JAN 27, 2005—
2005 POWERTECH (ST. PETERSBURG, RUSSIA, JUNE 2005)
PANEL SESSION: PART A:
EUROPE: STATUS OF INTEGRATING RENEWABLE ELECTRICITY PRODUCTION INTO THE GRIDS (PANEL SESSION PAPERS 291)
(T J HAMMONS AND Y SAßNICK)

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Panelists and the Titles of their Presentations (Parts A & B) are:

PART A

0. T. J. Hammons Chair International Practices for Energy Development and Power Generation, Glasgow University, UK and Yvonne Saßnick, Vattenfall Europe Transmission GmbH , Berlin, Germany. Panel Session Introduction: Part A-- Europe: Status of Integrating Renewable Electricity Production into the Grids

1. Bernd Michael Buchholz, Vice President, Siemens AG, Erlangen, Germany and Yvonne Saßnick, Vattenfall Europe Transmission GmbH, Berlin, Germany. The German Experience of the grid integration of renewable energy sources
2. Nikos Hatziargyriou, National Technical University of Athens, Athens, Greece; I Skotinos, National Technical University of Athens, Athens, Greece; and A. Tsikalakis, National Technical University of Athens, Athens, Greece. Status of Integrating Renewable Electricity Production in Greece: Prospects and Problems.
3. John Olav Tande, SINTEF Energy Research, Trondheim, Norway. Options for Large Scale Integration of Wind Power
4. Joao A. Peças Lopes, INESC Porto and Faculty of Engineering, Porto University, Portugal. Technical and Commercial Impacts of the Integration of Wind Power in the Portuguese System having in mind the Iberian Electricity Market.
5. Juan Manuel Rodríguez García, Fernando Soto Martos, David Alvira Baeza; Red Eléctrica de España., Madrid, Spain; and Susana Bañares, Red Eléctrica Internacional., Madrid, Spain.. The Spanish Experience of the grid integration of wind energy sources
6. D. Barry, ESB National Grid, Dublin, Ireland; and P. Smith, ESB National Grid, Dublin, Ireland.. Analysis of the Integration of Wind Generation into the Irish System

PART B

0. Bernd Michael Buchholz, Vice President, Siemens, Germany and Tom Hammons, Chair International Practices for Energy Development and Power Generation, Glasgow University, UK: Panel Session Introduction Part B: Europe: Status of Integrating Renewable Electricity Production into the Grids and Developments in Distributed Electrical Power Generation in Compliance with the Kyoto Protocol

7. Ahmed Faheem Zobaa, Cairo University, Giza, Egypt. An Overview of the Different Situations of Renewable Energy in the European Union
8. PAMUŁA Anna. Lodz-Region Power Distribution Company, Poland; SZYMCZAK Tomasz. Lodz-Region Power Distribution Company, Poland; ZAWORA, Jacek. Lodz-Region Power Distribution Company, Poland; and ZIELI SKI, Jerzy S. Lodz-Region Power Distribution Company, Poland. Some Remarks on Renewable Electricity in Poland.
9. Ola Carlson, Associate Professor and Stefan Lundberg, Lic., Chalmers University of Technology, Sweden. Integration of Wind Power by DC-Power Systems

10 A. Sauhats, V. Chuvychin, N.Gurov, V. Strelkovs, I.Svalova, Riga Technical University, Latvia; and O. Linkevics, J. Rivkins, VAS Latvenergo, A. Svalovs, Dispatch Centre of the Baltic Power Systems, Latvia. The Latvian experience and problems of the grid integration of renewable energy sources in the power system

11. Brendan Fox, Queen's University, Belfast, UK. Wind Intermittency, Mitigation Measures and Load Management.
12. Etienne Gehain, Research Division, Gaz de France; Jacques Deuse, Tractebel Energy Engineering. DEEP: a European Integrated Project with a Different R&D Approach to the Integration of Distributed Energy Resources and Renewable Energy Sources in Markets and Energy Grids

INTRODUCTION: PART A

This Panel Session will discuss the status of integrating renewable electricity into the grids in Europe.

The visionary targets of the European Community are to increase the share of the renewable energy resources between 1997 and 2010 from 14 to 22 % as well as doubling the contribution of the cogeneration plants for heat and power (CHP) on the total electricity production from 9 to 18 %. Consequently, the share of dispersed and renewable energy resources (DER) will cover 40 % of the whole electricity production in 2010. All countries have set their own targets to gain the common goal.

The DER in distribution systems will achieve an additional growth of more than 300 TWh/a to meet the challenging European targets. Additional, the wind power will grow preliminary by the way of large wind farms centrally feeding into the transmission grids with 20-30 GW installed power until 2010. Large offshore wind farm sites with rated power up to 1,000 MW are currently under investigation to be installed in the North and in the Baltic sea.

However, the output of most of the renewable energy sources depends on meteorological conditions and the CHP output is normally driven by the demand of heat which is higher in winter and lower in summer periods. The full load hours of the installed wind power capacity, for example, are approximately 1,400 – 1,600 h/a at onshore locations and between 800 and 1,000 h/a for photovoltaic plants.

Thus, if the contribution of DER in the electric energy generation shall achieve 40 %, their maximum possible contribution in the power balance must achieve 60 % of the European system peak load. A possible scenario is shown in Figure 1.

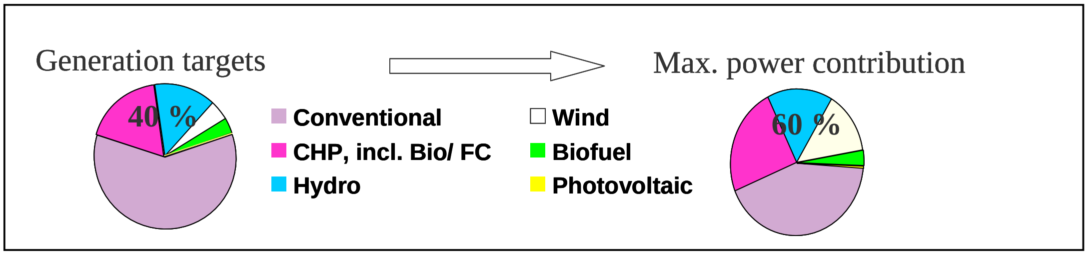

Figure 1. Generation Targets of the European Communities for 2010 and the Related Maximum Power Contribution of Renewable and CHP Generation

Such a large scale penetration of DER in the power balance will lead to a sustainable restructuring of the actual operation practice in power systems. A big number of different dispersed generation units in the range of some kW up to large centrally feeding wind farms of some 100 MW partially with an intermitting power output will be connected to all levels of the power system as shown in Figure 2. The question arises, how the existing high level of power quality can be kept under these fundamental changing circumstances.

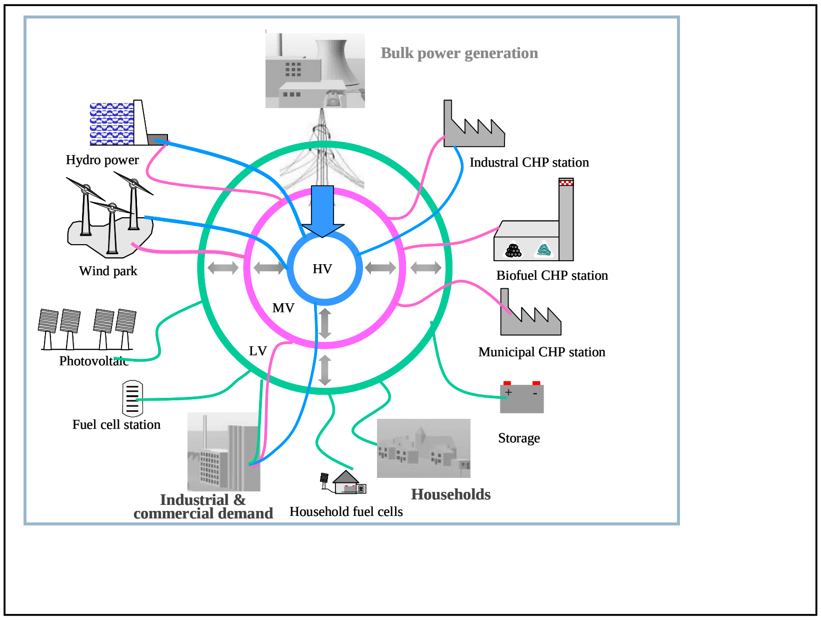

Figure 2. Power System Structure with Integration of Dispersed and Renewable Generation

To give an answer on this question the experience of the different countries with a large share of renewable and dispersed power generation shall be analyzed.

This Panel Session with 8 eminent Panelists from Europe will discuss the status of integrating renewable electricity into the grids in Europe where progress, developments and proposals in some European countries will be critically analysed, discussed, and reviewed. Based on the experience in these countries new recommendations and rules regarding the grid conformity, the reliability including the “fault ride through behaviour” and the dispatching of the renewable and dispersed generation units are necessary. In some countries new guidelines are in development or already exist, for example in Germany.

PANEL SESSION SUMMARIES:

1. THE GERMAN EXPERIENCE OF THE GRID INTEGRATION OF RENEWABLE ENERGY SOURCES

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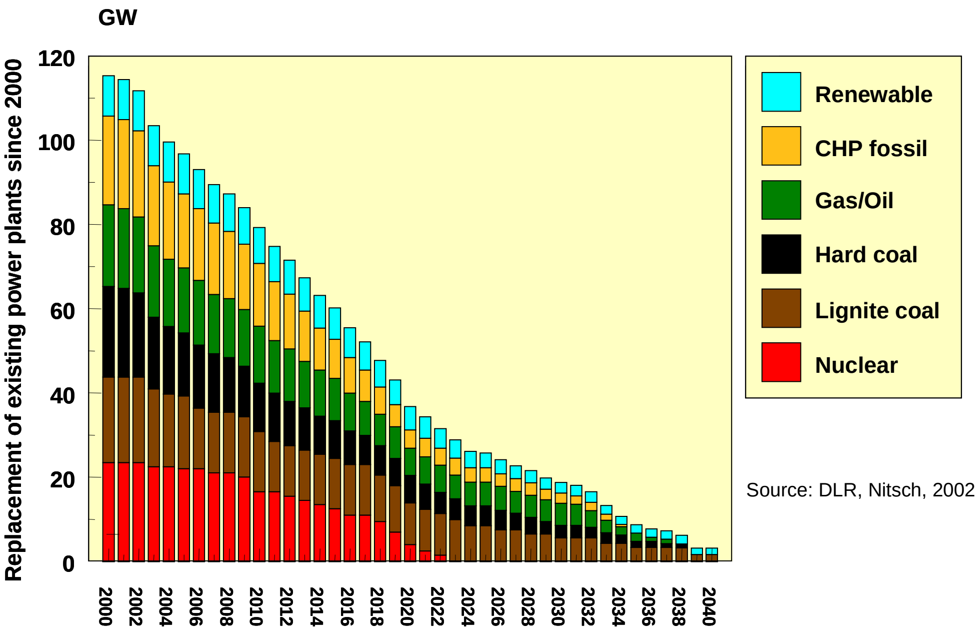
Yvonne Saßnick, Vattenfall Europe Transmission GmbH, Berlin, Germany

1. Prospective development of renewable energy generation

In Germany today the annual energy generation of ~ 520 TWh/a comes from approximately

- 56 % coal fired power plants,
- 28 % nuclear power plants,
- 8.5 % renewable energy sources,
- 7.5 % gas and oil fired power plants.

In the next decades there will happen a fundamental change in the generation structure in the result of the political decision to shut down all nuclear power stations and accordingly the need to substitute the most of the actual power stations for reasons of aging. In Figure 1 the expected decommissioning of generation capability is presented.



Source: DLR, Nitsch, 2002

Figure 1. Need for Replacement of Existing Power Plants

It is a political goal that only a part of the traditional power stations will be substituted by fossil fired generation plants. In this situation the targeted growth of renewable and dispersed generation plays a significant role. In the field of renewable energy the official goals are to achieve shares of 12.5 % in 2010 and 20 % in 2020 of the overall electric energy generation. However, this process seems to run faster as planned and the targets will be gained in 2007 and 2015 respectively [1].

In Figure 2 the actual development scenario of the installed renewable power capability in Germany is shown.

As presented, the share of hydro power will be kept on the actual level because of the lack of possible locations for new large hydro power stations. But all other renewable sources will grow significantly.

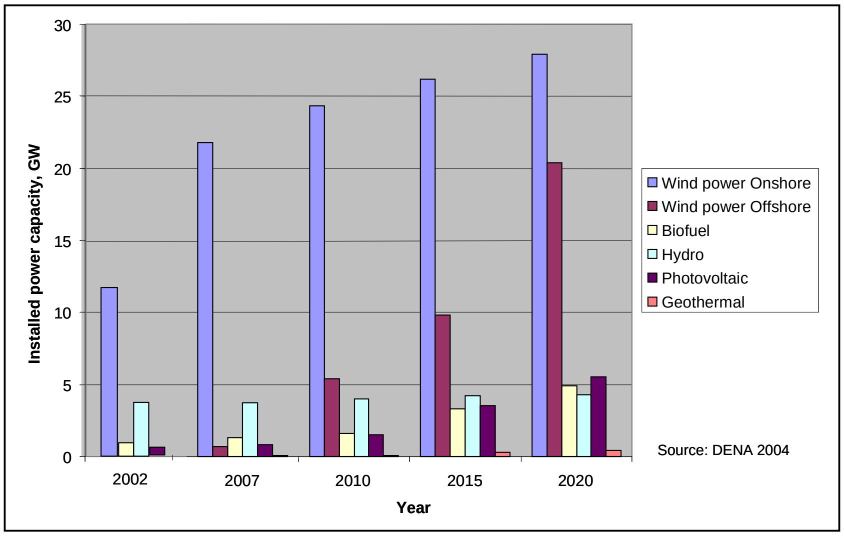


Figure 2. Development of renewable generation capability in Germany

A special high growth is expected in the wind power sector where Germany today has a share of ~50 % of the whole European capacity. Beginning from 2007 the further growth will be focused preliminary in offshore locations where large wind farms with some hundred Megawatt installed power will be erected. With the shown installed power capabilities and taking into account the achievable full load hours of the different generation technologies, the contribution of renewable energy sources in the whole energy balance of Germany will achieve ~30 % in 2020. However, their maximum contribution in strong wind situations may achieve:

- 70 % for peak load and
- 100 % for weak load coverage,

where 58% and 83 % of the shares respectively come from fluctuating sources with an intermitting output depending on meteorological conditions (wind, solar).

Such a large share of fluctuating power contribution requires advanced solutions to keep the power system security.

2. The economical incentives

The generation of renewable energy is co-financed by fixed prices on high levels for the different renewable power sources and with subsidies for heat and power cogeneration.

The fix prices are for

- wind energy - 8.7 Ct/ kWh,
- solar energy - 54 Ct/ kWh,
- biofuel energy - 6.6-10.2 Ct/kWh (depending on the plant size)

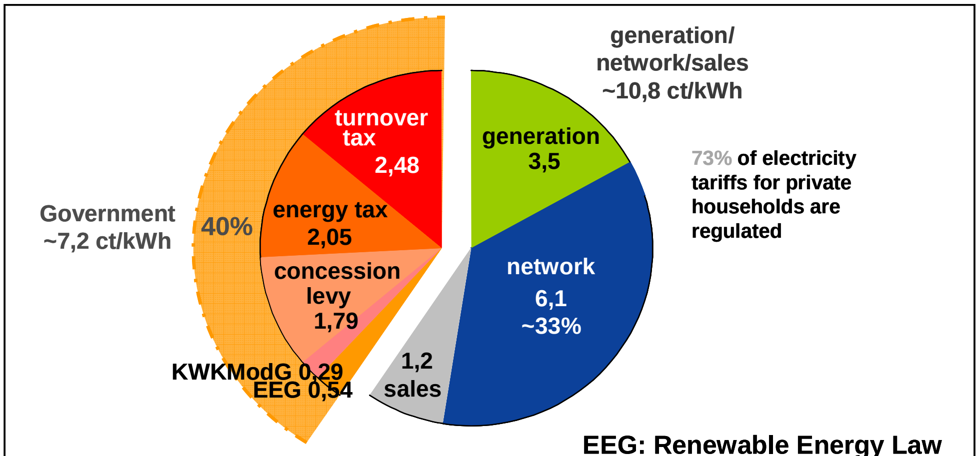
independently of the network level where the connection is provided. These much higher prices of renewable energy are paid by an additional charge of 0.54 Ct/ kWh (level 2003/04) from all customers in accordance with Figure 3. Additionally, the investors benefit from tax incentives for all capital expenses into renewable energy generation plants.

Consequently, a high profitability is the driver of the fast growth of renewable energy generation in Germany.

On the other side, the network operators are obliged by law to ensure the unlimited renewable power infeed. This obligation creates additional costs for:

- network enhancement from 2 Mil. in 2003 up to 40 Mil. in 2010,
- spinning reserve to compensate power fluctuations from 130 Mil. in 2003 up to ~400 Mil. in 2010

only for one of the 4 transmission system operators [2].



EEG: Renewable Energy Law

source: VDEW, 19.05.04 u. 05.11.03

KWKModG: CHP Law

Figure 3. Shares of the Energy Price for Household Customers

These costs are included in the charges for network use.

Figure 3 demonstrates the mean household price structure for electric energy in Germany.

3. Grid integration of large scale wind power in the transmission level

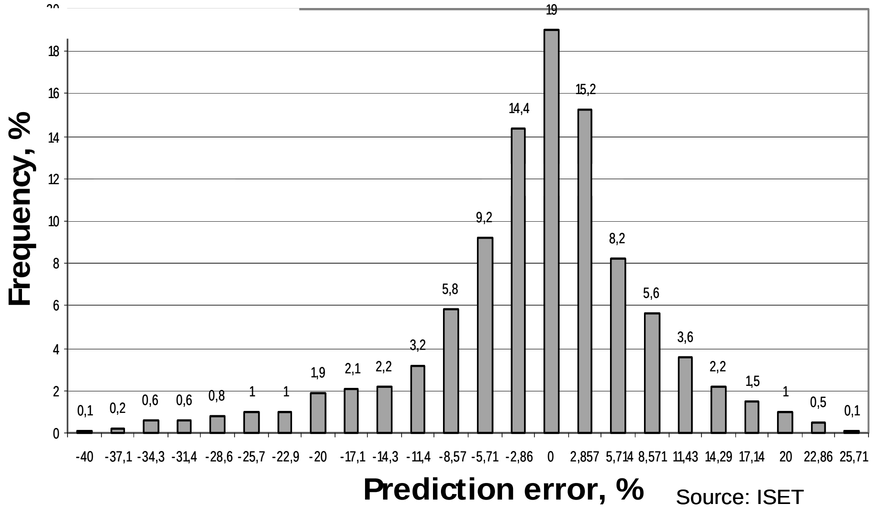
Infeed of power by large wind farms is fundamentally subject to different patterns as are the case with conventional power sources such as thermal, gas turbine or hydroelectric generating plants. Three major problems shall be solved in the first priority:

1. The wind power output depends on the meteorological conditions and may be intermitting. Besides the application of prediction tools for the power schedule planning a higher level of reserve power as before shall be provided.
2. As wind power infeed increases, the transmission capacity of the network is a further problem. Wind farms are mostly constructed in relatively underdeveloped regions in the North of Germany. The transmission networks in these regions have been expanded to only a limited extent. Appropriate transmission capacities must be created in order for the power to reach the load centers.
3. The fault ride through of wind power plants shall be adapted in such a way that the wind generators will contribute in the short circuit currents and in the network recovery after the fault clearing.

In most cases, the wind velocities in northern Germany, but also over the Baltic or the North Sea, are mostly within the range of 3 to 12 m/s.

Within this range, the power produced by a wind generator depends very considerably on the wind velocity. The wind power producers basically feed in the maximum possible power obtainable from the wind and they receive a statutory payment.

Thus, planning the power balance of a transmission system depends substantially on the precision of weather forecasts, quite particularly if the share of wind power generation accounts for a significant portion of the network load. Special prediction tools for the wind power generation are developed and applied. However, their accuracy is limited as shown in Figure 4 and additional reserve power - significantly over the level which is required for primary reserve to compensate outages in the UCTE grid (German share 750 MW) - shall be provided for ensuring a reliable system operation. A continuous work for improving the prediction accuracy is directed to minimize the reserve power.



Source: ISET

Figure 4. Distribution of Prediction errors for Day Ahead Wind Power Forecasts

The solution of the second problem - the grid enhancement is restricted by the legal difficulties and the long term permission process for the installation of new transmission lines. Moreover, existing conventional power stations will be offering their generating capacity on the free market, selling it throughout Germany or Europe. Consequently, free energy trading is suffering increasing constriction owing to a lack of transmission capacity and the installation of new transmission capacity will become mandatory. But, from an economic viewpoint, it is just the time to rethink the situation and to consider whether the network ought to be expanded for about 60 strong wind days per year, or whether generation management for wind power installations ought to be approved for this relatively short time.

Thirdly, apart from local impacts wind power also has a number of system-wide impacts because it affects

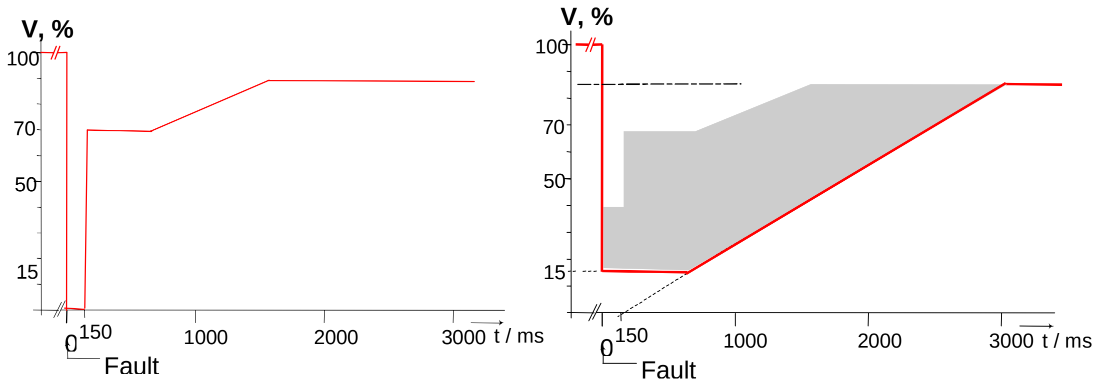
- power system dynamic and stability,
- reactive power control and voltage control,
- frequency control and load following/dispatch of conventional units

Three main aspects shall be fulfilled by wind generators:

- no excitation of power oscillations after grid disturbances,
- infeed of reactive power during and after system faults,
- maintaining system stability, minimize grid disruption.

Today wind turbines have single response to fault situations in the grid which result in instantaneous voltage drops. They trip off-line to protect their function until the grid recovers. The immediate loss of generation can impact system stability and lead to cascaded tripping of some thousand MW wind power. In [3] is demonstrated that faults in some grid locations can cause a power tripping much higher as the whole spinning (primary) reserve of the UCTE grid of 3000 MW.

For this reason new rules for the grid connection of wind power plants were established [4].



a - generators with a high short circuit power **b - generators with low short circuit power**

Figure 5. Conditions for the Stable Connection Remaining During Faults [4]

In Figure 5 the rules regarding the behavior of generation units during and after faults are demonstrated for the case that the fault happens close to the point of connection.

Three-phase short-circuit currents close to the point of connection with a fault clearing time of up to 150ms throughout the operating range of the generating plant must not result in instability or disconnection from the network if the short-circuit power (S’’sc) available on the network side is higher than 6 times the active connection power of the generating plants after fault clearance.

Three-phase short-circuits close to the connection point above the limit curve in figure 5-b must not lead to instability of the generating plants or to the disconnection from the network. Active power output must start immediately after fault clearance and be increased with a gradient of at least 20% of the active connection power per second. Within the shaded area, the active power output can be increased by 5% of the active connection power per second. It is likely that after fault clearance the operating voltage does not immediately reach the same value as before the occurrence of the fault, but that it remains at a lower value for some time.

The wind power technology of today belongs to the plants with low short circuit power. Thus, all new installations of wind power plants have to meet the requirements according figure 5 -b and advanced electronic control systems were designed to deliver ride-through capability at 15 % grid voltage for up to 500 ms.

4. Dispersed generation in distribution systems

Besides the connection of large onshore and offshore wind farms to the transmission grid a fast growth of dispersed energy resources (DER) in distribution systems is expected.

The problems to be solved at distribution level are:

- ensuring network conformity in accordance with the special rules of DER connection in medium and low voltage networks [5] e.g. regarding voltage quality, avoidance of equipment overloads, short circuit withstandability, influence on ripple control etc.
- contribution for the reliability of supply through provision of high availability and support of network recovery after faults.
- compensation of power fluctuations and dispatch of a stable power balance in clusters of different DER, storage units and controllable loads.

These main requirements are presented in Figure 6.

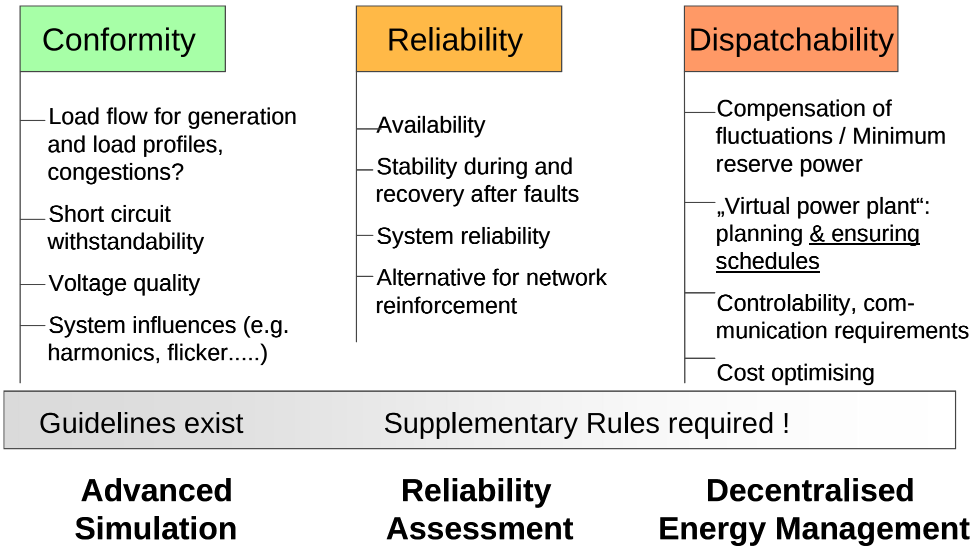


Figure 6. Requirements and provision means for a large scale penetration of DER

The response regarding the first two requirements has to be analyzed by typical network planning methods. The simulation and assessment tools for that are available and approved in pilot projects [6].

The dispatchability requires more.

At present DER units are operated without higher-level control, feeding in a maximum of power as supported by current political and regulatory framework conditions. The transmission system operator is obliged to ensure the power balance. This task will become more and more difficult under the conditions of a growing contribution of uncertain and intermitting power output of DER. In the future the stable grid operation, economical considerations and environmental benefits require an intelligent energy management to make the generation profiles planable also in the distribution level.

Those decentralized energy management systems have to balance required and available power in particular supply areas based on offline schedules for DER, storage units, demand side management capabilities and contractual power exchange.

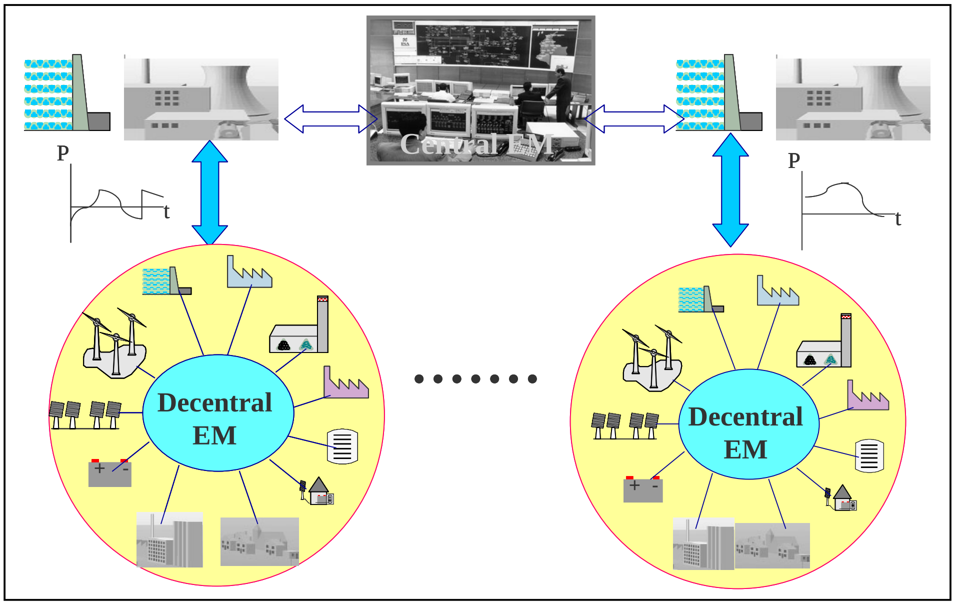


Figure 7. Future Task Splitting Between Central and Decentralized Energy Management

The central dispatching of the power balance will be supported by any decentralized dispatching systems as shown in figure 7.

Online monitoring and control of the units based on the schedules forms balanced supply areas for different supply scenarios, i.e. different combinations of DER, storage, and load units. For higher-level management systems these balanced “self sufficient cells” appear as “virtual power plants” which show similar reliable, planable, and controllable behaviour like traditional power plants. There are different possibilities for vertical and horizontal integration of these locally optimised cells into central control centres.

The adherence to the schedules has to be guaranteed online in operation to enable an exactly defined contractual power exchange of the balanced supply areas. Unplanned power fluctuations and deviations from the schedules require a fast adjustment of the real power flow within the individual period by dispatching controllable generation, storage units and demand in a one-minute time interval. The principle of the considered decentralized power management is presented in Figure 8.

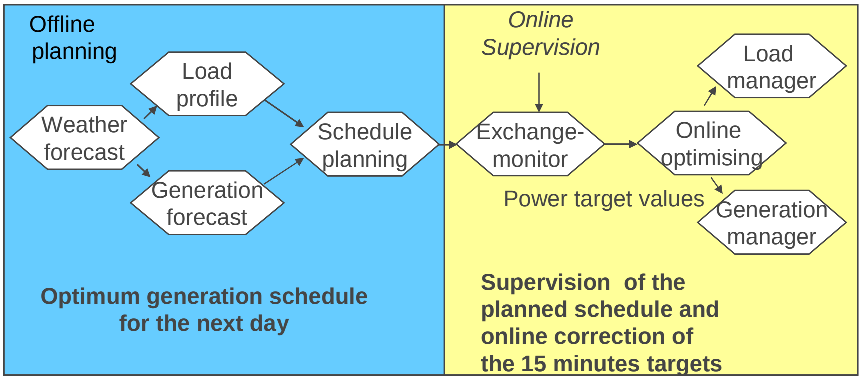


Figure 8. Principle of the Decentralised Power Management of DER

To cope with unavoidable prediction errors of generation and demand the unit commitment accounts for the determined reserve power locally, yet meeting all technical constraints. Thus central power reserves can be reduced.
From the technical point of view all needed means for operation with large scale integration of DER are available and proven in practice [7].

However, the actual legal and incentive situation described in chapter 2 acts against an introduction of “virtual power plants”. The legal and incentive frameworks have to be adapted that the idea of the “virtual power plants” can become reality.

5. Conclusions

As the main conclusion it shall be stated that the increasing share of renewable and dispersed generation has no technical limits if **Conformity and Reliability** in the context of the new guidelines [4,5] will be ensured **and** if their **Dispatchability** can be reached by technical means within an adapted legal and incentive framework.

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2. STATUS OF INTEGRATING RENEWABLE ELECTRICITY PRODUCTION IN GREECE, PROSPECTS AND PROBLEMS

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Abstract

Greece, as member of the European Union follows the European policies regarding compliance with the Kyoto Protocol, as expressed by the draft directive of 2001 on “A framework for greenhouse gas emissions trading within the European Community”. Accordingly, it is proposed that 38% of the CO_2 emissions in EU should be included in the quota system by 2010, with a penalty of 50   /tn of CO_2 exceeding the quota [1]. The state target of Greece is 20.1% RES penetration in Electricity production amounting to 14.5TWh per year [1, 2]. In this paper, the legal and financial framework for RES, the current level of installations, the problems faced by the new installations and the potential benefits from their installation are described.

I. LEGAL FRAMEWORK IN GREECE - THE FEED-IN TARRIF POLICY

The legal framework established in Greece (laws 2244/94, 2773/99) has provided a significant stimulus to the private sector to invest in RES. According to this framework, the private Sector can build RES units and sell the produced energy to the local power grid at fixed prices (feed-in tariffs). In island networks, the Greek Utility, Public Power Corporation (PPC) is obliged to buy all wind power produced at a fixed price of 90% of the retail price of the kWh (7.97   ct/kWh). In the Greek mainland this price is set at 6.45   ct/KWh [3, 4].

In order to increase the development of RES there have been calls for tender for two measures within the 3rd Community Operational Framework Programme "Competitiveness” [5].

The first one provides aid for investment in co-production, RES and energy saving systems. The second project aims at the promotion of RES on the islands and the improvement of quality and reliability of electricity supply in these regions. Moreover projects that aim at the network expansion so that RES at regions with high wind potential can be installed are financed. Financing RES installation is as follows [5]:

- Wind Energy 30% of the installation cost
- PV greater than 40% of the installation cost
- Geothermal greater than 50% of the installation cost
- Biomass energy greater than 50% of the installation cost

As a result, since 1994, there has been significant development of Wind Power, especially on the island of Crete, while further proposals for installing Wind Parks in Crete, Greek islands and eastern parts of the mainland have been positively qualified, as described in the next Section.

II. THE GREEK ENERGY PRODUCTION SYSTEM - RES INSTALLATIONS IN GREECE

The Greek energy production and transmission system consists of the mainland power system to which some of the Aegean Sea islands as well as Ionian sea islands are interconnected. The Greek mainland system is also interconnected to Albania, FYROM and Bulgaria via AC lines and with a HVDC line with Italy. The Hellenic Transmission System Operator (HTSO) is the operator of the system. As far as RES are concerned the HTSO:

- Is obligated to grant priority access to RESe installations up to 50 MWel.
- Is obligated to enter into a 10-year contract (Power Purchase Agreement) with the RES producer, for the purchase of his electricity. The contract includes a renewal option.
- The RES production of an independent power producer, or the surplus electricity production of a RES autoproducer, is sold to the HTSO at a pre- determined buy-back rate, which is a fixed percentage of the corresponding consumer electricity rate.

Moreover there is a number of small isolated distribution networks in isolated islands and three larger networks including HV lines, Lesvos, Rhodes and Crete. In these networks Public Power Corporation is the sole buyer and operator of the system and the RES production is remunerated at a fixed percentage of the corresponding consumer electricity rate.

The installed power capacity in Greece is 12138 MW and the total energy production during 2003 was 52.2 TWh..1.7% of the demand is met by Wind Turbines Production and 6.7% from the hydroelectric stations [4]

The installed power capacity in Greece is by 97% owned by (PPC) and the majority of energy (56%) is produced by Lignite units in Northern Greece. Private sector constructs power plants consuming Natural Gas in Gas Turbines Combined Cycle [3] units.

Greece is a country with significant wind and solar power potential. On the islands of the Aegean Sea and the island of Crete, in Thrace, Evia and other eastern parts of the mainland there exists high Wind Potential with an average wind velocity over 8 m/sec. The majority of the installed wind farms are on these eastern regions of the country as Figure 1 depicts.

Greece is also the country with the maximum duration of sunshine within the European Countries. Installation of Solar collectors per Capita is the highest in Europe exceeds 250 m^2 per capita [2]. However, the installed capacity in PV is rather low. The PV installations at autonomous regions for houses, telecommunications etc reach 49% of the installed capacity whereas the majority of grid-connected applications are installed in Greek islands [6] mainly on Crete.

Greece has also many rivers that are exploited by larger hydroelectric stations, but can be further exploited for the installation of small hydroelectric units. The following table (Table 1) provides the installed RES capacity in Greece. Table 1 summarizes also the positively qualified RES installations in [3, 7].

Table 1: Installed capacity of RES in Greece and positively quantified projects

RES type	In operation	Under construction	New project	TOTAL
Wind	417 MW	139 MW	3120 MW	3676 MW
Small hydro	61 MW	53 MW	293 MW	407 MW
Biomass	21 MW	5 MW	80 MW	106 MW
PV	3 MW	-	-	3 MW
TOTAL	502 MW	197 MW	3493 MW	4192 MW

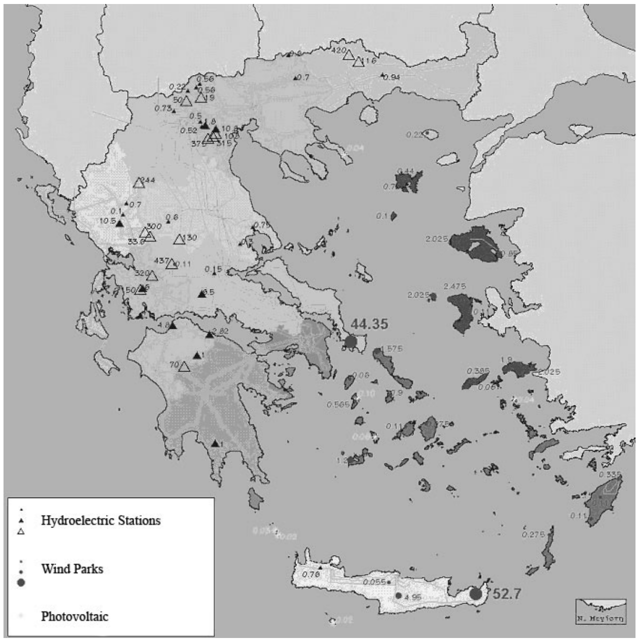

Figure 1: Distribution of RES in Greece

III. PROBLEMS OF RES INCREASE IN GREECE

Three main difficulties exist in the increase of RES share in Greece. The first is the weak transmission system in the high wind potential regions. This problem is even more serious in the autonomous island power systems, where dynamic security concerns lead to upper limits in the installed capacity of RES [8]. In the Greek mainland the transmission network has to be expanded or enforced in areas of high wind potential like Evia, Thrace and Peloponnese.

The second difficulty is the complex process for obtaining installation and operation license, since many institutions have to approve the installation site. Investors often have to obtain more than 30 licenses, in order to build a private power generation site [9]. Bureaucracy is a major drawback for the private sector, since the whole process may take up to three years.

Last, but not least is the opposition of local communities in several areas of Greece to the building of new RES installations. Lack of information and local interests can delay or even cancel the development of RES or the construction of the necessary network connections.

IV. TWO PILOT SITES

Two examples of increased wind power penetration are the islands of Kythnos [10] and Crete [8, 11].

Kythnos is a small non-connected island, where a Wind Park of 665kW and a PV station of 100 kW have been installed. The total demand of the island in 2002 was 5630 MWh, whereas the peak demand during summer (August) was 1605kW. The minimum demand was 120 kW during October. 10.2% of the island demand is met by the Wind Turbines production and 1% is met by the PV station production. The total annual renewables penetration exceeds 11 %, but some times the Renewable Energy Sources (RES) penetration reaches 100%. For more than 1000 hours per year, RES penetration exceeds 40% [10].

Crete is the largest autonomous system in Greece with 510 MW of installed thermal capacity during 2002. The installed wind farms capacity is 81 MW and their production accounts for the 10% of the annual energy demand. The instantaneous energy penetration has reached 39% [8, 11]

These two cases show that the wind power penetration especially in Greek islands can be significantly increased.

V. BENEFITS FROM RES IN GREECE

In this Section the potential benefits from increased RES penetration in the Greek power system are estimated. It should be noted that the operation of the Wind Parks does not only displace fuel, but it has also a major effect on the operation of the thermal units. This is mainly due to the considerations of the minima of the committed thermal units and the necessary spinning reserve that generally increase the operating cost of the system.

A recent study for Crete compares the costs of the actual operation of the system in year 2000, including compensation of the private wind power producers, to the operation costs for supplying the same load only by the thermal units, dispatched in an optimal way [12]. Where possible, the actual Unit Commitment is used. Table 2 summarizes these results for year 2000. Table 3 provides the resulting emissions reduction due to Wind Turbines installations.

Table 2: Economic Results for Crete

	Heavy oil (tn)	**Diesel Oil (klt)**	**Cost (k)**
Actual	263,166.5	283,303	178,505.6
Purely thermal	269,014.3	324,499	181,099.3
Difference	**5,847.76**	**41,196**	**2,593.7**
Percentage savings	**2.22%**	**14.54%**	**1.45%**

Table 3: Results of the Emissions Reduction on the Island of Crete due to Wind Turbines Installations

	Total Emissions Avoided	
	tn	**(%)**
Particles	**60.07**	**(7.27%)**
SO$_2$	**368.49**	**(2.41%)**
NO$_X$	**260.7**	**(6.03%)**
CO$_2$	**119.415**	**(7.78%)**

A relevant study has been performed for the Greek interconnected energy production. Most units in the Greek mainland are lignite units. There are also some natural gas, combined cycle and diesel units. In this study, a typical summer day of the year 2003 (17th of August) is examined. Using an appropriate unit commitment program based on the MORE CARE algorithms [13, 14] various wind power penetration scenarios have been examined [15].

In the first case unit commitment and economic dispatch have been performed assuming two levels of spinning reserve, 10% and 15% of the load and zero power produced from RES. In the other two cases, the same two levels of spinning reserve and 5% and 10% RES penetration during the day's total energy demand have been assumed. In this way the financial effects of RES can be evaluated, as well as the amount of the CO_2 emissions avoided by their use.

For the RES financial impact two cases have been examined. In the first case, we assumed that the energy provided by the RES did not have any operational costs. In the second case the tariffs applied for the RES energy production, have been taken into account, i.e. 0.065 ct/kWh. Table 4 (in two parts) demonstrates the results of our analysis.

Table 4a corresponds to the zero operational cost of RES and Table 4b to the second case. The negative profit (meaning loss) in columns 3 and 4 indicates that for high wind penetration reaching 10% for a level of spinning reserve set at 10%, there is a small economic loss compared to the zero RES case. That is reasonable, since lignite units have very low fuel cost.

Table 4.a: Results of the Economic and Emissions Reduction Analysis on the Greek Mainland (part I)

Penetration lev	**Reserves (%)**	**RES Generation (MWh)**	**Profit 1 ( )**	**Profit 1 (%)**
0%	**10%**	0	0	0
5%		8015,89	672304	8,48
10%		16031,79	1004879	12,67
0%	**15%**	0	0	0
5%		8015,89	645586	7,64
10%		16031,79	1196290	14,16

Table 4.b: Results of the Economic and Emissions Reduction Analysis on the Greek Mainland (part II)

Penetration level (%)	**Reserves (%)**	**Profit 2 ( )**	**Profit 2 (%)**	**CO_2 reduction (tn)**
0%	**10%**	0	0,00	0
5%		151271	1,91	2654
10%		-37187	-0,47	11431
0%	**15%**	0	0,00	0
5%		124553	1,47	1902
10%		154224	1,83	6200

On the other hand we can observe in column 5 in Table 4.b that we have a significant CO_2 emissions reduction. The decrease of CO_2 emissions is larger in the case of 10% spinning reserve than in the case of 15%. This is predictable, since units at reserve operation are producing according to the CO_2 gas emissions curves more kg of CO_2 per MWh.

Overall we can conclude that the use of RES reduces in most cases the operating cost of the Greek interconnected system, and can significantly reduce the CO_2 gas emissions. The spinning reserve policy applied has an important effect on these costs.

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3. OPTIONS FOR LARGE SCALE INTEGRATION OF WIND POWER

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ABSTRACT

This article demonstrates options for large scale integration of wind power. Two cases are considered. One is considering a connection of a large wind farm to fairly week regional grid, and the other is considering the power system balancing of large magnitudes of wind power. It is demonstrated that local control actions enables quite large wind farms to be operated at fairly week grids, and that marked based balancing tackles large magnitudes of wind power.

Introduction

The worldwide development of wind power installations now includes planning of large-scale wind farms ranging in magnitudes of 100 MW, and is considered to constitute a significant part of the renewable power production planned in Europe and in the world. This is a challenging development that will have an impact on the power system stability and operation as outlined in section 2. The development is sound however; wind power is a cost-effective renewable source that by application of adequate control technologies and marked based solutions can smoothly be integrated into the power system. Two cases are applied to demonstrate this. One is considering connection of a large wind farm to fairly week regional grid (section 3), and the other is considering the power system balancing of large magnitudes of wind power (section 4). It is demonstrated that local control actions enables quite large wind farms to be operated at fairly week grids, and that marked based balancing tackles large magnitudes of wind power.

Impact on power system stability and operation

Voltage control – reactive power compensation

A main challenge related to voltage control is to maintain acceptable steady-state voltage levels and voltage profiles in all operating conditions, ranging from minimum load and maximum wind power production to maximum load and zero wind power. Capacitor banks and transformer tap changers represent the most common means to control voltage profiles. Another challenge in this context is related to the control (or limitation) of the exchange of reactive power between the main transmission grid and the regional distribution grid.

Voltage stability

The output power from wind farms may vary significantly within a few seconds, and depending on the applied wind turbine technology, so will also the reactive demand. If the power system cannot supply this demand, a voltage instability or collapse may occur. Sufficient and fast control of reactive compensation is required to relax such possible voltage stability constraints related to wind farms, which can be provided through the use of wind turbines with active voltage control, or by using external compensators, such as Static Var Compensators (SVCs).

Transient stability

Traditionally, the protection systems of wind turbines have been designed to disconnect and stop the units whenever a grid fault (temporary or permanent) is detected. With increasing integration of wind power there are and will be system requirements implying that wind turbines must be able to “ride through” temporary faults, and contribute to the provision of important system services, such as momentary reserves and short circuit capacity. This puts emphasis on transient stability performance, power oscillations and system damping. Control equipment within wind farms enabling both power and voltage control becomes increasingly important in this context.

Thermal transmission capacity constraints

Thermal transmission capacity problems associated with wind power integration may typically be of concern in only a small fraction of the total operating time. Applying control systems to limit the wind power generation during critical hours may be a possible solution, or if other controllable power plants are available within the congested area, coordinated automatic generation control (AGC) may be applied. The latter alternative may be beneficial as energy dissipation may then be avoided.

Power fluctuations – frequency control

Wind energy is by nature a fluctuating source of power. In a system where a significant part of the power generation comes from wind, system operational issues, such as frequency regulation and congestion management become a challenge due to the normal variations in the available wind power. Systems with substantial supply from wind farms thus call for flexible and improved solutions with respect to secondary generation control.

Adverse impact from interaction of power electronic converters

Modern wind turbines utilizing power electronic converters provide enhanced performance and controllability compared to traditional fixed speed solutions. With increasing use of power electronics, however, there may be uncertainties with respect to possible adverse control interactions within the wind farm itself. Converter modulation principles and filter design are important issues that must be addressed and analysed as part of the wind farm design and installation.

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In summary, most of the challenges described above may result in operational conditions that adversely affect the quality of the voltage and power supplied to customers. Additionally, there may be system operational problems, such as congestion management and secondary control that not only affect the wind farm in question but the entire network. Thus, the problems suggest coordinated control solutions that maintain secure operation of the network, and at the same time allow for maximized and profitable integration of wind power. Indeed, large scale integration of wind power does not only set requirements to the power system, but also the wind power technology must be developed to system needs. The development of IEC 61400-21 [1] specifying procedures for characterizing the power quality of wind turbines and the various grid codes setting system requirements to wind farms, e.g. Eltra [2], are examples of such development.

Case – local control

The case study considers the connection in Norway of a large 200 MW wind farm to a typical regional distribution grid, see Figure 1. The study is based on an actual system, though slightly modified to serve the purpose of this paper. The regional distribution grid is connected to the main transmission grid via a long 132 kV line with a thermal power capacity limit of about 200 MW. Considering that the hydropower plant is rated 150 MW and that the local load may be as small as 14 MW, a conservative approach would suggest that the wind farm capacity should not exceed 64 MW (i.e. 200 – 150 +14), or indeed 50 MW (i.e. 200-150) to ensure operation if the local load disconnects. However, contrary to such conservative planning, this case demonstrates that installation of a much larger wind farm is viable.

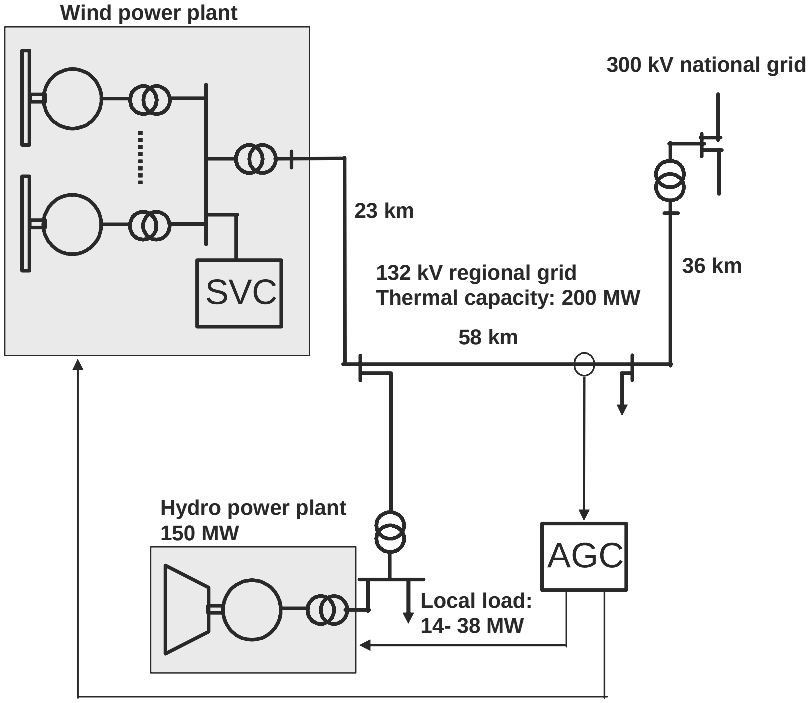


Figure 1: Outline of case study regional grid. Operation of a 200 MW wind farm is viable using the Static Var Compensator or built in reactive control capabilities of modern wind turbines for securing voltage stability, and using Automatic Generation Control (AGC) for controlling that the thermal capacity of regional grid is respected.

Due to environmental constraints, it is not an option in this instance to upgrade the 132 kV line for higher thermal power capacity. Hence, power electronics and control systems are applied to allow connection of the large wind farm.

Ref [3] shows that as long as the thermal capacity of the 132 kV line is respected, voltage control and stability is ensured by application of a Static Var Compensator

(SVC) and/or utilization of the reactive control capabilities of modern wind turbines with frequency converters. This is illustrated in Figure 2; reactive support enables a stable voltage for feed-in of 0 to 200 MW of wind power, whereas without reactive support, the wind farm size would have to be restricted to about 50 MW.

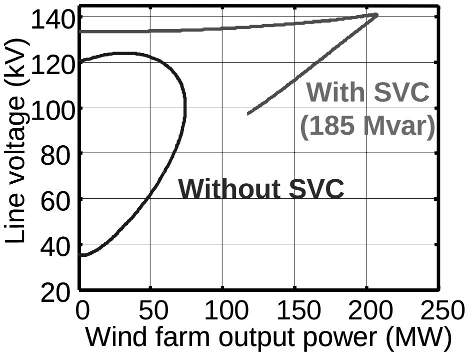


Figure 2: Result of dynamic simulations of power system with 0-200 MW of wind power [3].

Ref [4] demonstrates that Automatic Generation Control (AGC) of the hydropower plant can be used to avoid overloading the 132 kV line. This is illustrated in Figure 3, showing a result of a dynamic simulation verifying the performance of the AGC.

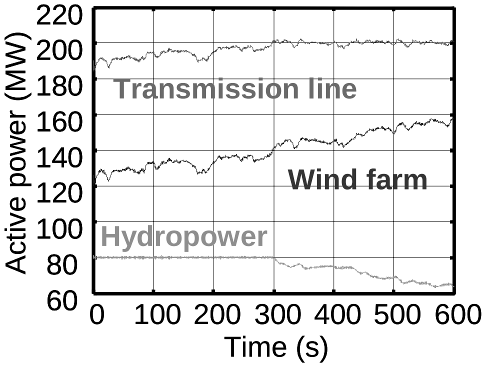


Figure 3: Result of dynamic simulation of power system with 200 MW wind farm and AGC control of hydropower plant [3].

The AGC operation influences the annual output and energy sales from the hydro and wind power plants. As found in [5] however, the impact on the energy sales is (surprisingly) moderate, see Table 1.

Table 1: Case study results with 200 MW wind farm for two cases of AGC control, i.e. control hydro (reschedule production) or control wind (reduce production), and for the case of unlimited grid capacity (non-congested case) [5].

	Control hydro	Control wind	Non-congested
Wind power (GWh/y)	609	551	609
Hydropower (GWh/y)	646	657	657
Local load (GWh/y)	219	219	219
Line load (GWh/y)	1036	989	1047

Case – market based power balancing

EU regulation requires that market based principles shall be used for congestion management. In the Nordic power system also the real time frequency control is handled through a joint balancing market.

This case considers actual operational data from the Nordic power system (see Figures 4 and 5). On 8 January 2005 there was a storm affecting southern Scandinavia initially causing high wind power production in Denmark. At a certain time however the wind turbines started to cut-out due to excessive wind speeds and the wind power production was reduced from 1800 MW to 100 MW during the afternoon hours. The loss of wind power production amounted to more than half of the consumer loads in Western Denmark. Figure 6 shows how this situation was handled in operation. The loss of generation was compensated through the balancing power market (mostly activated in Southern Norway) and by regulating the HVDC link between Norway and Denmark from full export to full import in the same hours. The example illustrate clearly that the Nordic power system can handle large amounts of wind power through the existing marked based mechanisms.

Secure operation requires that sufficient reserves and transmission capacity are available in such situations. In a future system with high penetration of wind power throughout Europe, the operational challenges with respect to operating reserves, frequency control and transmission capacity are expected to become increasingly important.

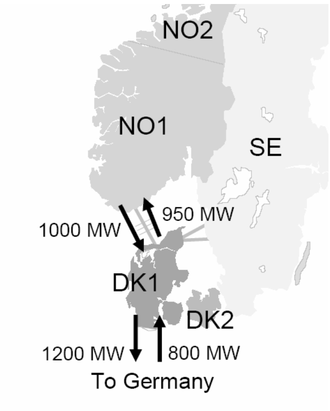
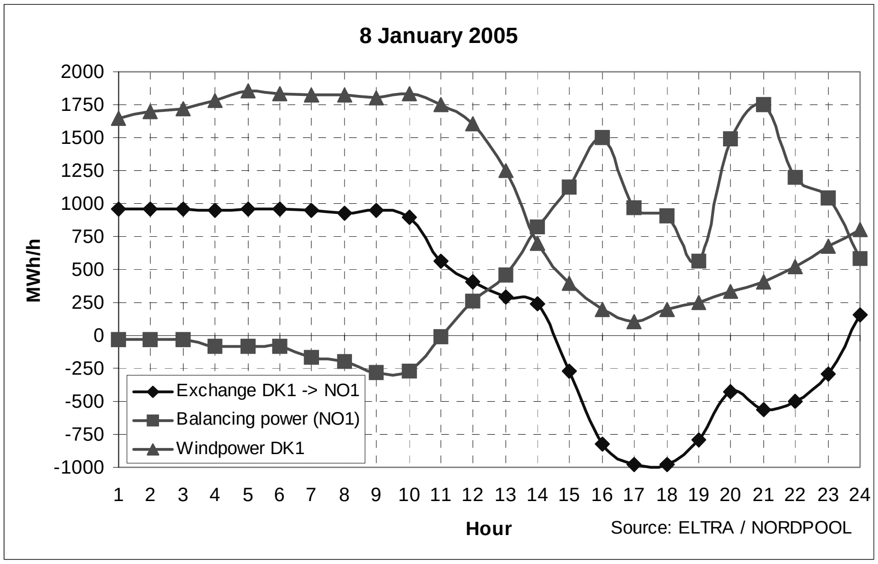


Figure 4: Map showing parts of Nordic market (Elspot) areas and normal transmission capacities between Western Denmark and Germany and between Denmark and Norway.



Source: ELTRA / NORDPOOL

Figure 5: Actual hour-by-hour data of wind power in Western Denmark (DK1), balancing power in Southern Norway (NO1) and power exchange over the HVDC line between Southern Norway and Western Denmark.

Conclusion

This article has demonstrated options for large scale integration of wind power. Local control enables operation of a large wind farm on a fairly week regional grid, and marked based balancing tackles large magnitudes of wind power. A future with high penetration of wind power throughout Europe seems thus viable, though the operational challenges with respect to operating reserves, frequency control and transmission capacity are expected to become increasingly important.

Acknowledgement

The financial support from Statkraft and the Norwegian Research Council to SINTEF Energy Research for carrying out the work presented in this article is acknowledged.

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Biographies

John Olav Giæver Tande was born in Trondheim in 1962. He received his M.Sc. in electrical engineering from the Norwegian Institute of Science and Technology in 1988. He has worked as a research scientist at Norwegian Electric Power Research Institute (1989), Risø National Laboratory (Denmark, 1990-97) and SINTEF Energy Research (1997-). Throughout his career his research has focused on electrical engineering aspects of wind power, and he has broad experience within the field including heading EU projects and working groups of IEC and IEA.

Kjetil Uhlen (MIEEE 1995) was born in 1961. He received the Sivilingeniør degree from the Norwegian Institute of Technology in 1986 and a PhD degree in control engineering from the same institute in 1994. Since 1987 he has been employed at SINTEF Energy Research in Trondheim, presently as a Senior Research Scientist. His main technical interests are operation and control of electrical power systems.

Terje Gjengedal, SMIEEE, was born in Sandane in 1958. He received a MSc and a PhD in electrical engineering from The Norwegian Institute of Technology in 1983 and 1987 respectively. He has a broad range of experience from R&D, universities, and industry and power utilities. He is currently working with Statkraft Energi as Manager of Department of Power Production Coordination. He is also working as a Professor at the Norwegian University of Science and Technology, NTNU, in Trondheim

4. TECHNICAL AND COMMERCIAL IMPACTS OF THE INTEGRATION OF WIND POWER IN THE PORTUGUESE SYSTEM HAVING IN MIND THE IBERIAN ELECTRICITY MARKET

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Abstract

Portugal is committed towards the EU to an ambitious target of attaining 39% of renewable energy production by 2010, as defined in the RES Directive. Although the Portuguese production structure already has a large contribution from hydro power, presently all these units are only able to deliver about 12 TWh (average year). The new big hydroelectric investments, together with the mini-hydro power stations that are expected to be ready until 2010 will not be able to increase largely this share of needed renewable energy. For a forecasted total production need of about 62 TWh in 2010, 24 TWh need to be produced from renewable energy sources. The missing renewable energy should be produced exploiting wind energy, meaning that by 2010 a wind power capacity of more than 4.000 MW should to be in operation. At the same time Spain is also increasing wind power integration, such that by 2010 more than 13.000 MW are expected to be installed. The Spanish and the Portuguese electric power systems are facing at the same the challenge of a regional electricity market – the Iberian Electricity Market. This requires that wind power integration must be tackled having in mind technical and commercial concerns. This paper analyses these issues.

1. Present and Future Situation Regarding Renewable Energy in Portugal

Portugal is committed towards the EU to an ambitious target of attaining 39% of renewable energy production by 2010, as defined in the RES Directive. Although the Portuguese production structure already has a large contribution from hydro power, presently all these units are only able to deliver about 12 TWh (average year). The new big hydroelectric investments, together with the mini-hydro power stations that are expected to be ready until 2010 will be able to provide only about an additional 1 TWh of energy. For a forecasted total production need of about 62 TWh in 2010, 24 TWh (39%) need to be produced from renewable energy sources.

The missing energy should be produced from other renewable power sources, with a major contribution from wind power. At present, there are already about 500 MW of installed capacity in wind power. Up to 2007, a total capacity of about 3250 MW has already been committed, following the call of the beginning of 2002. Having in mind the expectable contribution from other non-hydro renewable power sources this means that more than 4000 MW of wind power need to be installed by 2010. In fact, only wind power has enough technical maturity and flexibility to be able to fill the gap of missing renewable energy.

Figures 1 and 2 describe the structure of energy production and installed capacity as it was in 2001 and the expected ones for 2010.

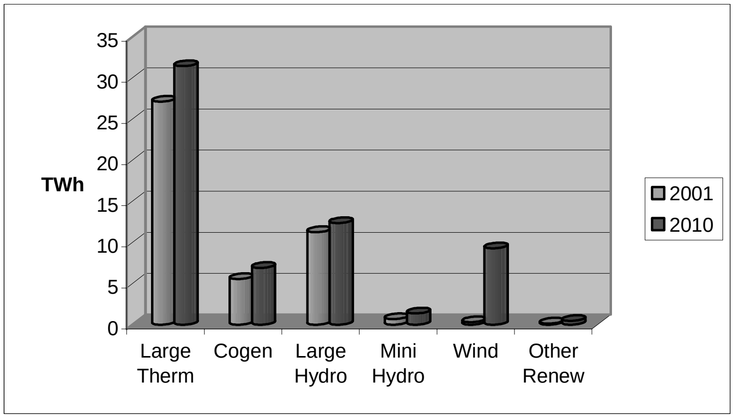

Figure 1 – Structure of the energy production in Portugal 2001 / 2010

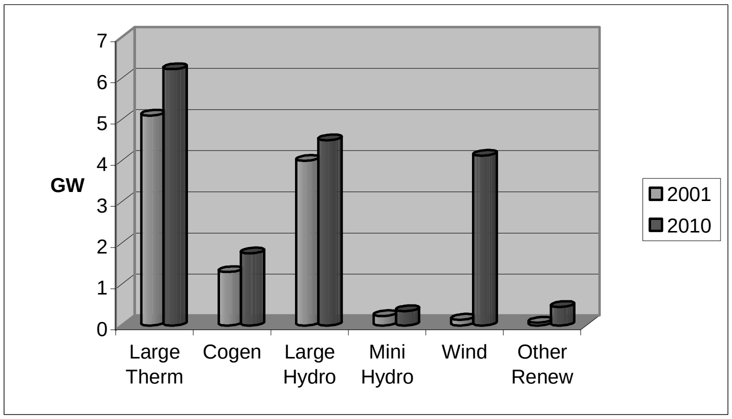

Figure 2 – Structure of the installed capacity in Portugal 2001 / 2010

A feed-in tariff scheme has been developed to remunerate all renewable power sources (with the exception of the large hydro) allowing the wind energy to get a very interesting payment. An average value of 82 /MW.h is used to pay the wind energy delivered to the grid [1]. This generation is considered under a legal umbrella of a Special Regime Generation (as in Spain), having priority, in terms of its absorption by the grid, over other conventional forms of energy.

For this purpose the Portuguese TSO developed an ambitious expansion and grid reinforcement plan to allow the integration of large shares of Special Regime Generation. Such planning was however developed assuming very conservative criteria regarding the simultaneous generation of these units. According to the Portuguese regulations, after the acceptance by the regulator of these expansion plans the corresponding costs will be passed to the final consumers through the transmission tariffs.

2. The Iberian Electricity Market

On January 20th of 2004 the governments of Portugal and Spain signed the treaty that creates the Iberian Electricity Market (MIBEL) with the objective of providing access to a common electricity market for all agents (consumers and electricity producers) operating within the Iberian peninsula. The MIBEL treaty created an Operator for the Iberian Market (OMI) that started with two poles: one in charge of the day by day operation – OMEL – situated in Madrid and dealing with the daily and intra-daily spot markets; and the other one in charge of the short and medium term future contracts for physical trading of standardized packages of power quantities for a maximum period of time of one year – OMIP – situated in Lisbon. Until April 20th of 2006 the commercial societies owning OMEL and OMIP will merge to create the single OMI. Apart from the trading through the spot market and the futures market it is also possible to exploit bilateral trading arrangements for contracts with a minimum horizon of one year. Although the interconnection capacity between Portugal and Spain still presents some technical limitations (Portugal – Spain between 1200 and 1500 MW; Spain - Portugal between 1000 – 1250 MW), it is expected that MIBEL could be in operation until June 2005,.

Spain is also committed for 2010 to an important target regarding renewable energy production. In fact Spain aims to assure that 29% of its energy will be produced from renewable power sources. For this purpose Spain has largely pushed wind energy ahead, such that presently more than 6.000 MW are already in operation aiming at 13.000 MW by 2010.

With such a large amount of wind power generation in the Iberian system several technical and commercial problems appeared and need to be properly dealt.

2.1 Technical issues

In Portugal, most of the wind generation is situated in the North of the country, near the areas where the hydro production is installed, which may provoke congestion problems in the lines that bring the power flows to the large consumption areas of Lisbon and Porto. The possibility of installing in wind parks a capacity larger than the one the grid accepts is being considered in some cases but it still requires the definition of clear and structured procedure from TSO side. Since total wind generation will rarely inject into the grid the nominal capacity value, such an approach allows the increase of wind penetration without massive grid reinforcements. However this requires increased wind park monitoring output.

The management of such large amounts of wind generations requires therefore the adoption of the following measures:

1. Increase in monitoring and control of wind parks;
2. Installation of tools to provide wind power forecasting capabilities within different time horizons;
3. Evaluation of transient and dynamic stability of the system following system disturbances (considering also ride through default characteristics);
4. Re-evaluation of the reserve margins used to operate the system;
5. Identification of procedures to solve technical constraints in the system considering the characteristics of wind energy converters installed or to be installed.

The Spanish TSO has already implemented some of these technical measures imposing technical requirements regarding monitoring and control in its new Grid Code and developing tools for wind power forecasting [2,3].

Studies regarding dynamic behaviour of the Portuguese / Spanish interconnected grid have been conducted by both TSO, leading to the identification of wind power penetration limits for specific operating conditions. One of the critical issues is related with a sudden loss of wind generation due to a system disturbance, leading to an increase in the power flow imported from neighbouring control areas, which may provoke in some scenarios overloads in the interconnection lines. Since the interconnection capacity is limited, either from Spain to Portugal or from France to Spain, this may become quite critical, especially in situations where the interconnection flows are large due to the expected increase of commercial exchanges.

2.2 Commercial issues

As already mentioned in Portugal wind generation is remunerated through feed-in tariffs, while in Spain wind energy can be either remunerated through special feed-in tariffs or can participate directly in the daily market [2], having a similar treatment as a conventional generator.

For daily markets to operate in a situation characterized by a considerable presence of wind power generation, with priority regarding other conventional forms of energy, it is required that power predictions tools and additional regulatory mechanisms should be used. In a total liberalized consumption scenario, if these approaches are not used it will be impossible to identify the closing of the market. For this purpose, in Spain [2], wind generators are now requested to deliver a forecast of their wind energy generation levels even if they are remunerated according to feed-in tariffs. In this case penalties for imbalances larger than +/-20% apply. Wind generators participating in the daily market are required to inform the pool on the expected generation amounts for the next hours (30 hours in advance). Penalties for energy imbalance will also apply in this case. In Portugal similar procedures will have to be implemented next in order to allow for the operation of the common market.

While there will be no enough interconnection capability the Iberian daily market will have to exploit market splitting mechanism, requiring wind power forecasting amounts, for each control area (Spain / Portugal), to be delivered to TSO and market operators.

3. New Tools to Help Managing the System

The fact that in the Iberian Peninsula there is also a considerable capability of hydro generation suggests that hydro and wind power should be used in a combined way, namely using hydro generation to compensate for changes in wind power. Also the combined use of hydro pumping storage facilities and wind power should be promoted, since these facilities are available in both the Portuguese and the Spanish system.

However there are not yet interesting commercial mechanisms to force generation agents to exploit such hydro storage compensation capabilities in case of generation imbalances. There are no intermediate commercial tools between the intra-daily markets and the use of reserves when imbalances in generation are foreseen. In fact the intermittent nature of wind generation demands complementary generation to be available when the generation imbalances are forecasted in very short term. Such complementary generation can be modelled as a call option on electric energy, while the exercises of such call options depend on the availability of the wind generation.

In Portugal, wind energy can get two remuneration levels according to the period of the day [1], provided that the wind park developer selects such option at the beginning of the operation. During valley hours the average value for wind energy remuneration is 54 /MWh while during off-valley hours it is 103.84 /MWh. Assuming that wind energy can be stored in water reservoirs, after pumping during valley hours or when congestion problems exist in the grid, to be delivered to the system during off-valley hours, it can be demonstrated that such operation becomes interesting for wind park developers, as described in [4]. Even with round efficiencies of around 75% in this water pumping storage / generation cycle, it can become economically interesting to exploit such an approach because of this difference in wind energy payment.

The utilization of wind power aggregation agents, acting as a kind of virtual power plants, has already been designed for the Spanish system and will be most probably adopted for Portugal due to the need in harmonization of the technical procedures to follow in system operation management.

4. Conclusions

The electric power system of the Iberian Peninsula will be facing large technical and commercial challenges that result from a large amount of wind power integration (more than 17.000 MW of installed capacity in 2010 for a peak load of about 50 GW) and the development of a regional integrated electricity market.

The introduction of new technical and commercial concepts and tools is needed to help managing properly the system as well as the use of new wind energy conversion systems able to provide ancillary services like reactive power and voltage support, primary reserves and secondary reserves coming down.

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Biography

.A. Peças Lopes was born in Portugal where he obtained an Electrical Engineering degree (5 years course) in 1981 from University of Porto and a PhD. degree also in Electrical Engineering from the same University in 1988. In 1989 he joined the staff of INESC as a senior researcher. In 1996 he got a postdoctoral Aggregation degree. He is presently Associate Professor with Aggregation in the Dept. of EE of the Faculty of Engineering of University of Porto and he is also Adjoint Coordinator of the Power Systems Unit of INESC Porto and a senior member of the IEEE. He led in the last years several research and consultancy projects in the field of the integration of renewable and distributed energy sources in Portugal and abroad.

5. THE SPANISH EXPERIENCE OF THE GRID INTEGRATION OF WIND ENERGY SOURCES

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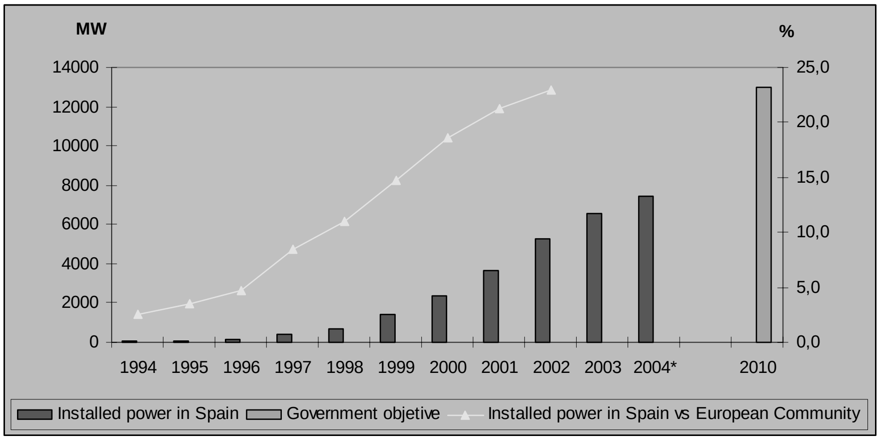
Abstract:

There are over 7900 MW of installed wind power in the Spanish Electrical System. This amount of installed power, compared with a load peak around 38.000 MW, has a big impact on system operation. Some particularities of the Spanish Peninsular Power system, a satellite of the UCTE interconnected network, with weak interconnection ties with the rest of Europe, suggest that this integration should be analysed very carefully. The already collected real-time experience and the events experienced have created an interesting background for the integration of wind energy without jeopardising the actual levels of quality and allowing the achievement of the national and European environmental targets.

This paper describes the actual situation of the integration of wind power in Spain, presents the actual regulation, especially on the economic incentives, and reports the experience and the next steps to be followed for a harmonized integration of wind energy

1. Introduction

Until recently, installed wind power was anecdotic, and its influence on the system insignificant. Over the last few years however, the installation of wind power generation connected to the Spanish electric power system has grown very fast. This growth has proved even more rapid than the average growth within the European Community, as illustrated in figure 1.



* up to 20th July

Figure 1. Evolution of wind power generation connected to the Spanish electric power system and comparison with growth in European Community.

By relating wind-installed power with other figures, we can demonstrate that the importance of wind generation in Spain is not less than in other countries like

Germany or Denmark (figure 2). When we compare wind-installed power with population (indirect way of comparing installed power with the size of the electric system), Spain appears to have a size comparable to Germany. If we compare wind installed power with import exchange capability, Spain fares well above other countries. This means that the transient support that Spain can receive from other countries, due to the Principle of Joint Action, is small compared with the wind-installed power.

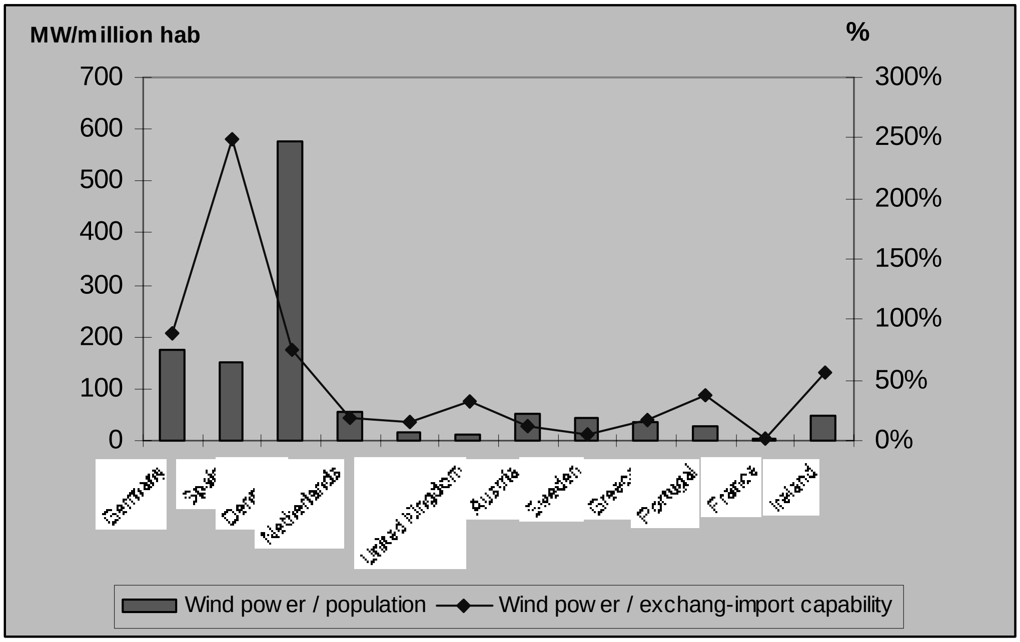


Figure 2. Relation of wind power installed vs. population and vs. exchange capability.

2. Actual economic incentives for wind energy on the Spanish Regulation [1].

Wind power producers are entitled to transfer their production to the system through the electricity distribution or transmission company whenever the absorption of the energy by the network is "technically possible".

Wind power producers may chose from two different options in order to incorporate their production into the system. They can opt for:

(a) **Participating directly in the Spanish Wholesale Electricity Market**, either presenting bids or establishing bilateral contracts. In both cases wind power producers have the same treatment as the "ordinary regime" as far as ancillary services are concerned. If they opt to participate directly in the Spanish Wholesale Electricity Market presenting bids, their production has the following treatment concerning congestion management:

- Their production can not be withdrawn on the grounds of network congestion problems (excepting on real time management) if they bid as price takers (bids at a price of 0 / MWh).

- Their production shall be incorporated for solving technical constraints, provided their bid price is less than 70% of the reference tariff[1] as defined in [1] article 2 (excepting on real time management). The producers shall be connected to a distribution company that in turn is connected to a point of the transmission network in which the System Operator (REE) has identified a constraint problem.

(b) **Selling the energy to the distributors**. Wind power producers are entitled to sell their production to the distribution companies, which are obliged to buy this energy. The distribution companies deduct this production from the buying bids that they have to present to the Spanish Wholesale Electricity Market in order to supply their captive customers.

The above is also what current applies to production from all renewable and high efficiency plants, integrated in the so-called “special regime”, as opposed to the “ordinary regime”.

Depending on the option chosen, wind power producers are retributed as follows (table 2):

(a) **Participating directly in the Spanish Wholesale Electricity Market:** Hourly Marginal price of the Wholesale market or price negotiated in bilateral contracts + subsidy + incentive + complement for reactive power + complement for fault ride through capability - deviation from production programs (see **“Treatment of deviations from production programs”)**

- Subsidy: percentage (40%) of the yearly electricity average tariff or reference tariff as defined in [1] article 2.

- Incentive: percentage (10%) of the yearly electricity average tariff or reference tariff as defined in [1] article 2.

- Complement for reactive power: percentage of the yearly electricity average tariff or reference tariff as defined in [1] article 2, (table 1). Producers can also renounce to this complement and participate in the reactive power market (not in place yet).

- Complement for fault ride through capability (withstanding voltage sags): for 4 years, the 5% of the yearly electricity average tariff or reference tariff as defined in [1] article 2.

(b) **Selling the energy to the distributors:** Regulated tariff + complement for reactive power + complement for fault ride through capability - deviation from production programs (see **“Treatment of deviations from production programs”)**.

- Regulated tariff: percentage of the yearly electricity average tariff or reference tariff as defined in [1] article 2. Irrespective of inshore or offshore installations, the above percentage is established as follows:

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[1] The reference tariff for year 2004 is 7,2072 c /kWh

  - For installed capacities ≤ 5 MW: 90% of the tariff during the first 15 years after commissioning, and 80% afterwards;
  - For installed capacities > 5 MW: 90 % of the tariff during the first 5 years, 85% during the following 10 years and 80% after that period.
- Complement for reactive power: Percentage of the yearly electricity average tariff or reference tariff as defined in table 1.
- Complement for withstanding voltage sags: Same as option (a).

Table 1. Complement for reactive power.

Power factor	Active & reactive energy	%		
	Power factor	Peak	Plain	Off-peak
Inductive (lag)	< 0,95	-4	-4	8
	< 0,96 & ≥ 0,95	-3	0	6
	< 0,97 & ≥ 0,96	-2	0	4
	< 0,98 & ≥ 0,97	-1	0	2
	< 1 & ≥ 0,98	0	2	0
	1	0	4	0
Capacitive (lead)	< 1 & ≥ 0,98	0	2	0
	< 0,98 & ≥ 0,97	2	0	-1
	< 0,97 & ≥ 0,96	4	0	-2
	< 0,96 & ≥ 0,95	6	0	-3
	< 0,95	8	-4	-4

The reported tariffs, subsidies, incentives and complements will be reviewed in 2006 and afterwards in each 4 year period. Irrespective of this, prices will also be reviewed when wind power generation reaches 13 000 MW of total installed capacity.

The treatment given to deviations differs, depending on the option chosen to incorporate the production in the system, as follows (table 2):

(a) **Participating directly in the Spanish Wholesale Electricity Market:** Same treatment as ordinary regime, which basically follows the principle that those installations that deviate from their programs, pay the overall cost of solving the deviation of the whole system, in proportion to its own deviation.

(b) **Selling the energy to the distributors:** Wind power producers exceeding 10 MW of installed capacity are permitted a deviation of 20% from their forecast (they are obliged to give this forecast to the distribution company they are connected to). Deviations exceeding that range are paid at a price consisting of a percentage (10%) of the yearly electricity average tariff or reference tariff as defined in [1] article 2.

Table 2. Summary of the retribution schemes for wind energy.

	Participating directly in the Spanish Wholesale Electricity Market	***Giving the energy to the distributors***
Hourly Marginal Price or Price negotiated bilaterally	*Depends on the market*	--------------------------------
Regulated tariff	-----------------------------------	*5,76576-6,48648 c /kWh*
Subsidy	*2,88288 c /kWh*	--------------------------------
Incentive	*0,72072 c /kWh*	--------------------------------
Complement for reactive power	*Depends on power factor and time of the day*	*Depends on power factor and time of the day*
Complement for withstanding voltage sags	*0,36036 c /kWh during 4 first years*	*0,36036 c /kWh during 4 first years*
Deviation from programs	*Depending on deviations*	*Depending on deviations*
TOTAL (not including complement for withstanding voltage sags)	***3,60360 c /kWh + market or negotiated price + complement for reactive power - cost of deviations***	***From 5,76576 to 6,48648 c /kWh + complement for reactive power - cost of deviations***

3. The Spanish experience.

The minimum voltage protection systems in Spain’s wind farms must comply with the specifications of Ministerial Order of 5th September 1985 [2]. In accordance with this Order, it is mandatory the installation of three instantaneous minimum voltage relays between phases in the connection point of wind farms. The relays must provoke instantaneous disconnection of the wind farm when voltage drops below 85% of the average value between phases.

In order to integrate as much generation as possible, a delay in the disconnection of wind parks during disturbances has been considered. However, it has been confirmed that some technologies cannot stand such a delay.

With wind penetration levels currently being reached in Spain, in the event of short-circuit in the transmission network –even if it is correctly cleared, the minimum voltage protection system may cause instantaneous disconnection of a significant number of wind farms, with the consequent loss of power generation. Studies that have been carried out [3] show the importance of minimum voltage protection systems in wind farms and system stability. Figure 3 (real experience, not fiction or simulation) presents the total wind production in the Spanish Peninsular Electrical System during the 18th of January of 2004. The curve shows the wind production in peninsular Spain, with some sudden trips of production coincident with correctly cleared short-circuits in the transmission network. In this case, the interrupted production does not exceed 500 MW, but should the short-circuit occur in a day with more wind, or wind installed power increases, the amount of production disconnected will also increase

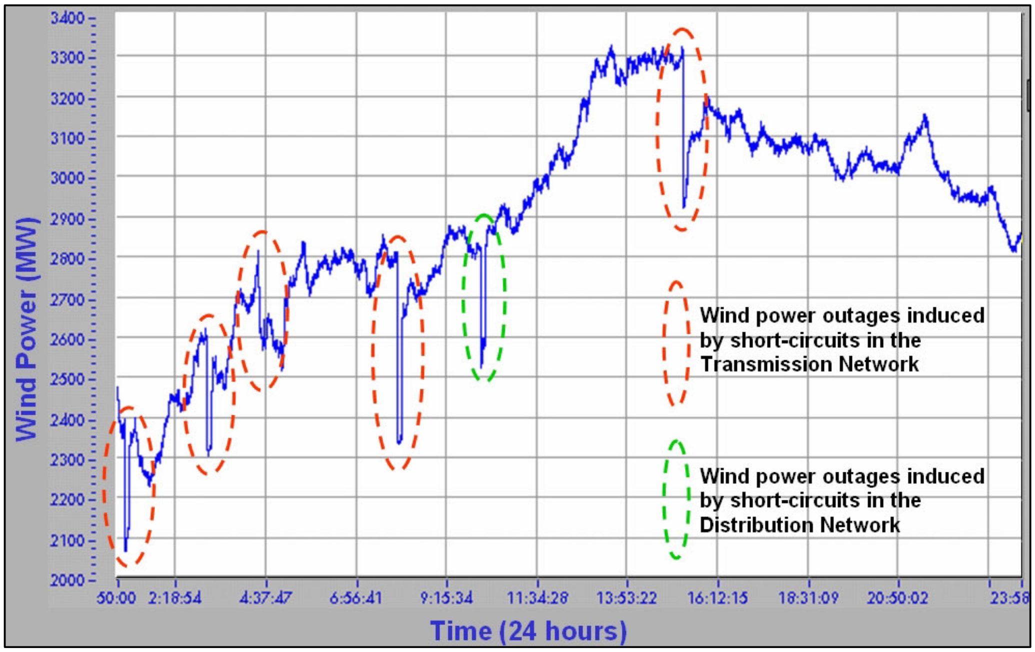

Figure 3.-Wind power trips induced by faults on the Network (MW).

In order to evaluate the influence of these trips in the system security, the amount of connected ordinary regime plants is very important because they help contain the disturbance and recover the system parameters after the disturbance. For this reason, the same amount of wind production loss would be more severe in low demand condition than in peak demand condition.

Being aware of this drawback, REE has proposed to the Regulator new technical requirements [4] in order to integrate a big amount of wind generation in the Spanish electric system, maintaining the actual security and quality standards. Of course, for this purpose it is needed that wind generators meet some requirements for improving the fault ride through capability (do not disconnect in the grey area of figure 4 and not consuming active or reactive power during the disturbance).

REE regularly evaluates the maximum wind power penetration that is compatible with system security according to transient stability analysis in different situations. According to this evaluation, some times it was required to reduce wind generation for example the first of January of 2004. The different responses of wind generators in four distribution areas in Spain, to a request for limiting the production is shown in figure 5. These graphs display the aggregated production of the distribution zones.

The first of the four graphs shows the production of a zone that has a control centre, with a very good response. Conversely, the request to limit the production has not been correctly followed in the other zones

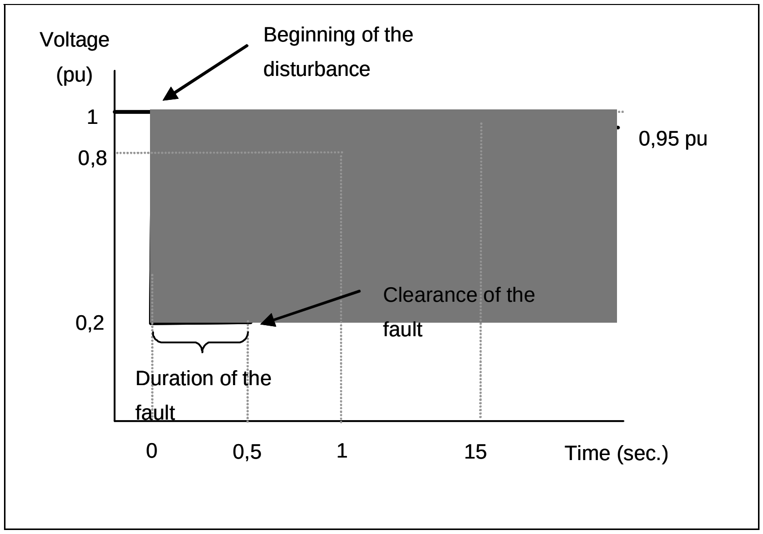

Figure 4.- Proposed voltage-time curve by REE in the connection point.

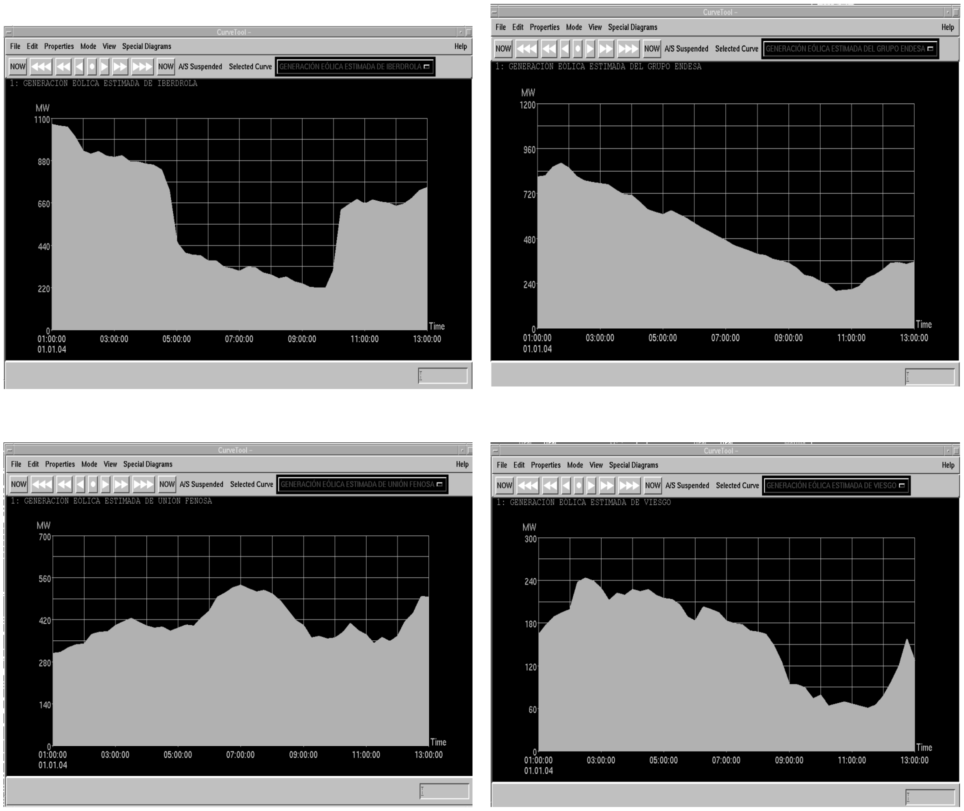

Figure 5.- Wind production in four different distribution areas.

These case studies confirm the importance of connecting all wind generation plants to a control centre to effectively inter-act with the System Operator.

5. Conclusions

Wind power is different from conventional sources of energy due to three main reasons: prime mover, the wind, location of resources and the electrical machines. Controllability and availability of wind power significantly differs from thermal or hydro generation because the primary energy source can not be stored and is uncontrollable. Wind power does not complicate very much short term balancing and all wind turbine types can be used for it, although variable speed wind turbines have better capabilities. Long term balancing is problematic. The power generated by wind turbines depends on the actual value of the wind speed. When there is no wind, no power from wind turbines is available. Wind turbines complicate the long term balancing task, particularly at high wind power penetrations.

More than 7900 MW in wind mills are already connected to the Spanish Peninsular Power system networks, this “enormous” amount requires advanced solutions in order to keep the actual level of power quality, such us the development of dispatching centres (under the ownership of the TSO or others) which transmit with accuracy the orders given by the TSO to the wind farms.

The integration of wind power is possible, but requiring the development of adequate procedures which harmonised and made compatible the technical requirements and the market rules.

Considering the reduced contribution of wind generators to short-circuit power and the high meshed level of the European Networks, a short-circuit on the transmission network can lead to widespread voltage dips to neighbouring TSOs. Therefore, the “fault ride through capability” of wind generators is an useful requirement to prevent large outages of windpower dependent on the given regional potential gradient area.

6. References

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6. ANALYSIS OF THE INTEGRATION OF WIND GENERATION INTO THE IRISH SYSTEM

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Abstract-- The European Union RES-E target for renewables for Ireland is 13.2% in 2010. ESB National Grid estimate that this corresponds to an installed capacity of 1,000 MW wind generation, together with some hydro and biomass. In order to determine the technical issues associated with accommodating various levels of wind generation from a system perspective, a number of areas need to be examined.

Wind generation may be constrained for two reasons: transmission reasons and "wind reasons" due to the inherent variable and unpredictable nature of the wind. ESB National Grid has undertaken to carry out analysis of the effect of the wind on the system in isolation of transmission constraints. To this end, ESBNG has a devised a work programme, which can be split into two main strands: an Initial Investigation and a Detailed Technical Analysis. A report is programmed for completion by the end of April 2004.

Introduction

The European Union RES-E target for renewable energy in for Ireland is 13.2% in 2010. This corresponds to an installed capacity of about 1,300MW of renewable energy sources comprising 240 MW of hydro, 92 MW of bioenergy and 1,000MW of wind. 1,000MW of wind in 2010 could represent up to 25% of the Irish system's installed capacity at a given time and would mean that the Irish synchronous system would have one of the highest amounts of wind generation as a percentage of installed capacity in the world. Notwithstanding the other issues involved in installing such a significant amount of wind generation on the system in the time between now and 2010, there are a number of power system issues which need to be addressed. The Irish system, which is interconnected with the Northern Ireland system, is one of the smaller synchronous systems in the European Union. There are a number of challenges facing the Transmission System Operator, particularly in the areas of frequency and voltage control.

Overview of the Irish System

The transmission system in Ireland consists of the 400kV, 220kV and 110kV systems. It comprises over 5,800 km of HV lines and cables and over 100 HV transformer stations where the voltage is reduced for onward local distribution at voltages of 38kV, 20kV and 10kV. It is a largely a meshed system, that is for each connection point on the system there is more than one line or cable going from that connection point. Two 400kV overhead lines run almost the entire width of the country from the Moneypoint generation station on the west coast to the Dublin area on the east coast. The 220kV network is the backbone of the grid and comprises a number of single circuit loops around the country. The larger generation stations (typically >100MW) are connected to the 220kV or 400kV networks. The 110kV network, which constituted the entire transmission system prior to the 1960s, is meshed and so provides parallel paths to the main 220kV system. The transmission system generally comprises overhead lines, except in limited circumstances, such as in the centre of Dublin and Cork cities, where underground cables are used.

The Distribution System consists of 94 sub-transmission substations, 77 at the 110kV to 38kV level and 17 at the 110kV to MV level. The 38kV network, which forms the backbone of the distribution system, consists of 5,700km of overhead lines and 500km of underground cables. There are 471 38kV substations. In the MV network, there is 76,100km of overhead lines and 5,300km of underground cables, encompassing 183,100 pole-mounted MV/LV substations and 14,500 ground mounted substations. Finally, in the LV network, there is 60,400km of overhead lines and 10,500km of underground cables

The peak demand on the Irish system this year was 4285MW, with the installed capacity on the system of 5579MW. The main source of energy on the Irish system is from fossil fuel plant, gas, oil and coal making up the largest part. Gas-fired plant represents the largest energy source on the system with a 42% share, coal-fired plant next providing 28% of the energy and oil-fired plant comprising 15%. The remaining 15% is made up of peat-fired plant (peat is an indigenous fuel in Ireland), hydro plant, one pumped storage plant of 292MW, CHP (Combined Heat and Power) and wind generation.

Wind on the Irish System

At present, there are 32 wind farms connected to the Irish electricity system, amounting to 236MW. This is split between 38.75MW connected to the transmission system and 197MW connected to the distribution system. The amount of wind connected on the system represents roughly 4% of the system's total installed generation. However, in the next two years, 380MW of wind generation is due to connect to the transmission system and a further 245MW to the distribution system. This will bring the total amount of wind on the system to 860MW, which would represent 15% of the installed capacity on the system. Furthermore, applications to connect to the system amount to a further 1366 MW bringing the potential total to 2208 MW. This would represent a far higher proportion of wind than in any other synchronous power system in the world.

Reason for the Analysis of Wind on the System

With the advent of large amount of wind generation on the Irish System, it is expected that it will be necessary to constrain wind generation at certain times. Wind will be constrained for two reasons: transmission reasons and 'wind reasons' (due to the variability & predictability of the wind). It is expected that the extent of constraining wind for transmission reasons, under the current access regime, would be reasonably limited. ESBNG has undertaken to carry out analysis of the effect of the wind on the system in isolation of transmission constraints. To get a meaningful result, it will be necessary to model both the variability and the predictability of the wind.

Variability of the wind is an issue for the system operator as the conventional plant must be able to ramp up/ ramp down to meet the load and cope with the variance of the wind. For example, as the load drops off at night time and generators are reducing load, the wind may be increasing. It must be investigated if it is possible to meet demand or whether wind would have to be constrained in advance, in order to permit the conventional generators to meet the decreasing demand.

Predictability of the wind is an issue for the system operator as, if the system operator cannot determine when the amount of wind generation on the system is going to change then more operating reserve must be carried in order to cover the *risk* of that happening. ESBNG uses the More CARE programme to forecast the output of wind generation. This programme has been running for 2 years, with 11 geographically-dispersed wind farms in the forecast. The result is then scaled up to make a country-wide forecast. It forecasts 48 hours ahead, on an hourly basis, but there is a 4.5 hour (3.5 hour in winter time) time lag before it gets the HIRLAM data from the national meteorological service Met Éireann. The wind forecast for the last two years will be compared with the real data for that time period to establish the accuracy of the wind forecasting. In particular, the accuracy of programme in forecasting high wind situations (leading to WTG shutting down) and the frequency and nature of events on the system where More CARE did not forecast unusual wind events on the system will be examined.

Secondly, the effect that a large amount of wind would have on the system for different system demands and generation profiles will be investigated. The issue will be the ability of the plant mix that is expected to be on the system in 2010 to ramp up or down in order to accommodate the wind generation and at what point is the plant unable to meet the load and accommodate all the wind on the system (ie the variability). Also the unpredictable nature of the wind will be modelled at this stage. A suitable software tool will be used to examine the effect that wind has on the system. It will need to contain the system demand information, the generation data including heat rate curves, ramp rates, minimum up & down times, fuel prices and scheduled outage data. Other parameters/constraints will be modelled such as spinning reserve. The forced outage rate will also be modelled.

Programmes for Analysis of Wind Generation

In order to examine the technical issues surrounding the integration of a large amount of wind onto the Irish System, ESBNG have a devised a work programme, which can be split into two main strands, Initial Investigation and Detailed Technical Analysis, which is scheduled for completion by the end of April 2004.

Strand 1 – Initial Investigation Phase

Strand 1, the initial investigation phase, will take approximately 3 months, beginning November 2004. First, Strand 1 will identify typical historical wind generation patterns. Then, scaling these wind generation patterns up to 1000MW of installed wind capacity, and assuming fixed forecast error, operating strategies for conventional generation will be devised to facilitate these typical wind profiles given a set of typical system demand curves. This analysis will allow determination of the capabilities of conventional plant mix to accommodate increased wind penetration, and initially estimate the level of wind curtailment that may be operationally necessary, ignoring the economic aspects. The effect of intra-15 minute period fluctuations of wind will be examined in this phase.

Strand 2- Detailed Analysis Phase

Strand 2, a more detailed technical analysis phase, is provisionally estimated to take approximately 6 months and will commence in parallel with Strand 1. Strand 2 will develop on the initial analysis in Strand 1 in the following areas: it will consider future wind profiles that take into account more diversification, consider the impact of wind forecasting in more depth, use a projected conventional plant portfolio for 2010, and assess the economic impacts of accommodating large amounts of wind on the system. The power system operating strategies developed in Strand 1 will be evaluated from both operational and economic perspectives. A report is programmed for completion by the end of April 2004. It is ESBNG's intention to publish the timetables for the work programme on the ESBNG website.

There is other work on-going in ESBNG, but outside the remit of the above analysis, such as the detailed analysis of wind forecasting modules & techniques and the dynamic modelling of the behaviour of wind turbines under various system conditions. Future work that is necessary, but outside the remit of the analysis detailed above, would be the following (but not limited to): analysis of the wind on the island of Ireland, analysis of the situation beyond 1,100MW of wind and detailed economic analysis of the cost of accommodating large amounts of wind on the system.

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Papers 7-12 and Introduction to PART B in PART B

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