more expensive equipment in order to appear more like conventional generators?

1.1.3. Means to face production-consumption balance

- **Demand Side Management**. An improved agreement between consumption and production would also improve the real-time operation.

- **Energy storage** : Means to face imbalance between consumption and production: operation and EMS in situations with imbalance between consumption and production within a certain area must be investigated in-depth in order to ensure operation with a high penetration of wind energy. A number of solutions must be developed, such as:
  - -*Electricity storage facilities*. Regenerative fuel cells, pumped storage are important technologies for storing large quantities of electrical energy. While pumped storage is already been fully exploited for peak shaving with limited possibilities for extension, the regenerative fuel cells would offer a flexible means for storing energy. If this technology could reach technical and commercial maturity this would significantly improve the real-time operation in systems with high penetration of fluctuating wind energy.
  - -*Energy Conversion.* The feasibility for conversion of (surplus) electricity into Hydrogen should be investigated.
  - -*Possible modifications on conventional power plants*. The present control possibilities including response time for the existing thermal power plants should be analysed.

1.2. Design and operation of the transmission grid : Connection technology for LSOWE

1.2.1. Technical feasibility limits for LSOWE grid connection

Grid integration of large-scale offshore wind wind farms may be constrained by the technical limits of state-of-the-art grid connection equipment. The number of (parallel) cables between the wind farm and the onshore grid connection point will often be limited for economic or environmental reasons.

Operating conditions : Rapid technological progress is made in the areas of sea cable technology and offshore electrical equipment. Questions to be answered are : What are the maximum (power, voltage, …) ratings for state-of-the-art sea cables, transformers and switchgear.

Maximum distance from shore : For offshore wind farms at a large distance from the shore losses and reactive power production in the sea cable(s) may become important. A question to be answered is : what is the maximum distance from the shore for which grid connection using current technology remains technically and economically feasible ?

1.2.2. Reliability and maintainability of offshore electrical equipment

There is currently little experience with high-capacity transformers and switchgear installed on offshore platforms. The environmental conditions in an offshore environment may significantly reduce equipment reliability (e.g. marine corrosion). Access for maintenance will not always be possible. Design changes to improve reliability and maintainability may yield significant benefits for the development of large-scale offshore wind farms.

The same issue becomes even more important when it is considered to install power electronics (frequency converters, …) offshore.

Information is required regarding the behaviour of electrical equipment in a highly aggressive offshore environment, and regarding developments aimed at improving reliability and maintainability.

1.2.3. AC/DC conversion technology

Whereas most of the current offshore wind energy projects use an AC link for the grid connection, the possibility of using DC links has never been excluded, and due to technological progress in the field of AC/DC conversion technology, DC links may become the preferred choice for future offshore wind farms.
Questions to be answered are : What performance can be expected from state-of-the-art AC/DC conversion technology (in particular, capital cost and electrical losses)?
Economic Break-Even Distance for DC connection. Another important question to be addressed is : From what distance may DC links be considered as being economically more interesting than AC links, taking into account the current state-of-the-art in AC/DC conversion technology. This distance will be a function of MW capacity.
Ease of connection
HVDC may offer control benefits which allow connection to a weaker part of the network, so saving costs. If underground cable is required for the onshore section, for environmental reasons, HVDC may be cheaper than AC.

1.2.4. Improving LSOWE grid connection reliability

Redundant grid connection systems. By increasing the redundancy in the grid connection system it is expected to improve the availability and the reliability of the system. On the other hand, increasing redundancies will also increase the system complexity and cost. Given the limited available information on the reliability of offshore electrical equipment, it is not excluded that increasing redundancy will effectively decrease the overall system reliability. Some questions to be answered are therefore : What is the optimal degree of redundancy to be used in LSOWE grid connection systems ? How must emergency (back-up) power for equipment in the wind farm be provided ?
Internal Wind Farm Grid Lay-Out
Many different designs have been considered for the internal grid of large-scale wind farms. The lay-out adopted for the internal wind farm grid may have an important impact on the global wind farm availability and on investment costs. A question to be answered is therefore : What is the optimal internal grid lay-out ?

1.2.5. Innovative solutions

New wind turbine concepts have been proposed which might significantly alter the cost and the feasibility of grid connection of large scale offshore wind farms. For instance, systems using DC generation in the wind turbines, combined with IGBT-based DC/AC conversion onshore have been announced. The impact of these new designs on grid connection must be analysed.

1.3. Impact of LSOWE on power system performance:

1.3.1. Power Quality issues :

Various factors contribute to voltage fluctuations at the terminals of a wind turbine generator: aerodynamic phenomena (wind turbulence, tower shadow effect, etc) short circuit power at the grid connection point,(?), number of wind turbines, and the type of wind turbine control systems. Under particular connection conditions, this may result in a significant flicker level. As a consequence, some limitations for installed power could be recommended in case of a weak network or particular polluting devices. This is especially valid for offshore wind farms, as the grid connection point may be a weak point of the grid and the building of a reinforced transmission line may not be feasible for environmental reasons.

- Required grid characteristics (Installed power versus short circuit power)
- Impact of long-distance power cable to shore on power stability
- Suitability of existing guidelines for Power Quality Assessment

However typical power quality issues, like flicker, harmonics, voltage fluctuations and variations (during normal operation and during switchings of the wind turbines) is a less problem for LSOWE due to the soothing effect of the number of wind turbines within the wind farm and due to the improved power quality behaviour of today's wind turbines. This problem will be treated in chapter 2.3.1.

1.3.2. Impact of wind turbine generator type and power electronics on power quality

- The impact on voltage control depends primarily on the connection point and the generating plant power output. Present day onshore wind parks have a relative low power output and are connected to the Medium Voltage grid system, which means they rarely have a significant impact on voltage control. But in the event of substantial power increase or wide-scale connection to the High Voltage grid, existing specifications might be changed to account for the impact on voltage control.
- Until some years ago, generator technology for wind turbines used to be mainly based on fixed speed induction generators. For several years however, variable speed induction generators (using IGBT rectifier - DC link - inverter technology) have consistently won an increasing share of the market.). The main advantages of the variable speed wind operation are to reduce drivetrain requirements and to optimise the energy conversion. The power quality such as flicker, harmonics, voltage and frequency variation can be controlled by variable speed wind turbine generators using a power electronics interface. The type of interface used for connecting the wind park unto the network has a determining impact on harmonic interference. Thyristor technology for inverters generates low frequency harmonics (250 Hz to 1 kHz), whereas IGBT technology generates high frequency harmonics (1 kHz to 1 MHz) depending on interface power rating.

1.3.3. Dynamic grid Stability analyses

- The large installed capacity combined with long transmission distances to the net may create problems of instabilities and excessive reactive current transmission. It may be advisable to perform dynamic analyses to understand the nature of the unbalance and to correct the situation.
- Incident conditions (short circuits, voltage dips,..) may have to be simulated with models which incorporate the interface technology (direct coupling, inverter interface, power electronics interface,..) since the interface technology appears to have a determining impact on the system behaviour under incident conditions. For fixed-speed wind turbines, the drive-train characteristics must also be simulated. What is the state-of-the-art in dynamic grid stability analysis tools? Are suitable models available?

1.3.4. Secondary Control requirements

Secondary control is the system-wide adjustment of the production in the neighbouring zone to a new operating situation to maintain balance between production and consumption with a time constant of the orders of 10-15 minutes. The introduction of LSOWE may have an impact on the required dispatchable power. How can this be done ? With hydro power or pumped storage? What is the additional cost to guarantee the needed dispatchable power? In a free market, will this cost increase the cost of ancillary services ? Can the wind farm or wind turbines be controlled satisfactorily to control power, power gradients, and voltage? What does a TSO really need?

1.3.5. Contribution to ancillary services

Ancillary services: are the services needed to transmit the energy from generation plants to end users with guarantees concerning power system dependability. The main ancillary services concern active power and frequency regulation, reactive power and voltage regulation and system restoration after collapse (blackstart capability). We may notice the fact that in terms of quantities, wind turbine generators are expected to take a large part of renewable generation in the future (EU target 11.9 % of the total Renewable energy production in 2010). As a consequence, we should pay great attention to the ancillary services capability of this energy production. Is it sufficient to rely on a market approach, or are firm technical requirements necessary?

1.4. Power system planning and grid access

In a fully liberalised market, the power utility context moves from a monopolistic structure, with technology driven developments, towards an open production competition with market driven developments. The collegial interaction between former geographical monopolies disappears completely.

Superimposed on this trend are some policy driven developments in the field of Renewable Energy, which cannot be handled by the open market as such.

The TSO will remain in hands of geographical monopolies, however subject to “strong” national supervision.

This new situation poses a series of challenges in the power system planning for satisfactory operation of the system as a whole and in particular for the large connecting large offshore wind parks , such as:

- Impact of the **grid code** (connection code) on generating investments (and profitability). The grid code contains the national requirements for the user of the network with strict procedures for connection and information exchange.
- **Technical requirements** for small scale generation and impact in case of substantial penetration of these small scale units. The criteria have been fixed as for conventional onshore wind farms and may not be flexible enough to handle large offshore wind park connections.(e.g. Belgium : Operational reserve should at least be 10% of the total production of the park, with the possibility to recover lost capacity within 15 minutes).
- Impact of **geographically concentrated generation** (particularly large wind parks) on national and interconnected grid development. Special attention should go to investigate the grid capacity along the coastline. Note also that the coastal areas are mostly located at the end of the transmission line, which is not conceived to transmit power in the reverse direction.
- Stability of the context (ruling) in order to perform reasonably long term planning, particularly for large offshore wind parks, which is necessarily policy (and not market) driven. The EU proposal to force **priority access** for Wind energy to the grid is an example.

1.5. Financing of large offshore wind farms

1.5.1. Investment budget for LSOWE

Contrary to onshore wind projects, the offshore technology is not in an advanced state to evaluate the total investment budget with enough precision. Indeed the foundation costs and the interconnection costs, which can easily exceed the cost of the wind turbines, contain some large unknowns and may vary considerably from site to site.

1.5.2. Investment risk of LSOWE

LSOWE contain considerable risk elements that can have a large impact on the production, and hence on the revenues. There is not enough experience with offshore wind parks to evaluate the technical availability, due to inaccessibility for repairs. Advances in technology (based on past experience) may possibly increase the technical availability and hence the production capacity which is a considerable risk factor to reckon with. Operation and maintenance costs are very difficult to predict. No guarantees can be given regarding lifetime of wind farm equipment in harsh offshore conditions.

1.5.3. Financing conditions and insurance for LSOWE projects

- Financing institutions are currently prepared to invest in offshore wind energy projects. Nevertheless, these projects are considered as high-risk investments. **Financing conditions** (e.g. minimum equity versus loan, rates,..) may therefore be higher than for conventional, and even onshore technologies.

- Important investments in LSOWE will only be possible if the inherent investment risk can adequately be **insured**. Therefore, it should be examined to what extend and under what conditions insurance companies are ready to insure offshore wind farms.

1.5.4. Impact of support mechanisms for LSOWE development

Under the current liberalised market conditions, Renewable Energy technologies, face significant barriers to be widely used such as

- High capital cost
- Lack of network infrastructure
- Lack of confidence in these new technologies
- Technical problems associated with the geographical distribution of available potential, and the stochastic nature of the primary energy (Wind)
- Legislative barriers for obtaining construction and operating licenses.
- Electricity trading mechanisms which inequitably penalise unpredictability.

Support mechanisms :

The most critical policy issue towards the EU white paper targets concerns the support mechanisms to be established for Renewable energy (including LSOWE): Across Europe, there exist a wide range of support mechanisms such as :

Fixed feed-in tariffs : (e.g. Germany) : not market based, but highly effective for promoting local industry

- Quota system (with or without penalties) : Competition based mechanisms ensure that the quota are obtained with the cheapest technologies.(e.g. Belgium)
- Public tender approach (cfr former NFFO in the UK) :
- Green certificates (Denmark, Netherlands) : A market based approach where the Wind park generates kWh and certificates which are both handled separately and traded. This requires however a large enough trading area (e.g. European) to be effective and stable. However, this presupposes harmonisation rules at the European level.

2. State-of-the-art Summary

2.1. Interaction between production and consumption – Energy Management Systems

Energy Management Planning is described in [1] as follows :
In all electrical systems *the production* and *the consumption* should always be in close conformity as it would otherwise be physically impossible to keep the system frequency within the allowable tolerances. This balance is the primary reason why continuous production planning is a necessary activity for all utilities. In addition, production planning is of course contributory to the economic and environmental optimal operation of the electrical network.
Focus on the economic optimisation including risk management is increasing with the liberalisation of the electricity markets in the EU and the subsequent competition between the utilities.
It is a precondition that the overall long-term planning ensures the availability at all times of the necessary production and transmission capacity.
Energy Management Planning can be split up into the following activities:

- Load Forecast / Unit Commitment :
- Primary and Secondary Control
- Security Analysis
- Training
- Emergency Control.

2.1.1. Production and consumption patterns

2.1.1.1. Consumption patterns

Generic and national information regarding diurnal and seasonal variations of consumption patterns is systematically collected by national grid operators. Well-proven load forecast tools are available. These tools are used on a daily basis for generating unit commitment. In most countries generic information on consumption patterns is publicly available.

2.1.1.2. LSOWE Production patterns

Generic information on diurnal and seasonal variation of wind energy production can readily be derived from measured wind data eg. [30,31]) Also, production statistics are available in several countries from utility companies or other organisations.

Short-term variability (i.e. variability on a time-scale of 10 minutes) and long-term variability (i.e. variability on a time-scale of 12 to 24h) of the power production of the existing onshore wind farms has been analysed for Germany [2], Denmark and the Nordic Countries [21]. The applied methodology can easily be extended to LSOWE applications.

Worst-case power gradients typically occurring in large wind farms in normal operation are of the order of 10 to 15% of rated power in 15 minutes. It is however expected that much larger variations in the power production of LSOWE can be caused by passing weather fronts and thunderstorms, which could possibly cause a nearly simultaneous shut-down of all wind turbines in the wind farm (though not in several wind farms at once). Quantitative investigations into these power gradients are not publicly available.

An important question to address is this: is it better to cope with variability of output by:

- curtailing wind production during critical periods (in the worst case, ceasing production entirely during storms or other critical periods);
- technical measures to reduce the variability (storage, power gradient limits, VAR control etc.);
- utilising (and paying for) the ability of conventional thermal and hydro plant to compensate for variability of wind production.

2.1.1.3. Production/Consumption Imbalance

In principle the existing information should be sufficient to assess the unbalance between consumption patterns and consumption patterns. The result will however depend largely on local circumstances. Generic assessments (e.g. On a European scale) are only meaningful if cross-border transmission capacity limitations are taken into account.

Since the development of LSOWE has a concentrating effect on wind energy production (i.e. a larger proportion of the total wind energy production is concentrated in some specific areas), it may be expected that the development of LSOWE increases the production/consumption unbalance. Part of this unbalance may be compensated by a geographical smoothing effect (if cross-border transmission capacity is sufficient). For the remaining part however, additional energy management measures are required.

2.1.1.4. Spatial correlation

A study of equalising effects from wind energy in Northern Europe [6] has shown that wind power from sites with a separation of more than 1500 km is nearly uncorrelated. This leads to a smoothing of the wind power production. Change on a time scale of 12 hours can reach ca +/- 30% about once a year. The existing study only considers existing onshore wind farms. An extension of the study based on LSOWE plans in the different EU countries, would yield valuable information regarding the impact of LSOWE development on Energy Management .

2.1.2. Energy Management

2.1.2.1. Demand side Management

By means of currently available information technology, existing demand side management systems (e.g. Double or dynamic tariff systems during night hours and switching of interruptible loads) could be extended to take into account the availability of power from wind energy.

Such measures, although not specifically taking into account wind energy production, are now standard practice with most electricity suppliers for managing peak demands.

RISOE has published a study on the possibility to recharge electric cars with LSOWE by using a tariff signal. The electric cars are in standby in the garage and when the signal is present (thus when there is offshore energy) they charge. RISOE indicates that the cars are often in the garage and that it would be the best way to use clean energy in transport (technology H2 is in gestation).

2.1.2.2. Increasing flexibility of conventional plants

The increased unbalance between production and consumption created by the development of LSOWE can to some extent be covered by increasing the flexibility of conventional power plants. Conventional power plants have some flexibility allowing them to participate in secondary control and to compensate for load variations by modulating their power output. The extent to which conventional power plants can be modulated depends on the type of plant. Hydro-power plants are among the most flexible, even if pumped hydro-power plants often can only be modulated in turbinating (power producing) mode. Fossil-fuel fired plants also have some modulating potential, although modulating is significantly more difficult for coal-fired plant which have a relatively high start-up lag time, and a much higher thermal inertia than for instance gas-fired plants.

In all cases, increasing the flexibility of conventional power plants inevitably decreases their efficiency (due to operation at a sub-optimal working point, and due to increased start-up and cool-down losses). Therefore the extent to which conventional plants can be modulated, may in practice be largely determined by economical constraints. It should also be noted that the modulating potential of co-generation plants is often very small due to constraints imposed by the heat demand. The increased penetration of co-generation plants effectively reduces the modulating potential of the existing conventional power plants.

Few studies are known in which a detailed assessment is performed of the potential and the cost of operating conventional power plants in a modulating mode to compensate for the variability of large-scale non-dispatchable wind energy [27]. However, pilot projects (e.g. Hybrid generation consisting of wind power in parallel to a gas-fired power plants) are underway in some countries. There has been various studies on this subject in Ireland

2.1.2.3. Compensation of power gradients via fast dispatching

Power output from LSOWE plants may rapidly decrease when storm fronts pass, and all wind turbines in the wind farm are nearly simultaneously shut down (when the wind speed exceeds the cut-out speed).

In some countries, it is a requirement from the TSO that the (negative) power gradient caused by the LSOWE plant should never exceed a reduction from 100% of rated power to below 20% in 2 seconds.

Even so, with a large penetration of LSOWE plants, a significant amount of rapidly dispatchable power may be required to compensate for the LSOWE power gradients.

However, in countries where the power system comprises large units (such as 1000 MW nuclear power plants), rapidly dispatchable power of some kind should already exist to cover an unexpected shut-down of one of these large units. Mostly, (pumped) hydropower plants will be used for this purpose. For many countries the existing capacity of rapidly dispatchable plants will be sufficient to cover for the power gradients occurring in their offshore wind farms.

Notice that in [28], it is stated that the Danish requirements for transmission-connected wind farms will make them the fastest-responding generating plants on the system (power ramp rates of 5 MW/minute in controlling mode).

2.1.3. Energy Storage

Technically, storage is a perfectly viable solution for the unbalance between production and consumption. The cost of energy storage may however often be prohibitive, either due to low efficiency (eg. Pumped hydropower) or due to high investment cost.

Although energy storage should be investigated at the level of the entire electricity system (and not only in relation to offshore wind energy), research efforts aiming to decrease the cost of energy storage will definitely be beneficial to the development of LSOWE.

2.1.3.1. Pumped Hydropower

Pumped Hydropower Technology is technically mature, and can in many cases be implemented without unacceptable environmental consequences. However the cost of pumped hydropower is high, mainly due to low efficiency and high investment costs. Typically, the COE[1] for electricity from pumped hydropower ranges between 0.02 and 0.1 EUR/kWh.

2.1.3.2. Hydrogen

Hydrogen technology is often considered promising for use as an energy vector and for energy storage. Research activities in this area are ongoing. The technical maturity of hydrogen technology however remains very uncertain.

2.1.3.3. Regenerative fuel cells

According to [1], a technology which looks promising for maturity by 2010 is the so called Regenerative Fuel Cell(=RFC) under development by Innogy (UK)[2].

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[1] Cost of Energy (COE) calculated assuming an economical life-time of 40 years and an actualisation rate of 7%.

[2] “ The REGENESYS system” by Price et al., Power Engineering Journal, Institution of Electrical Engineers, Vol.13 Number 3, June 1999.

The principles of the technology are verified on small-scale laboratory tests and are based on the electrochemical conversion process such as is used in the fuel cell technology. The RFC comprises two compartments separated by an Ion-selective membrane, separating the electrolytes flowing through each compartment. Electrodes are immersed in the electrolyte as electron transfer surfaces, but do not take part in the electrochemical process and so do not limit the energy storage capacity. The energy storage capacity (MWh) is determined by the size of two external reservoirs containing the two different electrolytes which are pumped through the fuel cell, while the capacity (MW) is determined by the surface area of the ion-selective membrane.

Plans are to build a demonstration plant to provide 120 MWh of energy and up to 15 MWe power rating. The authors claim a full conversion cycle (Electricity-chemical-electricity) of about 70%, with interesting dynamic operating capability including quick start (response time of the order of 0.02 s), quick switching from charge to discharge mode, and can be modulated by a control system. Such system would be able to store the total electrical energy from a 5 MWe wind farm during 24 hours. Such storage system combined with adequate wind prediction models could to a large extend compensate for the supply/demand forecast errors.

This technology promises to be a good alternative to pumped storage power plants, because they have a short response time, are flexible in MW and MWh and independent from dedicated sites. Furthermore, this new technology could become interesting in the future for the delivery of ancillary services, in general.

The Regenesys system should be tested in Laeso (Denmark).

2.1.3.4. Other solutions

Smaller scale techniques are available such as batteries, flywheels, superconducting magnetic storage and super-capacitors, but do not have the power and energy storage capacity needed for storing large quantities of intermittent energy such as produced by LSOWE feeding into the main transport grid.

2.1.3.5. Long distance storage

Long distance storage (using for instance the large Scandinavian hydropower capacity) could in principle be a viable energy management option. Currently however, long distance storage on a European scale is not feasible due to technical restrictions on cross-border electricity transmission, reinforcement costs, and due to the organisation of the electricity markets in Europe.

2.1.4. Forecasting tools

According to [1], energy management of electrical systems implies that the production is adjusted to the inevitable load variations throughout the year, all the way down to day level – even down to hourly or quarter of an hour level - by following the prognoses for the load. The load forecast is at first based on statistical data for consumption during previous years adjusted to the expected development in consumption and on a day-to-day basis corrected for temperature conditions, other climatic factors and the actual consumption on the previous days or weeks. On basis of these prognoses a Unit Commitment Plan is prepared showing which production plants should be in operation, and the output which they are to feed to the network within given intervals. In this planning process considerable consideration is paid to the operating costs of the various plants as the base load should be covered by those plants which have the lowest production costs inclusive of net losses. Consideration should also be made to start-up costs, which may vary greatly.

Pumped-hydro plants are very suitable to cover peak loads, which normally occur a few times a day. If such plants are not available other production plants must be scheduled for these situations.

The producers on the power market must also consider the expected price level on the Power Exchange and any constraints in the network when their Unit Commitment Plan for the following day is prepared.

Obviously any electrical system can absorb a certain amount of unregulated and stochastic production from LSOWE as the system must be designed and operated in order to accommodate the changes in the consumption, a trip of a conventional production unit or a fault on a transmission line. However, the exact amount of LSOWE that can be accepted without any modifications of the procedures or tools for system operation must be carefully analysed in each case.

For systems with a high penetration of LSOWE, the most significant difference is that in addition to prognoses of the consumption, prognoses are also to be prepared of the unregulated wind power production. Such prognoses are necessary both for the TSO and for the players on the power market that own significant wind power production sites as well.

2.1.4.1. Development of forecasting tools for wind energy production

In recent years wind energy forecasting tools have been developed in countries such as Denmark or Germany (e.g. [12],[13],[14],[24]). These tools are being applied by utilities for trading and unit commitment purposes. Also, some forecasting tools are available on a commercial basis. Projects are currently underway to merge some of the existing forecasting tools.

2.1.4.2. Suitability for balancing requirements

Currently available forecasting tools are in general not considered sufficiently reliable for assessing balancing requirements, i.e. to dispatch other power plants to compensate for the short-term variability of wind farm output. It is not expected that this will change with the development of new models. Other short-term energy management solutions (e.g. Energy Storage or Modulation of Conventional Power Plants) remain necessary to compensate the short-term variability of wind power.

2.1.4.3. Suitability for trading requirements

Currently available forecasting tools are to some extent considered sufficiently reliable for use in electricity trading (i.e. for day-ahead planning of purchase and sales bids on the power exchange). This means that, with careful risk management methods, the average accuracy of forecasts is sufficient to limit financial losses due to erroneous forecasts to an acceptable level. However, trading based on forecasting tools is currently applied to the average wind power from many different wind farms dispersed in a certain geographical region. With LSOWE it may be expected that wind power will be geographically more concentrated, and more advanced forecasting tools may be required.

2.2. Design and operation of the transmission grid : A. Connection technology for LSOWE

Overviews of currently existing electrical connection technology for LSOWE technology haven been presented in e.g. [18], [25]. Special workshops dedicated in particular to HVDC transmission for offshore wind farms have also provided a useful discussion forum on this subject.

2.2.1. Feasibility limits

2.2.1.1. Cable length

For large distances to shore, cable losses become important, and cable cost may become excessive. The maximum distance from shore for which grid connection is technically and economically feasible depends on the choice between AC and DC transmission. With state-of-the-art AC technology the maximum distance is in the order of a few hundred km [29]. With DC technology the maximum distance has no practical upper limit.

2.2.1.2. Operating conditions

Using state-of-the-art technology, the maximum (active) power which can be transmitted by a single three-phase AC cable between wind farm and shore is about 30-40 MVA for a transmission voltage of 30 kV, and about 140-150 MVA for a transmission voltage of 150 kV. This implies that very large offshore wind farms (with an active power larger than 100 MW) would require more than one cable at a 150kV transmission voltage. Cables may run in parallel tracks, but safety distances are required between the cables, which causes an increased use of sea surface often in vulnerable areas close to the cost. [Due to electric interference or to installation requirements??]

It should also be noted that advanced power cable technology would allow transmission up to 450kV for single-phase cables, and that DC transmission of about 600 MW should be possible through a single cable operating at 500 kV.

2.2.1.3. AC/DC conversion technology

Very important developments have been made recently in forced commutation AC/DC conversion technology (Voltage Source Converter based HVDC), which could possibly make DC grid connection of offshore wind farms economically attractive in the near future (eg. [26]).

Whereas conventional (natural commutation) has been in use for more than 50 years, it is still unclear whether the new forced commutation systems are sufficiently mature for large-scale application in offshore conditions.

Even if the economical analysis of different grid connection options is very much project-specific, it is estimated that HVDC-based links may become more attractive than AC links starting from distances of about 50km from the shore.

It should also be noted that the HVDC-technology offers additional benefits regarding transmission network and power quality management (e.g. STATCOM (abbreviation?? functionality) (cfr. 2.2.3).

2.2.2. Reliability / Maintainability

2.2.2.1. Component Reliability

With adequate design measures (protection levels, sheltering, use of gas-insulated closed switchgear, …) state-of-the-art electrical equipment is considered sufficiently reliable for offshore installation.

2.2.2.2. Component Maintainability

Maintenance requirements for offshore electrical equipment are expected to be similar to requirements for land-based installations (about one service visit per year). Maintenance costs are however very difficult to estimate, since they highly depend on accessibility and work conditions. This uncertainty can only be reduced by feed-back from test and demonstration projects.

2.2.2.3. Grid connection lay-out

Whether or not a redundant grid connection lay-out (e.g. Two separate cables between wind farm and shore, or an interconnected internal wind farm grid) is necessary to assure a sufficiently reliable grid connection, is project-specific. The question can be answered by straightforward risk analysis, provided that adequate cable failure data and cable repair times are available.

2.2.3. Innovative solutions

The development in recent years of power electronics equipment to the point at which it can be used in electricity transmission is a major development in electrical engineering. According to [1], the most important features of this development are, firstly, reliable application of thyristor equipment in High Voltage Direct Current (HVDC) equipment and in Static Var Compensators (SVC) and, secondly, the more recent advent of IGBT or GTO devices with a controlled on/off capability at power levels compatible with the necessary rating for transmission. This technological advance opens new possibilities for power equipment permitting better management of transmission networks through rapid, continuous and flexible control of reactive and active power flows. Such techniques are of interest to those faced with new challenges in their transmission activities, such as increasing environmental pressure and deregulation, both resulting in a less predictable future. In fact, this electronic equipment enables more extensive use of the thermal capacity of power lines, without decreasing the stability margin.

2.3. Design and operation of the transmission grid : B. Impact of LSOWE on power system performance

2.3.1. Power quality

Electricity is supplied at a specified quality level, expressed (as regards voltage characteristics) in terms of standard thresholds for the following (ref. [1]) :
- voltage imbalance;
- slow voltage fluctuations;
- rapid voltage fluctuations and flicker;
- harmonics.

The voltage quality rules governing network access for generating plant operators define minimum network characteristics at the connection point[3], plus minimum technical conditions for the plant (for existing producers or new incomers). These rules are determined to ensure that consumers enjoy supply quality within applicable standards.

Various factors contribute to voltage fluctuations at the terminals of a wind turbine : aerodynamic phenomena (wind turbulence, tower shadow effect, etc), short circuit power at the grid connection point. Under particular connection conditions, this may result in a significant flicker level. As a consequence, some limitations for installed power could be recommended in case of weak network or particularly polluting devices.

Special attention should be paid for LSOWE since the grid connection point may be a weak point and correlatively the building of a new onshore transmission line, in opposition with environmental politics, may be required.

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[3] The supply terminals mark the limit of the properties defined in the connection agreement between power system administrator and generating plant operator.

2.3.1.1. Flicker

Experience from onshore wind farms shows a noticeable impact on flicker levels on small island grids (e.g. [19]). Similar effects might be expected from large offshore wind farms.

However, in general flicker emission is not considered to be a limiting factor for the development of LSOWE for the following reasons :

- Flicker emission of wind turbines is highly dependent on the wind turbine technology. Modern variable or semi-variable speed wind turbines show relatively low flicker emission levels.
- High frequency fluctuations of power output from wind turbines in a wind farm are not correlated. Increasing wind farm size does not cause an equally important increase of the flicker level.
- Large offshore wind farms need to be connected at a sufficiently high voltage level to limit transmission losses. Typically at high voltage level (e.g. 150 kV) the short-circuit power of the grid at the point of common coupling is sufficiently high to limit flicker to an acceptable level.

2.3.1.2. Harmonics and interharmonics

Harmonics and interharmonics are not considered to be a limiting factor for the development of LSOWE. Even if inverters used in modern variable speed wind turbines or HVDC systems generate harmonics and interharmonics, standard filter techniques can be applied to limit the emission of harmonics and interharmonics to an acceptable level.

2.3.1.3. Impact of long-distance sea cable on power quality

A particular feature of offshore wind farms, compared to onshore wind farms, is the influence of the power cable between the wind farm and grid connection point on power quality. The power cable generates reactive power which may need to be compensated. Some voltage control problems may be expected, e.g. due to severe inrush transients when switching on transformers.

It should also be noted that the power cable may have a beneficial impact on power quality by acting as a harmonics filter.

2.3.1.4. Power quality assessments

Current assessment methods for flicker, harmonics and interharmonics (e.g. Draft IEC 61400-21, which is expected to be issued as an international standard in 2001) are considered suitable for application to large scale offshore wind farms.

2.3.1.5. Power quality measures

It is expected that variable speed wind turbines will in general augment the power quality of large scale offshore wind farms. Additional measures which may be taken are : installation of filters for harmonics, VCS-controlled switching to reduce switching transients.

In severe cases STATCOMs or SVCs may be installed to reduce or eliminate flicker. The same functionality is obtained from state-of-the-art HVDC-links.

2.3.2. Grid Infrastructure

2.3.2.1. Grid requirements

There are no generic or firm requirements regarding grid characteristics at the grid connection point for connecting large scale offshore wind farms. The required voltage level will be dependent on the wind farm active power output. Typically wind farm sizes in the range of 100 MW would require connection at the 150kV level. The required Short-Circuit Power Level also depends on the wind farm nominal power. Some countries and grid operators limit the allowable ratio of wind farm nominal power to short-circuit power at the grid connection point. However the limiting ratio appropriate for small wind farms is likely to be inappropriate (conservative) for large wind farms.

2.3.2.2. Grid suitability

In general the transmission grid is not very strong in coastal areas, except for areas with significant industrial or harbour activity, or in cases where nuclear power plants have been built close to the seafront. Therefore onshore grid connection (i.e. covering the distance from the shore to the nearest substation where the grid is sufficiently strong) may represent a significant part of the total offshore wind farm cost. This is especially true when the use of overhead lines is not acceptable for environmental protection reasons, and cables must be used instead.

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2.3.2.3. Grid reinforcements

The strength of the currently existing grid in coastal areas may become a limiting factor to the large-scale development of offshore wind energy. The impact of this limiting factor has until now not been taken into account in offshore wind energy potential studies.

Connecting large-scale offshore wind farms will require some grid reinforcements in coastal areas (cables and switchgear) . There seems to be a need for studies into the relationship between the technical-economical offshore wind energy potential, and the investment cost required for grid reinforcements. There is also no clear view on whether grid reinforcements should be born by the project developers, or by the grid operators (see 2.4.1.7).

2.3.3. Grid stability

2.3.3.1. (Static) stability

Slow voltage variations can be eliminated by means of tap-changing transformers and/or reactive power control, and should therefore not become a limiting factor for the grid connection of large scale offshore wind farms.

Set points of grid protection equipment should in principle not be affected by the presence of offshore wind farms. Neither will the control system set points of other power plants be directly affected (although the introduction of large amounts of wind power will increase the control effort to be performed by these control systems).

2.3.3.2. Loadflow-analysis

Load flow analysis is required to assess the feasibility of connecting large-scale offshore wind farms to the grid. Traditional load flow analysis methods are suitable, although some stochastic features need to be taken into account due to the variability of wind power production. Load flow analysis should cover all realistic scenarios. As a minimum, four scenarios must be analysed, comprising minimum and maximum wind farm output, combined with minimum and maximum 'system' demand, taking into account possible shut-down of conventional plants.

2.3.3.3. Dynamic grid stability

Dynamic grid stability issues may be a limiting factor to the grid connection of large offshore wind farms. In particular, the dynamic impact on the transmission grid of a nearly simultaneous shut-down of all wind turbines due to high wind speeds (above cut-out wind speed) should be taken into account. The importance of dynamic grid stability issues depends to a large extent on the imposed specifications for connecting wind farms to the grid. Most specifications imposed until now (mainly intended for dispersed wind power generation connected to the medium voltage grid), simply allow wind farms to disconnect in case of grid faults (and to reconnect when normal grid conditions are restored). A similar requirement cannot be imposed in case of large-scale, geographically concentrated wind power generation. For example, the Eltra specifications imposed in Denmark, require the wind farm to withstand three-phase grid faults without attempt to reclose, and two-phase faults with an unsuccessful attempt to reclose [28]. These requirements may lead to modifications in the wind turbine control systems. Dynamic grid analyses are required to demonstrate that the specifications can be met.

2.3.3.4. Dynamic Grid Analysis

State-of-the-Art Dynamic Grid Simulation Codes in use in many countries (such as EUROSTAG, NTUA, INETI, …) are suitable for the analysis of dynamic grid stability of offshore wind farms. In general these codes have standard models for synchronous generators, and even for standard asynchronous generators. However, further development of wind turbine/generator models is required to take into account the particular dynamic behaviour of advanced (variable speed) wind turbine generators and their power and speed control systems.

2.3.4. Impact on national grids

Primary and Secondary Control

According to [1], by primary and secondary control is meant the production control which is necessary to handle the inevitable difference between prognosis and the actual load including of losses. The turbine controllers in the controlled units are to engage automatically and increase the production in case of frequency drop or reduce the production in case of frequency increase. This is called primary control and is as such part of the Automatic Generator Control (AGC), acting with a time constant in the range of 1 sec.

The primary control is defined by the following two parameters :

- Spinning Reserve (MW);
- Droop (%).

Sufficient and fast primary control ability is necessary in all electrical systems and must be very well co-ordinated to avoid instability. The co-ordination embraces both the geographical dispersion and the above mentioned primary control parameters.

The control possibilities including response time are highly dependent on the type of plant as hydro plants have far better control possibilities than thermal plants. Within the framework of NORDEL, among others, so-called ”Power Station Specifications” have been prepared which set up specific requirements to the utilities’ capability of participating in the primary control.(see also chapter 3.2.2.1)

The primary control ability is at the present not commercially available on the deregulated power market.

Secondary control is the subsequent system-wide adjustment of the production to a new operating situation in order to maintain the frequency to its nominal value, e.g. 50 Hz. There is a desire in order to keep the exchange of power across borders within the planned programmes. The time constant of the secondary control is roughly 10-15 minutes from the time that the intervention of the primary control is achieved.

In some cases, e.g. in large nuclear power plants, the secondary control is automatic. In other cases, the secondary control is performed manually at the power plants on request from the regional dispatch centre.

LSOWE plants – at least with today’s technology – do not constitute reserves of primary or secondary control.

Therefore, a high share of unregulated production causes a markedly higher need for secondary control on conventional units in order to compensate for the stochastic production from, e.g. wind power. A high production from LSOWE plants often means that the primary utilities are forced down in the load area and as such away from the economic and technical optimum operating load.

Additionally, the ability to perform primary and secondary control may be expected to be a valuable product in a competitive market, as regulating power could be sold to the TSO for a price above the spot price. A large LSOWE production on European level would then require a higher amount of regulating power thus increasing the value/costs for this product.

2.3.4.1. Reactive Power

Even using advanced variable speed technology, wind farms can only generate reactive power to a limited extent. Unless the wind farms are grid connected through innovative HVDC-links with STATCOM-functionality, the development of LSOWE, partially replacing conventional power plants, will increase the reactive power generation requirements for the remaining conventional plants.

2.3.4.2. Primary control

Due to the short-term variability of wind power, the development of LSOWE will impose an increase of the primary regulation effort on all non-wind generators operating in the interconnected grid system, unless primary control requirements are equally imposed to the wind farms (i.e. unless wind farms are treated on an equal basis compared to conventional power plants).

At present, there are no studies showing quantitatively how much additional primary regulation will be required from conventional generators, if (offshore) wind energy develops according to national plans without primary control requirements.

Since some countries have already decided that wind farms should participate to primary control, there is manifest a need for the development of improved methods allowing offshore wind farms to participate to primary control. [Is this achievable?]

2.3.4.3. Secondary control

Due to the short-term variability of wind power, the development of LSOWE will impose increased secondary (frequency) control requirements to the generators in the national systems to which the wind farms are connected (due to operating practices and international rules), unless secondary control requirements are equally imposed to wind farms.

2.3.4.4. Unit Commitment and Spinning Reserve

Whether or not the development of LSOWE will create unit commitment problems will largely depend on the availability of reliable wind power forecasting tools.

Spinning reserve requirements will probably need to be adapted, taking into account the relative unpredictability of wind power generation, but also the possibility of losing an entire offshore wind farm due to grid faults, unless redundant grid connection is provided.

2.4. Design and operation of the transmission grid : C. Power system planning and grid access for LSOWE

2.4.1. Grid access requirements

The main operating requirement of an electrical power system is that voltage and frequency should be kept within permissible ranges. This determines both service quality and safety factors (ref. [1]):

- power system dependability directly determines the quality and continuity of service offered to consumers, especially since large-scale electricity storage is not yet a viable option for palliating the wide variations in consumer demand with season and time of day;
- protection of persons and property (under normal and incident conditions) is an increasingly critical issue given the growing dependence on electrical power in many aspects of everyday life.
- To ensure dependable power system operation, the operator must substantiate satisfactory performance of system components, both in the network (line protection efficacy, waveform quality, etc.) and in the generating plant (stability, supply capacity, impact on regulation, etc.). The term "performance" is used here, to refer indistinctly to functionality's, technical characteristics and capacities.

Voltage regulation

To maintain contractual voltage quality and ensure system safety (i.e. avoiding voltage collapse), the system must be capable of keeping voltage within the permissible range.

As far as the power system is concerned, the crucial factors are voltage regulation and reactive power capabilities at the supply terminals, i.e. the busbar of the generating plant. Generating plant performance requirements are therefore specified at this location.

Again at the supply terminals, generating plants must be able to withstand voltage variation within "normal" and "exceptional" ranges, the former being specified with no duration or performance limitation.

Frequency regulation

The supply frequency reflects the power system's generation/load balance, and should be maintained close to rated value. This requires a certain spinning reserve, to compensate against incidents, natural demand fluctuations, and generating plant tripping . The primary frequency regulation system is responsible for automatically adjusting generating plant output to accommodate changes in load.

UCPTE (Union for Co-ordination of Production and Transmission of Electricity) rules on primary frequency regulation[4] for member organisations state that above a power level determined by the connection voltage, generating plant operators must afford a constructive primary reserve capacity of at least 2.5% of the total plant power output.

Other recommendations specify the frequency ranges within which equipment is required to operate (normal frequency range of 49.5 to 50.5 Hz, plus exceptional frequency range).

Currently, in some countries voltage regulation and frequency regulation demands for LSOWE are identical to those of other power plants (ref. Denmark Eltra). In other countries no specific requirements are imposed. Nevertheless, when LSOWE forms a significant part of the total generating capacity, voltage and frequency regulation requirements can only be fulfilled if :

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[4] UCPTE recommendations on primary frequency regulation: UCPTE ground rules

- the LSOWE take part in frequency and voltage regulation, which requires development of improved wind turbine control systems ;
- the burden of frequency and voltage regulation is put on the traditional non-renewable generating capacity, and the cost of frequency and voltage regulation is accounted for in the transmission fees.

The development of LSOWE may therefore require :

- to re-examine the UCPTE (supranational TSO) rules in respect with regulating capacity and margins at individual TSO level;
- to provide voltage and frequency regulation on wind turbines by using electronic power converters in combination with variable speed and pitch control;
- to implement non regulated RES-E with associated Static Var Compensator (SVC) for voltage control and/or energy storage (SMES, Pumped storage, Reversible Fuel Cells) for both frequency and voltage control.

Like the network itself, a generating plant (with its regulation system) should possess electromechanical characteristics capable of ensuring uninterrupted operation of the power system under incident conditions.

Very broadly, we distinguish between two types of incident situation: those which involve separation of the generating plant from the power system (to form an island or separate network), and those which do not.

Incident conditions without separation from power system

Because of the difference between protection plans for interconnection networks (400 and 225 kV) and distribution networks (less than 100 kV), we must specify the generating plant connection point. Specific incident conditions for examination could include the following :

- static stability or stability-related performance under minor incidents
- stability under heavy transients: response to single-phase/three-phase short-circuit or voltage dip
- behaviour under slow voltage collapse

On the opposite, voltage stability is a major issue. For instance, wind plants using induction generators are very sensitive to voltage drops which leads to loss of the wind turbine generation for the grid. As for the power electronic systems it is possible to operate, to a certain limit, at less than full voltage output capability, these wind turbines should not lose synchronism and thus stay stable after slight voltage drops. According to the French Technical Requirements for Power Plants Connection[17], it is required to IPPs plants to be stable and to stay connected to the grid after a defined voltage drop pattern. As a conclusion, it appears that requirements into generator manufacturer design for better stability to voltage variations, are still needed in order to avoid transfer limits on power from remote LSOWE plants.

An important design and operation requirement for safe utility and TSO operation is overall system stability on typical faults.

In a conventional system, this is essentially an electromechanical problem, whereby the behaviour of the (synchronous) production units is essentially represented by adequate models.

LSOWE plants with voltage sensitivity (inverters) or "induction generator" behaviour may well drop out for faults far earlier than the conventional generators in the grid.

In case of massive LSOWE injections, this may have unexpected adverse effects on the stability of the remaining system.

On the side of LSOWE technology, developments should be made to allow "reconnection in flight" of production units after a transient fault in the network. This supposes correct discrimination of the "external" fault by the wind turbine generator, safe disconnection without irreversible effects (blown fuses …) and smooth reconnection as soon as the normal grid conditions are re-established.

On the side of conventional network techniques one should consider network operation strategies, in which a substantial LSOWE production may disappear without resulting in system instability or voltage collapse.

Incident conditions with separation from power system

Following a serious incident, an isolation of generating plants from the power system may occur, in which case they may be isolated altogether or remain connected to an isolated sub-network. Generating plants must be able to withstand the resulting transient and sustain a satisfactory situation under these conditions (islanding or isolated sub-network) until restoration of normal conditions as part of the main network

2.4.1.1. Technical requirements

All grid operators apply technical requirements (e.g. Related to reactive power, flicker and harmonics,…), but these requirements vary greatly from country to country.

Some of the existing regulations are specifically adapted to wind power generation, but in most cases these special regulations are limited to connection at the MV-level. As such they may not be applicable to large offshore wind farms which will require connection at the HV-level.

Regulations specifically developed for large wind farms connected to the HV grid have already been developed in Denmark If LSOWE develops significantly it may be expected that technical requirements for grid connection of offshore wind farms will become very similar to requirements imposed to other kind of power plant.

2.4.1.2. Non-technical requirements

Among the non-technical requirements imposed by most grid operators in a liberalised market is the requirement for a power purchase agreement (PPA) between the project developer (producer) and a client (consumer).

2.4.1.3. Grid support requirement

Regarding grid support requirements, two very different approaches are currently in use :

1. In some countries (eg. DK) grid support requirements (primary and secondary control, reactive power production) are shared between all generators on a pro rata basis. In this case LSOWE plants must participate to grid support ;

2. In other countries (eg. UK, B), grid support is provided by some generators only, in return for an economical incentive. In this case a free market for so-called ancillary services exists, alongside the free market for the physical electricity. This means that LSOWE plants have no obligation to participate to grid support, but they may choose to do so for economical reasons. It is important that the markets in ancillary services are fairly set up and regulated.

2.4.1.4. Impact

Requirements imposed by national grid codes are in general not considered to be a limiting factor for the development of LSOWE. From a technical point of view, even the most stringent current requirements can be fulfilled by using state-of-the technology. Nevertheless compliance with grid code requirements may cause a significant cost increase for some LSOWE projects.

2.4.1.5. Suitability

In general the requirements imposed by national grid codes are considered as being not particularly suitable for non-predictable, highly variable energy sources, with the exception of the Danish requirements which have been specifically developed for use in offshore wind energy.

In all cases, project developers may have to take additional measures to comply with the grid codes, such as : use of variable speed wind turbines, special purpose remote control systems (with individual power set points for the wind turbines, …)

In the long term, HVDC transmission and/or on-site storage facilities with controllable reactive power output, might present interesting opportunities allowing LSOWE plants to meet grid access requirements more easily.

2.4.1.6. Priority access

Priority access can be relatively easily accomplished for a small number of small-scale renewable energy projects (e.g. < 10MW). For large-scale offshore wind farms however, unrestricted priority access would create significant additional costs for the transmission system and/or the other generators. Then it has to be decided how these costs are calculated and distributed amongst the stake-holders. The question is : ‘Who pays for priority access ? The project, the other generators, the customers, or the tax-payers ?’.

2.4.1.7. Ownership

In some countries (e.g. UK, B, …) sea cables will be owned by the LSOWE project, and ownership limits will be decided on a project by project basis. In some other countries however (e.g. DK) the sea cables are owned by the national grid operator, who effectively extends his grid to the location of the LSOWE plant. This causes a significant cost reduction for the LSOWE project (as the grid connection cost is largely incurred by the grid operator who transfers this cost to all customers).

2.4.2. Ancillary services

According to [1], ancillary services are services needed to transmit the energy from generation plants to end users with guaranties concerning power system dependability. The main ancillary services concern active power and frequency regulation, reactive power and voltage regulation and system restoration after collapse.

Primary regulations : voltage and frequency

LSOWE plants using induction generators without any power electronic interface to the system (cf. §5.2.1.2) can not ensure satisfactory performances, as far as primary regulations (voltage as well as frequency) are concerned, particularly when no wind, the basic power source, is blowing.

Concerning voltage control or VAR control (reactive power), the two other groups of generation systems (cf. §5.2.1.1 and §5.2.1.3) can provide good performances and hold a unity power factor. This is a well established result for generation systems using conventional alternator. For generation systems using power electronic interfaces, it is possible to operate less than full voltage and thus to hold a various range of power factor.

According to the French Technical Requirements for Power Plants Connection[5], IPPs are required to maintain their output voltage to the nominal value plus/minus 5%, and thus to be able to regulate the voltage in one of the three different following options decided with the System Operator : at constant voltage, at constant reactive power output, or according to the linear relation $U = Uo + k.Q$ (Uo nominal voltage, Q constant reactive power output and k constant reactive droop).

Contribution of stochastic RES generation (e.g. wind turbines or PV) to frequency control is possible only if they use power electronic interface. But in such cases, an efficient frequency control would lead to decrease the energy output and consequently decrease their economical profitability.
Moreover in case of high penetration of stochastic RES generation in a network, power fluctuations from stochastic RES generation increase the need of spinning reserve[6] and frequency control includes an extra burden on the conventional power plants.
According to the French Technical Requirements for Power Plants Connection to, for example HTB[23], it is required to IPPs to provide spinning reserve equal to 2.5% of their nominal power. For the time being, nothing is specified for RES generation but should be in the future as far as RES penetration is expected to increase.

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[5] French Technical Requirements for Power Plants Connection, for units under 120 MW and connected to HTB voltages (45 kV to 225 kV, 400 kV excluded) – Arrêté du 30 décembre 1999.

[6] According to the UCPTE Ground Rules, the loss of 3000 MW of generation in the UCPTE grid must lead to a frequency collapse under 200 mHz. This point is the basic data to determine the spinning reserve needed for the grid.

Technical solutions (blades and speed control, electronic devices, etc.) are possible for RES generation plants so that they can participate to frequency control. The funding of these technical solutions may be balanced in the new energy market by the ancillary services payment and less power fluctuation from stochastic RES may imply lower additional spinning reserve for the system.

Black start

Black start ancillary service is the ability for a plant to generate power after a complete collapse of the network (no more voltage and other generation).
Even if black start capability is not frequently required for traditional power plants, except for hydro units, it may be profitable for biopower and geothermal plants to propose this ancillary service particularly if they are well geographically located (e.g. close to a large power plant).

2.4.2.1. Reactive power

If required, LSOWE plants can contribute to reactive power generation. Controllable reactive power generation (i.e. with set points for reactive power determined by the grid operator) is however most easily accomplished by means of variable speed wind turbines and/or VSC HVDC transmission.

2.4.2.2. Primary control

If required, LSOWE plants can contribute to primary control (i.e. production/consumption balancing on a 10sec time scale), although this is associated with a significant energy penalty.

2.4.2.3. Secondary control

If required, LSOWE plants can contribute to secondary control (i.e. production/consumption balancing on a 10min. time scale), although as before this would be associated with a significant energy penalty.

2.4.2.4. Black-start capability

In general wind turbines require a pre-existing voltage source with stabilised frequency and can therefore not provide black-start capability. From a purely technical point of view, by means of advanced technology, black-start capability could be realised, but only at a very significant cost.

2.4.2.5. Ancillary service opportunity

In principle, delivery of ancillary services, could be seen as an new economical opportunity for LSOWE plants. Nevertheless, wind farms can only provide ancillary services at a very significant cost. Therefore it is unlikely that LSOWE plants could become competitive to conventional plants on the ancillary services market, and it is equally unlikely that ancillary services would become a major source of revenue for LSOWE projects.

2.4.3. National Grid

2.4.3.1. Offshore grid extensions

Offshore extension of the transmission grid (i.e. the creation of offshore substations owned and operated by the TSO) may have an important cost reducing effect since this would allow to share grid connection resources between different wind energy projects in the same area. Shared grid connection has the additional benefit of reducing the environmental impact of the sea cable and its landfall. A single 100 MW cable is indeed expected to have lesser environmental impact than 5 separate 20 MW cables. Nevertheless, taking into account the current technological limits for 3-phase AC connection, large clusters of offshore wind farms (many times 100 MW) will still need several cables, unless HVDC links are used.

In principle it would also be feasible to interconnect several offshore substations by means of sea cables to create an interconnected offshore grid. This would increase the grid connection reliability of offshore wind farms. Nevertheless, it should be noted that onshore grid reinforcements are far less expensive and much easier to maintain than an offshore grid.

2.4.4. International Grid Aspects

2.4.4.1. ACE requirements

International Area Control Error (ACE) requirements force national TSOs to keep the imbalance between production and consumption on a 15min time-scale within pre-set limits, either by secondary control of production units, or by cross-border traffic. If these ACE requirements are not changed to reflect the increased production variability induced by large concentrations of LSOWE plants in some areas, this would severely penalise the countries having installed LSOWE. This would also effectively prevent achieving a truly international market for electricity from wind.

2.4.4.2. Cross-border transmission capacity

Both for long term transmission system planning as for daily operation of the European interconnected system a faithful representation is needed with sufficient (but not excessive) detail. These power system models, including data relating to production as well as equivalent network representations, should be developed and publicly made available or commercialised to all operators and players on the liberalised market at European scale.

An overview of exiting cross-border connections is presented in [1]. There is at present no comprehensive assessment the impact of cross-border transmission capacity on geographical smoothing of wind power variability , nor of the feasibility of long-distance energy storage.

2.4.5. Power System Planning

Long term planning has been carried out for long by utilities as they had to prepare generation and transmission investment plans to be submitted, amongst others, to national authorities and their management boards. Although it is expected that this practice will evolve in the near future according to the introduction of the market liberalisation, it is worthwhile examining how such planning practices were undertaken until now. Indeed, indicative planning will remain a necessity for national authorities in order to monitor their electrical system and for the utilities, in order for them to comply with their own market share of the electrical power demand.

Long term planning covers time spans from one to 20 years. Each time-span can be divided in several sub-periods for analysis purposes. Several categories of analysis are currently undertaken in the framework of long term planning :

- investment planning, either by use of a pluri-annual optimising model or by simulating scenarios of investments on an annual basis using techniques of probabilistic costing;
- probabilistic generation costing, for the simulation of the generation system on an annual basis;
- reliability analysis in generation and transmission, usually by using Monte Carlo simulation techniques.

Currently available methods and tools for long term power system planning can already cope with centralised large-scale renewable energy sources, connected to the transmission grid. (ref. [1]) As such these methods should be suitable to deal with LSOWE.

2.5. Financing of large offshore wind farms

2.5.1. Investment budget

Generic information regarding investment budgets is available from many feasibility studies and to some extent from existing offshore wind energy projects. The available data however do not cover the entire range of cost influencing parameters (such as distance from shore, water depth, wind and wave climate, soil conditions, …) which may be encountered in case of a significant Europe-wide development of LSOWE.

It should be noted that some of the above conditions, in particular soil conditions, may show significant variations even within a single country. For some projects, the differences may be large enough to require the use of different foundation solutions.

It should also be noted that investment costs related to the compensatory measures are difficult to evaluate by the lack of experience : example for the radar’s or the UHF emissions, for protections anti-erosion, for the compensations of the fishermen. The costs of dismantling can be integrated in the initial invest (2% of the total budget as on the Danish projects, which appears weak) or in exploitation by constituting a reserve (as what is required in Belgium). Their evaluation is very difficult today. In addition, the regulation will be able to evolve (and will evolve): will it be possible in 20 years simply to explode the monopiles ?

2.5.2. Investment risk

Investment risk for onshore wind energy projects is well known and has been described to some extent [EWEC99, Raftery et al].
For offshore wind energy projects, additional risk arises due to :

- The possibility of major transport and installation delays due to bad weather,
- Large uncertainties on accessibility and availability
- Large uncertainties on O&M-costs (incl. Eg. Taxes and royalties)

In addition, even more far reaching risk may be caused by the application of relatively new technologies in environmental conditions that are badly defined. Questions remain related to eg. wake effects in large wind farms, lifetime of offshore wind turbines, etc.

Industry takes uncertainties into account by applying proper margins to budget estimates. However, for a better understanding and quantification of investment risk, it is required that operational feed-back from test and demonstration projects around Europe is analysed in a coherent way.

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In the long term, a cost reduction could be possible by the introduction of a cost sharing system between different operators.. This requires cross holdings between operators limiting the risks and reducing the costs. This organisation is different from those of the terrestrial projects, and will be easier to realise with operators of big size that with smaller size wind turbine developers. Thus these operators could share a data base on the available resources and on the maintenance costs like it is done in offshore oil Companies. This would create a professional organisation gathering these data for the benefit of all. It is necessary to note that on sea the actors are naturally more "united" by the difficult conditions and of the significant costs. A mutation of wind energy seems necessary to this stage. We could then propose to provide the foundations of such exchange structure between operators (with various under-topics : technology, impacts, compensation, dismantlement…).

2.5.3. Financing conditions

From the current developments of demonstration LSOWE projects of various sizes , it would appear that sufficient equity capital is available for financing LSOWE projects. Some major oil & gas companies and utilities have announced LSOWE projects which could be financed by company equity. Nevertheless, many other projects have apparently been announced well before financing was secured. It still remains to be determined under which conditions (due diligence, certification, insurance,…) bank loans will be granted for LSOWE projects. Only test and demonstration projects will allow to establish an answer to this question.
Even in a country such as Germany where financing is easily achieved for onshore wind energy, it is not certain that off-shore wind energy projects could be financed in the same way. Obviously the financial risk involved in a large-scale off-shore wind energy investment is much larger than the risk involved in a series of smaller on-shore wind energy investments.

2.5.4. Insurance conditions

Whereas insurance conditions for onshore wind energy are well established (and typically amount to about 2.5% ot the annual 0&M costs), it remains to be determined at which costs machinery breakdown and/or production loss insurance will be available for LSOWE projects. Only test and demonstration projects will allow to establish an answer to this question. The evolution of safety regulations may have an important impact on the evolution of insurance costs.

2.5.5. Support mechanisms

Support mechanisms applicable to LSOWE projects vary from country to country. Some of the existing support mechanisms are not applicable to large scale projects (e.g. 100 MW) connected to the HV-grid. There is no consensus regarding the suitability of the different existing support mechanisms for LSOWE projects.

3. Research Needs

Some research needs which readily appear from the State-of-the-Art Summary are (but which are not necessarily critical research needs defined in Chapter 5) :

- Systematic evaluation of the results of test and demonstration projects (2.2.2.2, 2.5.3, 2.5.4)
- Generic assessment of production-consumption unbalance based on : LSOWE plans in different countries, expected short-term and long-term variability (e.g. Based on reanalysis data), spatial correlation and cross-border transmission capacity with long-distance storage (2.1.1.4 and 2.4.4.2)
- Analysis of the economical effect (cost) of increasing the flexibility of conventional power plants to compensate for the variability of wind power, taking into account LSOWE plans in different countries (2.1.2.2)
- Evaluation of the feasibility and social acceptability of demand-side energy management measures to increase consumption when wind power is available (2.1.2.2)
- All Research aiming to decrease the cost of energy storage (2.1.3.1 and 2.1.3.2 and 2.1.3.3).
- Development of improved forecasting tools, adapted to large geographically concentrated production of wind power, and evaluation of the reliability of existing forecasting tools (2.1.4).
- Development of methods to decrease currently required safety distances between sea cables (2.2.1.2) ;
- Assessment of the reliability of VSC HVDC systems ; ‘marinization’ of VSC HVDC systems (2.2.1.3 and 2.2.3)
- Harmonisation of electrical protection and reactive power requirements (2.3.1.4 and2.3.1.5)
- Study of the impact of grid limitations on offshore wind energy potential ; study of the relationship between technical-economical offshore wind energy potential and cost of required grid reinforcements (2.3.2.3)
- Development of suitable wind turbine (generator) models for dynamic grid simulation codes (in particular for variable speed wind turbines) (2.3.3.3,2.3.3.4)
- Development of methods to allow LSOWE plants to withstand transient external faults without disconnecting from the network (2.4.1)

- Analysis of the economical effect (cost) of increased primary control and secondary control requirements imposed on conventional generators (2.3.4.2 and 2.3.4.3) and/or Analysis of the economical effect (cost) of requiring LSOWE plants to contribute to primary and secondary control (2.4.2.2 and 2.4.2.3) Research in support of finding a socially acceptable way of allocating the system cost created by LSOWE (grid reinforcement, priority access, increase control requirements for conventional plants, …) to the different stake-holders (LSOWE project owners, all generators, all customers, all tax-payers) (e.g. 2.1.4.6)
- Generic evaluation of LSOWE investment costs taking into account cost influencing factors (distance from shore, water depth, wind and wave climate, soil conditions, …) (2.5.1).

4. Ranking

The table below represents the results of the ranking of all issues of task 2.2 by the OWEE members. Rankings are weighted as follows

Weight	Rank	Description
3	'CRITICAL'	An issue is considered critical, if all of the following conditions are fulfilled : • (1) its solution will have a significant impact on the large-scale development of offshore wind energy (i.e. if no solution is found for this issue, the development of offshore wind energy will be limited or even prohibited), and • (2) the issue is not easily manageable with existing technology, and • (3) the issue will be important in the short-term (i.e. before 2010)
1	IMPORTANT	An issue is important if some, but not all, of the above mentioned conditions are fulfilled
0	LESS IMPORTANT	An issue is less important if none of the above mentioned conditions are fulfilled

The average ranking R_{avg} obtained by taking the arithmetic average of the individual ranking weights and by rounding to the nearest integer.

Topic		Avg. Rank	Participating countries												
			BE	DK	IR	IT	FI	FR	GE	GR	NL	PO	SP	SW	UK
1	**Interaction between production and consumption – Energy Management Systems**														
1.1	Production and consumption patterns														
1.1.1	Consumption patterns	1										1			
	Diurnal and Seasonal Variation	0	0		1	1	0	0	0	0	0	1		1	0
1.1.2	LSOWE Production patterns														
	Diurnal and Seasonal Variation	0	1		1	1	0	0	0	0	0	1		1	0
	Variability (10min)	1	0		1	0	1	3	1	1	0	1		1	0
	Variability (24h)	1	1		1	0	1	1	1	1	0	1		3	1
	Power Gradients	1	0		1	1	3	1	1	1	0	3		3	1
1.1.3.	Production/Consumption Imbalance	1	3		1	1	0	0	0	0	0	1		1	0
1.1.4.	Spatial correlation	1	1		1		1	1	0		0	1			
1.2.	Energy Management														
1.2.1.	Demand side Management	1	0		0	0			1		0	1		1	1
1.2.2.	Increasing flexibility of conventional plants	1	1		0	1		0	1		1	0			1
1.2.3.	Compensation of power gradients via fast dispatching	1	0		1	1	0	1	1		1	1		3	1
1.3.	Energy Storage	1	3		3	1		3	0		0	1		0	0
1.3.1.	Pumped Hydropower	1	1		1	1	0	0	1		0	1		0	0
1.3.2.	Hydrogen	1	1		1	0	1	1	1		0	1		0	0
1.3.3.	Regenerative fuel cells	1	1		3	1	3	1	1		0	1		0	0
1.3.4.	Other solutions	1	1		1			1	0		0	1		0	0
1.3.5	Long distance storage	1	1		1		3	0	1		1	1		0	0
1.4.	Forecasting tools	2			3							1			
1.4.1.	Development of forecasting tools for wind energy production	2	3		3	0	3	1	3		1	1		1	3
1.4.2.	Suitability for balancing requirements	1	0		1	1	3	0	1		0	1		1	1
1.4.3.	Suitability for trading requirements	2	1		3	1	3	1	3		1	1		1	3
2	**Design and operation of the transmission Grid : A. Connection technology for LSOWE**														
2.1.	Feasibility limits	0										0			
2.1.1.	Cable length	1	1		1		3	1	1	1	3	0		0	1
2.1.2.	Operating conditions	1	1		1		0	0	1	1	3	1			
2.1.3	AC/DC conversion technology	1	1		1	1	1	1	1	1	1	1		1	
2.2.	Reliability / Maintainability	1	1								3	0			
2.2.1.	Component Reliability	1	1		1	1	3	0	0	0	3	0		3	1
2.2.2.	Component Maintainability	1	1		3	0	3	1	1	1	3	0		1	0

Topic		Avg. Rank	Participating countries												
			BE	**DK**	**IR**	**IT**	**FI**	**FR**	**GE**	**GR**	**NL**	**PO**	**SP**	**SW**	**UK**
1	**Interaction between production and consumption – Energy Management Systems**														
1.1	Production and consumption patterns														
1.1.1	Consumption patterns	1										1			
	Diurnal and Seasonal Variation	0	0		1	1	0	0	0	0	0	1		1	0
1.1.2	LSOWE Production patterns														
	Diurnal and Seasonal Variation	0	1		1	1	0	0	0	0	0	1		1	0
	Variability (10min)	1	0		1	0	1	3	1	1	0	1		1	0
	Variability (24h)	1	1		1	0	1	1	1	1	0	1		3	1
	Power Gradients	1	0		1	1	3	1	1	1	0	3		3	1
1.1.3.	Production/Consumption Imbalance	1	3		1	1	0	0	0	0	0	1		1	0
1.1.4.	Spatial correlation	1	1		1		1	1	0		0	1			
1.2.	Energy Management														
1.2.1.	Demand side Management	1	0		0	0			1		0	1		1	1
1.2.2.	Increasing flexibility of conventional plants	1	1		0	1		0	1		1	0			1
1.2.3.	Compensation of power gradients via fast dispatching	1	0		1	1	0	1	1		1	1		3	1
1.3.	Energy Storage	1	3		3	1		3	0		0	1		0	0
1.3.1.	Pumped Hydropower	1	1		1	1	0	0	1		0	1		0	0
1.3.2.	Hydrogen	1	1		1	0	1	1	1		0	1		0	0
1.3.3.	Regenerative fuel cells	1	1		3	1	3	1	1		0	1		0	0
1.3.4.	Other solutions	1	1		1			1	0		0	1		0	0
1.3.5	Long distance storage	1	1		1		3	0	1		1	1		0	0
1.4.	Forecasting tools	2			3							1			
1.4.1.	Development of forecasting tools for wind energy production	2	3		3	0	3	1	3		1	1		1	3
1.4.2.	Suitability for balancing requirements	1	0		1	1	3	0	1		0	1		1	1
1.4.3.	Suitability for trading requirements	2	1		3	1	3	1	3		1	1		1	3
2	**Design and operation of the transmission Grid : A. Connection technology for LSOWE**														
2.1.	Feasibility limits	0										0			
2.1.1.	Cable length	1	1		1		3	1	1	1	3	0		0	1
2.1.2.	Operating conditions	1	1		1		0	0	1	1	3	1			
2.1.3	AC/DC conversion technology	1	1		1	1	1	1	1	1	1	1		1	
2.2.	Reliability / Maintainability	1	1								3	0			
2.2.1.	Component Reliability	1	1		1	1	3	0	0	0	3	0		3	1
2.2.2.	Component Maintainability	1	1		3	0	3	1	1	1	3	0		1	0

4.2.1.	Reactive power	1	1		0	1	0	1	0	1	0	1			0
4.2.2.	Primary control	1	1		0		1	0	1	1	0	1			0
4.2.3.	Secondary control	0	1		0		0	0	1	1	0	1			0
4.2.4.	Black-start capability	0	0		0		0	0	1	1	0	1			0
4.2.5.	Ancillary service opportunity	0	0		1		0	0	0	0	0	1			0
4.3.	National Grid	1										1			
4.3.1.	Grid strength	2			3	1	3	3	3	3	1	1		3	0
4.3.2.	Grid Reinforcement	1			1	1	1	1	1	3	1	1		3	0
4.3.3	Off-shore Grid Extension	1	1		1	0	3	0	1	3	0	1			0
4.4.	International Grid Aspects	1										1			
4.4.1.	ACE requirements	1	1									1			
4.4.2.	Cross-border transmission capacity	1	3		3	1	0	0	1			1			
5	**Financing of large offshore wind farms**														
5.1.	Investment budget	2	1		3	0	3	1	1		3	0		1	3
5.2.	Investment risk	1	1		3	0	1	1			3	0		1	3
5.3	Financing conditions	1	1		1	0	3	1			1	0		3	1
5.4.	Insurance conditions	1	1		3	0	3	1			3	0		1	1
5.5.	Support mechanisms	2	1		3	1	1	3			1	0		3	3

5. Critical Issues

Critical issues are those issues which have an average ranking above 1 in §4.

The solution of the critical issues will have a significant impact on the large-scale development of offshore wind energy (i.e. if no solution is found for this issue, the development of offshore wind energy will be limited or even prohibited). These issues are also not easily manageable with existing technology, and these issues will be important in the short-term (i.e. before 2010).

6. Critical Research Needs

Some of the research needs identified in §3 from the State-of-the-Art summary relate to 'critical' issues identified in §5. These 'critical' research needs are the following :

- Systematic, international evaluation of the results of test and demonstration projects (2.5.3)
- Development of improved forecasting tools, adapted to large geographically concentrated production of wind power, and evaluation of the reliability of existing forecasting tools (2.1.4).
- Development of suitable wind turbine (generator) models for dynamic grid simulation codes (in particular for variable speed wind turbines) (2.3.4.3)
- Development of methods to allow LSOWE plants to withstand transient external faults without disconnecting from the network (2.4.1)
- Analysis of the economical effect (cost) of increased primary control and secondary control requirements imposed on conventional generators (2.3.4.2 and 2.3.4.3) and analysis of the economical effect (cost) of requiring LSOWE plants to contribute to primary and secondary control (2.4.2.2 and 2.4.2.3)
- Generic evaluation of LSOWE investment costs taking into account cost influencing factors (distance from shore, water depth, wind and wave climate, soil conditions, …) (2.5.1).

7. Reference List

Nbr	Author	Title	Bibliographic Information	Micro-Abstract	Lang.	Avail.
1	STUBBE,Elie	IRENE 2010 Final Report	TEE Note IRENE/4NT/19/00 www.agores.com	This report presents the final results of the EC ALTENER-project ‘Integration of Renewable Energy in the Electricity Network’.	E	TEE
2	ERNST, B	Short-Term Power Fluctuations of Wind Turbines from the Ancillary Services Viewpoint	ISET, Kassel 1999		E	
3	Dirk Prior:	Nachbildung der Energiebedarfsstrukturen der privaten Haushalte- Werkzeug zur Bewertung der Energiesparmaßnahmen,	VDI-Verlag:VDI Fortschrittsberichte Reihe 6 Nr. 379, 1997			
4	VDEW	Ermittlung der Lastganglinien bei der Benutzung elektrischer Energie durch die bundesdeutschen Haushalte während eines Jahres	Frankfurt VWEW-Verlag1985			
5	Volker Quaschning:	Systemtechnik einer klimaverträglichen Elektrizitätsversorgung in Deutschland für das 21. Jahrhundert.	VDI-Verlag:VDI Fortschrittsberichte Reihe 6 Nr. 437, 2000			
6	Gregor Giebel:	On the benefits of distributed wind energy in Europe:	www.DrGiebel.de			
7	VDEW	Strommarkt Deutschland 1997- Die öffentliche Elektrizitätsversorgung,	Frankfurt:VWEW Verlag,1998			
8	Jeffrey A. Donahue	Role of HVDC Transmission for independent Transmission Projects.	IEEE Power Engineering Review, Feb. 2000			
9	Dusan Povh, Siemens	Development of Power Systems.	IEEE Power Engineering Review, Feb. 2000			
10	P. Weißpferd	Die Netzanbindung von Offshore-Wind parks.	Sonne Wind &Wärme 3/2000			

11		Baltic Cable:	Strom im Verbund. Preussen Elektra, Aug. 1997			
12	Kai Mönnich,	Vorhersage der Leistungsabgabe netzeinspeisender Windkraftanlagen zur Unterstützung der Kraftwerkseinsatzplanung	Dissertation, University of Oldenburg:			
13	H.G. Beyer, D. Heinemann, H. Mellinghoff, K. M÷nnich, H.P. Waldl,	Forecast of regional power output of wind turbines.	Proceedings of the European Wind Energy Association Conference and Exhibition 1999, Nizza.%, pages 1070-1073.			
14	Landberg, L,	Short-term prediction of the power production from wind farms	J. Wind Eng. Ind. Aerodyn., 80, 207-220. 1999.			
15	DEWI, ELSAM, DM Energy.	Wind turbine Grid connection and interaction.	Draft, not published until yet.			
16			IEEE Power Engineering, Sep. 2000, Vol. 20, Nr. 9			
17		Co-ordination of parallel AC-DC systems for optimum performance.	International workshop on feasibility of HVDC Transmission networks for offshore wind farms, Stockholm, 30-31 March2000.			
18	P. Gardner, L.M. Craig, G.J. Smith	Electrical Systems for Offshore wind farms	Garrad Hassan & Partners			
19	I. Kambouris et al	Penetration of Wind Power into the grids of the PPC. Current Status- Obstacles - Prospects	Proc. Of the National Cigre Symposium 1999, Athens			
20	P Christensten, M Mieritz	Integration of large scale offshore wind power plants	International Workshop on feasiblity of HVDC transmission networks for offshore wind farms, Stockholm, 2000			
21	Giebel, G	Equalizing Effects of the Wind Energy Production in Northern Europe determined from Reanalysis Data	Riso-R-1182(EN), May 2000			
22			Power Engineering Journal, June 1999 (www.iee.org.uk)			
23		Electricity from Offshore Wind	IEA CADDET Centre for Renewable Energy, , ISBN 1 9 00983 06 7, (www.caddett-re.org)			
24		IEA expert meeting on wind	Boulder USA April 2000			

		forecasting techniques				
25	W. Grainger, N. Jenkins	Offshore wind farm electrical connection options	OWEN			
26	F. Schettler, H. Huang, N. Christl (Siemens AG)	HVDC Transmission Systems using Voltage Sourced Converters – Design and Application	OWEN			
27	J. Pedersen, P.B. Eriksen (ELTRA)	Large Scale Integration of Wind Power and CHP into ELTRA's system.	2nd International Workshop on Transmission Networks for Offshore Wind Farms, Stockholm, 29-30/3/2001		E	Yes
28	P. Christiansen et al	New Requirements for Grid Connection of Wind Farms	2nd International Workshop on Transmission Networks for Offshore Wind Farms, Stockholm, 29-30/3/2001		E	Yes
29	W. Siepmann	AC Transmission Technology for Offshore Wind Farms	2nd International Workshop on Transmission Networks for Offshore Wind Farms, Stockholm, 29-30/3/2001		E	Yes
30		European Wind Atlas	Risö National Laboratory, 1989]			
31		The NCEP/NCAR 40-year reanalysis project,	Bull. Am. Met. Soc., 77 (1996)			

8. List of Acronyms

ACE	Area Control Error
AGC	Automatic Generator Control
ATC	Available Transfer Capacity (MWe)
CHP	Combined Heat and Power (Co-generation)
DSA	Dynamic Security Analysis
DSM	Demand Side Management
DTS	Dispatching Training Simulators
ELTRA	Management Agency of the Danish Grid
EMS	Energy Management System
ESI	Electrical Supply Industry
FACTS	Flexible AC transmission
GTO	Gate Turn-off
HTB	High Tension Bus
HV	High Voltage
HVDC	High Voltage Direct Current
IC	Interconnection Capacity (MWe)
IGBT	Insulated Gate bipolar Transistor
IPP	Independent Power Producer
LOEE	Loss of Energy Expectation
LOLE	Loss of Load Expectation
LOLP	Loss of Load Probability
LSOWE	Large Scale Offshore Wind Energy
LV	Low Voltage
MV	Medium Voltage
NFFO	Non Fossil Fuel Obligation
NORDEL	Nordic Electricity Grid
NTC	Net Transfer Capacity (MWe)
NTF	Notified Transmission Flow (MWe)
OWEE	Offshore Wind Energy Europe
OWEN	Offshore Wind Energy Network
PV	Photovoltaic
RES	Renewable Energy Sources (Primary)
RES-E	Renewable Energy Sources for Electricity Production
RFC	regenerative Fuel Cell
RTU	Remote Thermal Unit
SA	Steady State Security Analysis
SCADA	Supervisory Control Data Acquisition System
SMES	?
STATCOM	Static Commutation
SVC	Static Var Compensator
TRM	Transmission Reliability Margin (MWe)
TSA	Transient Stability Analysis
TSO	Transmission System Operator
TTC	Total Transfer Capacity (MWe)
UCPTE	Union for the Coordination of Production and Transmission of Electricity
UCTE	Union for the Coordination of Transmission of Electricity

	(Formerly UCPTE)
VSC	Voltage Source Commuted
WPPT	Wind Power Prediction Tool
WTG	Wind Turbine Generator