

European Wind Integration Study (EWIS) Towards a Successful Integration of Wind Power into European Electricity Grids



Final-Report 2007-01-15

European Transmission System Operators

Abstract: The support of renewable energy sources (RES) is one of the key issues in European energy policy. In order to cope with this challenge, European Transmission System Operators launched a European wide grid study on the integration of wind power, focusing on measures needed to be taken by legislators, regulators, grid operators and grid users, aiming at establishing a harmonised set of rules for the integration of wind power. This set of rules is vital for the secure and reliable operation of the electricity networks in presence of variable generation. The scope of work covers all the technical, operational and market aspects related to the integration of large scale wind power all over Europe. Attention will be later focused on system interaction of various wind turbines types, the effects of their variable power output on the system and their ability to provide system service to enable the stable operation of an electricity grid. The final objective is to obtain the necessary information for the technical and operational measures for risk mitigation and the secure operation of the European electricity grid identified by the steady-state and dynamic investigations on electricity grid models which are established within the study. For this, market and regulatory aspects will be taken into consideration.

1 MAIN FINDINGS

[A] Capacity Development of Wind Power installations and Geographical Allocation

As realisation of the Directive 2001/77/EC of the European Parliament and of the Council on the promotion of electricity produced from RES in the internal electricity market the wind power in Europe is expected to increase from 41 GW in 2005 to nearly 67 GW in 2008. The highest amount of wind power is concentrated in Germany, where ca. 40% of the total installed capacity is expected in 2008. This is followed by Spain and Great Britain. These 3 countries will represent more than 70% of the total installed capacity within Europe. Furthermore, Italy, France and Greece are expected to see strong increases in installed wind power capacity. Further increase of wind power integration is expected for the time horizon 2015.

[B] Impacts

Large load flows affect neighbouring transmission systems and reduce available cross border trading capacities

The expansion of variable wind power generation has significant effects on the European electricity system as a whole. A regional concentrated high wind power generation which is producing a high surplus of power generation such as in Northern Germany results in temporary large load flows through the neighbouring transmission systems. These unscheduled flows could reduce system stability and increasingly affect trading capacities.

Grid congestions – Need for additional/new grid infrastructure

New RES lead to local grid congestions and thus need new grid infrastructure. New wind farms are built on sites with high average of wind speed which are often far away from the main load centres. New overhead lines are therefore necessary to transport the surplus of electricity produced in these regions to where it is consumed. These investments are exclusively or at least mainly driven by the new RES generation sites. The variable contributions from wind power must be balanced almost completely with other back-up generation capacity located elsewhere. This adds to the requirements for grid reinforcements.

Bottlenecks

High wind power generation combined with high power production of conventional power plants in the North of Germany and additional large import from NORDEL result in large North-South power flows through the transmission system of Germany and neighbouring countries e.g. the Netherlands, Belgium, Poland and Czech Republic.

For the high wind scenario bottlenecks on internal and cross border lines in northern Europe are detected already for the time horizon of 2008. If a circuit is unavailable due to a disturbance in the grid the remaining lines can be overloaded up to 180%. Internal overloads are observed in Germany, Czech Republic, Poland, Belgium and the Netherlands for single circuit outages in case of high wind power production in northern Europe. Investigated measures to prevent these overloads are described in the detailed analysis.

Secure system operation at risk

Conventional power stations do not disconnect from the grid even following serious grid failures, instead they generally trip into auxiliary services supply and "support" the grid. Wind farms, however, have so far disconnected themselves from the grid even in the event of minor, brief voltage dips. Experience in grid operation showed that this can lead to serious power failures. In order to prevent the risk of large outages, manufacturers and operators must technically ensure that in the event of a fault, wind farms also support system stability.

Increasing need for balance power and reserve capacity

The day to day forecast of electricity production from wind energy is just possible to a limited extent. To balance the difference between generation and demand balancing power is needed. The need for balancing power increases proportionally with the growing wind power capacity. Depending on the different national rules different parties are responsible for providing the balance power. In case the TSO has to contract it the costs will be part of the tariff and by this be paid by all customers. As a consequence there is no incentive for the wind farms to reduce the costs of integration in the electricity system. Furthermore, a considerable amount of reserve capacity - being paid by the consumers - is needed for system adequacy and security.

Increasing grid losses and reactive power compensation

High wind power production remote from main electricity demand centres produces higher grid losses within the transmission system. Compared to scenarios with low wind power production the active grid losses e.g. in Germany are doubled in case of high wind power production in Northern Europe. In some other countries, e.g. Poland and the Netherlands, there is a noticeable increase.

High wind power production needs more reactive power because wind installations are built far away from the main load centres. Long distance transmission of wind energy leads to a higher load factor of the electric lines which thus consume more reactive power. In addition, in several parts of the system with a high reactive-power demand conventional power plants have been taken out of operation due to high wind power production. Before 2008 reactive-power generation must be installed directly at the extra high voltage level in order to provide the necessary reactive power.

Economic impact on conventional power generation

High wind power production causes regional overloading of transmission lines. Although the TSOs instituted grid expansion measures at an early stage, especially in the Northern region, it is unlikely that they will come entirely into operation by 2008. Therefore the existing priority rules for connection, purchase and transmission of RES-Electricity in some European countries will increasingly effect the power generation all over Europe. The investigation showed that in high wind situations a large proportion of cost effective power generation is pushed out of the market by renewable energy sources and/or the short-term auction capacity on congested channels must be reduced.

2 MAIN RECOMMENDATIONS

[A] Harmonisation of European support scheme for Renewables

At the moment the different national support schemes in Europe lead to a national and regional allocation of RES thus causing additional congestions in the systems. For this reason it is recommended to come to a harmonised support scheme in Europe which will ensure the utilisation of the most efficient sites and lead to more evenly spread installation of wind power capacity.

[B] Speeding up the approval procedures for new grid infrastructure

Licensing procedures for new RES sites and for grid infrastructure must go hand in hand. Often the approval procedures for grid infrastructure take too much time, delaying the required grid expansion. Therefore the legal framework and administrative procedures have to be set properly to speed up the licensing of grid infrastructure.

[C] Adjustment of market rules for imbalance management

The TSO's must rely on a generation portfolio that provides the balance power capacity needed at any time and at a high level of security. Grid capacities must be available for balance management as well. To let the market solve the problem of imbalance management wind generation should be made responsible for unbalances they create and provide adequate resources for balancing from the market, as already in place in some countries.

[D] Improvement of connection requirements for wind turbines

Most wind turbines do not actively contribute to grid stability. In the event of slight voltage or frequency drops in the transmission network – even if it is correctly cleared by the protection systems – the protection of wind generators may cause instantaneous disconnection of a significant number of wind farms with the consequent loss of power generation. The increasing share of wind power and the regional concentration in certain areas might lead to grid situations with sudden capacity losses of more than 3,000 MW which could be followed by large-scale blackouts. In order to effectively tackle this problem all power generators – including wind power producers - should be obliged to meet certain operational requirements such as fault-ride through capability or voltage support.

[E] Re-examination of priority rules for RES-electricity

Large long-distance load flows require a sufficient capacity of conventional generation for maintaining system stability. Investigation shows a change in power flows due to the need to transport the energy from remote wind power production areas to regions with high electricity demand. In order to maintain sufficient conventional capacities as well as their reasonable allocation over the respective grid areas the existing priority rules for the transport of RES electricity need to be re-examined. Furthermore it should be noted that national priority rules become legally questionable as they do not only discriminate against conventional electricity but also against “green” electricity from other EU member states. Volatile generation should better be regulated at European and National level in order to ensure the right for TSOs to reduce or switch off wind generation when security and stability of the transmission grid are endangered.

3 INTRODUCTION

This paper presents the first results of this joint investigation for the system integration of wind power, initiated by the European Transmission System Operators and supported by the EU. The study is focused on the extra high voltage grid and comprises extended steady state and stability investigations in all synchronous areas (ATSOI, NORDEL, UKTSOA and UCTE) for the installed wind capacities expected in Europe in 2008 and 2015 based on common European wide scenarios.

The European Wind Integration Study (EWIS) has the following objectives:

- To address the network issues arising from wind power, particularly those relevant to European TSO interests on wind issues;
- To seek proposals for a generic and harmonized European-wide approach towards wind energy issues addressing:
 - operational/technical aspects,
 - market organizational arrangements arising in Europe,
 - regulatory/market-related requirements,
 - common public interest issues and even some political aspects impacting the integration of wind energy
- To involve the most relevant TSO stakeholders, in the context of wind energy, in the project.

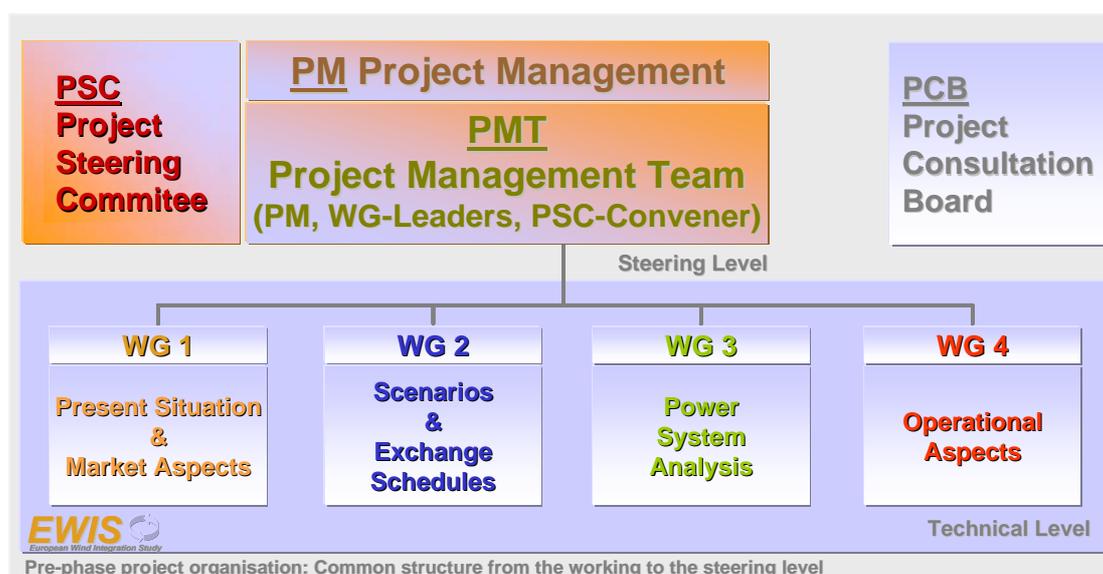


Figure 1: General project organisation for phase I

In order to cover the large scope of work, in the pre-project phase, 4 working groups are set-up. Each working group performs the specified tasks on an operational level (Figure 1). The management level consists of a Project Management Team. A Project Steering Committee provides overall project direction and makes main project decisions. Relevant external stakeholders with experiences related to wind power integration as the EC, the Association of European regulators, EURELECTRIC, EWEA, EFET & others are invited to join the project. Some of them, like EWEA are interested on a close cooperation, EURELECTRIC have already accepted.

WG 1	WG 2	WG 3	WG 4
Present Situation & Market Aspects	Scenarios & Exchange Schedules	Power System Analysis	Operational Aspects
<ul style="list-style-type: none"> ➢ Wind Development in Europe until 2008 <ul style="list-style-type: none"> ➢ Distribution of the Wind power production in EU ➢ Exchange with neighbouring Countries ➢ Generation Units 2008 ➢ Regulatory Framework Models ➢ Grid Connection Requirements ➢ Power system Operation 	<ul style="list-style-type: none"> ➢ Methodology of Scenario setting ➢ Scenario A <ul style="list-style-type: none"> ➢ High Load ➢ Low Load ➢ Scenario B <ul style="list-style-type: none"> ➢ High Load ➢ Low Load <p><i>Set up scenarios for the regional wind power infeed and conventional generation as snapshots.</i></p> <p><i>Exchange schedules between control areas will be established.</i></p>	<ul style="list-style-type: none"> ➢ Methodology of investigations ➢ Risk Analysis <ul style="list-style-type: none"> ➢ Congestions ➢ n-1 Analysis ➢ Risk Mitigation <ul style="list-style-type: none"> ➢ Grid re-inforcements ➢ Reactive Power Compensation ➢ Pan European Aspects <p>Investigations in all four synchronous areas</p>	<ul style="list-style-type: none"> ➢ Analysis of Risks, Tasks and incentives of market actors ➢ Risks in case of large wind penetration concerning system security and generation adequacy ➢ Analysis of risk management and risk mitigation ➢ Countermeasures ➢ Recommendation and compilation of the results

Figure 2: Scope of investigations in project phase I

In EWIS, necessary requirements for the further increase of wind power in the national/regional generation mix are analysed on the basis of the developed scenarios. The measures to counteract identified limitations of integration of wind power and the costs of such measures are also analysed. Interactions between operational/technical/technological constraints, market designs and energy policies for all synchronous areas in Europe are analysed. Consequences for the existing, medium and long term issues related to the integration of wind power are discussed. The final results will also comprise stability impacts for the time horizon of 2015 and give recommendations for harmonised grid code requirements for wind turbines necessary for successful integration of wind power into European electricity grids.

4 WIND POWER DEVELOPMENT IN EUROPE

Renewable energy sources (RES) play an increasingly important role within the European electricity system. A major contribution in future growth of RES capacities will come from new wind power. According to EWEA, the European Wind Energy Association, a five-fold increase in European wind power capacities is expected from about 34 000 MW in 2004 to 180 000 MW in 2020. As of 2004 about two thirds of the wind power capacities worldwide are located on the European continental UCTE grid.

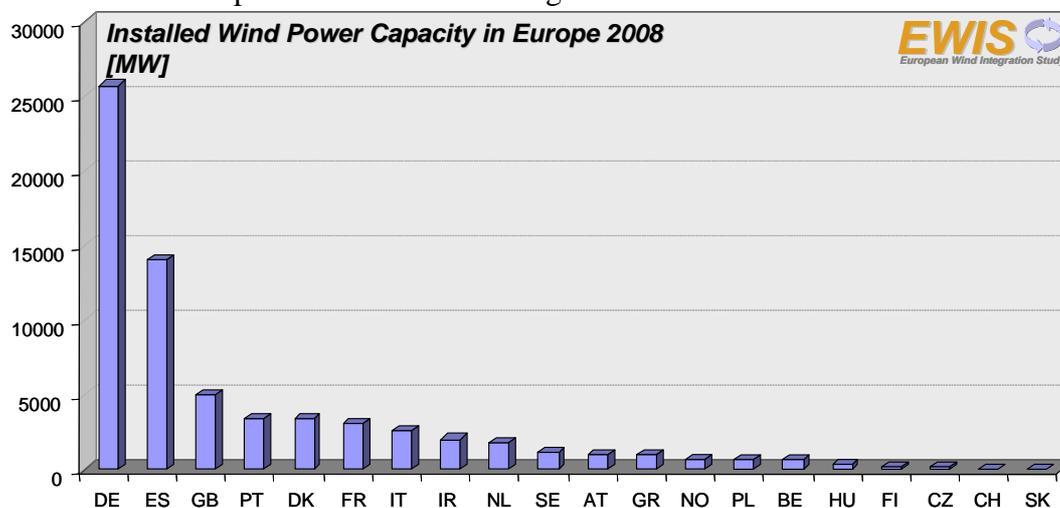


Figure 3: Installed Wind Power Capacity in Europe

Detailed analysis shows, that most European countries have plans to increase the installed wind power from 41 GW in 2005 (objective of the White Paper 1997 for 2010) to nearly 67 GW in 2008. Germany, Spain, Denmark, Portugal, France, Sweden, Ireland, the Netherlands, Italy, United Kingdom will be the countries with the most installed wind power. Most of the wind farms will be onshore, with some offshore plans in Germany (1.830 MW), Belgium (180 MW), United Kingdom (455 MW), Denmark (326 MW), the Netherlands (220 MW) and France (105 MW).

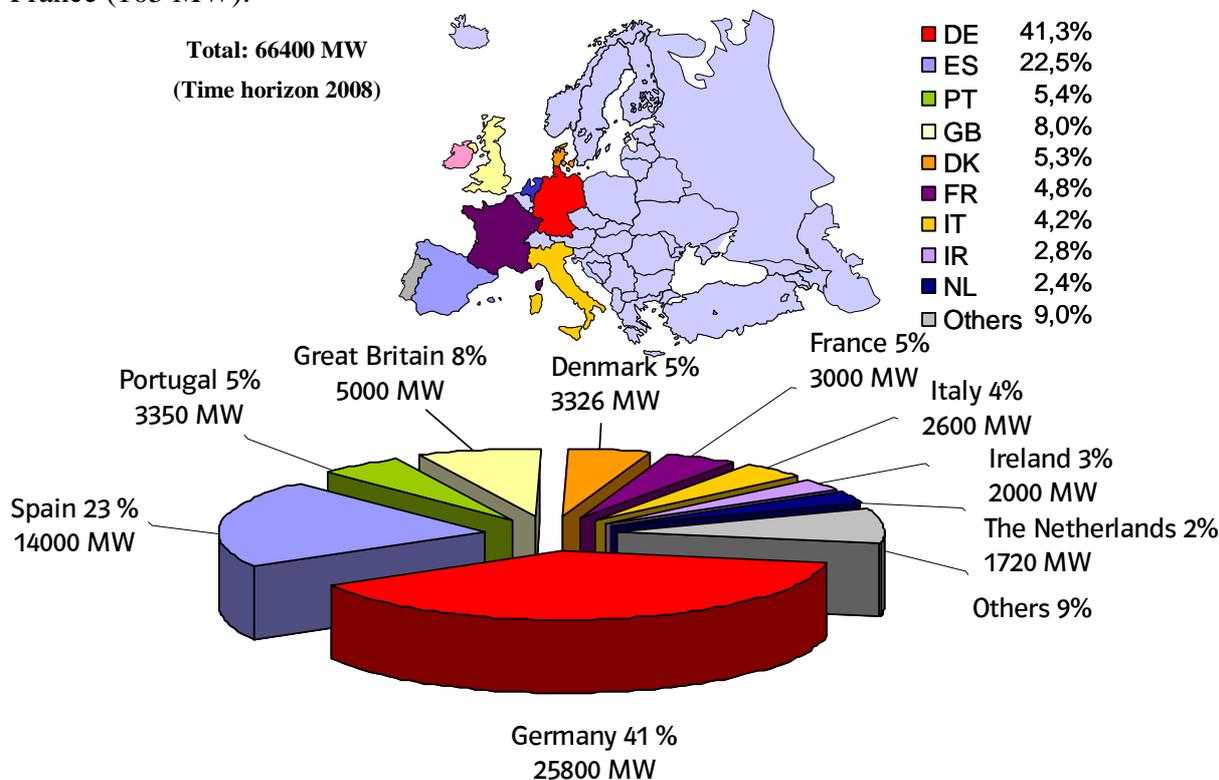


Figure 4: Concentration of Installed Wind Power

Figure 4 shows the collected data for the installed wind power in Europe available by the European TSOs, which are the basis for the investigations for 2008. The highest amount of wind power is concentrated in Germany, where ca. 40% of the total installed capacity is expected in 2008. This is followed by Spain and Great Britain, whereby these 3 countries will represent more than 70% of the total installed capacity within Europe. Furthermore, Italy, France and Greece are expected to see strong increases in installed wind power capacity. With such a high growth rate, there are currently serious doubts about the ability of the manufactures to correspondingly increase their production.

5 PRESENT STATUS AND MARKET ASPECTS

An analysis of the present situation in Europe shows that security of supply and cross border trading capacities in neighbouring countries are already affected by the high penetration of wind power. It is concluded that at present:

- Concentration of wind power in different regions within Europe produces large load flows through domestic and neighbouring transmission grids and interconnections. These loop flows can result in overloads of neighbouring transmission and interconnection lines.
- High wind penetration is making rescheduling actions in national power plant pools necessary.
- Market barriers due to the integration of wind power are observed.

At present, every Member State and other European countries have implemented their own strategies regarding support schemes for electricity generation from renewable sources, usually a combination of two or more mechanisms. The main strategy currently adopted by ETSO associated countries will be presented in the Appendix of the final report. The most common schemes are:

Feed-in tariffs and bonus model: These models have been the most widespread instrument in stimulating electricity generation using renewable energy sources. This mechanism consists of paying generators a fixed price or premium for the energy in order to provide a stable long-term price structure, reducing an important part of the market risks. This can either be a fixed price for the electricity (kWh) and the renewable value together (feed-in tariffs); or only a fixed price for the renewable value (bonus model - the electricity price is then market driven).

Priority of dispatch: Most electricity systems in Europe have priority of dispatch clearly established in their national legislation as indicated in the Directive 2001/77/EC. In a system with priority of dispatch, when there are grid congestions affecting both conventional and wind generation, priority is given to the wind and renewable generations. However, this varies throughout Europe, from Denmark where the transmission system operator (TSO) can restrict the production of conventional power plants, to the United Kingdom where there is no priority of dispatch for wind power. Nevertheless, due to the financial support mechanisms for renewable energy in the UK, wind power is still more expensive to curtail than conventional generation for congestion management purposes.

6 SCENARIOS AND EXCHANGE SCHEDULES

For the European Wind Integration Study scenarios and exchange schedules between control areas have been set up for the year 2008. These scenarios are the basis for the power system analysis in the EWIS study which is described in later sections.

The methodology used in setting the scenarios is divided into 2 modules:

- Selection of wind situation
- Adjustment of conventional power plants and exchange schedules

As a boundary condition for adjusting the conventional power plants and exchange schedules, the “Available exchange capacities” were established.

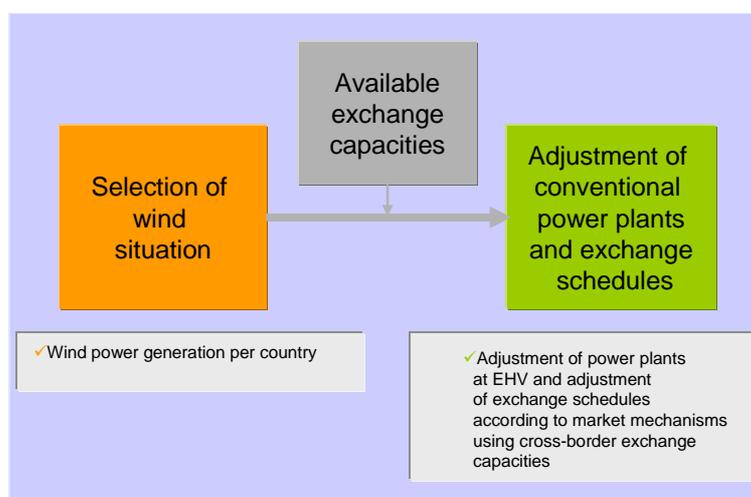


Figure 5: Basic Approach for Scenario Setting

6.1 Selection of Wind Situation

The expansion of wind power generation in some EU Member States has significant repercussions for the European electricity system as a whole. The concentration of wind power in Northern Germany is already producing load flows through the neighbouring transmission networks. In order to analyse the impact of wind power generation in Northern Europe on the electric infrastructure and the future infrastructure development a scenario with a high wind in Northern Europe was selected.

It is expected in 2008 that after Germany, Spain and Portugal will be the two countries with the highest installed wind power capacity on continental Europe (together the 3 countries represent 65% of the total installed capacity within Europe). Furthermore, Italy, France, Greece are expected to see strong increases in installed wind power capacity. As a result situations with high wind power generation in Southern Europe may have effects to the existing power plants in this region and may lead to strong power exchange to neighbouring countries.

Therefore, the study comprises two wind situations with major impact on the operation and security of the European transmission network:

Wind Situation UCTE North: Maximum wind power production of northern UCTE countries (Austria, Belgium, Czech Republic, Denmark, North-France, Germany, Hungary, Netherlands, and Poland)

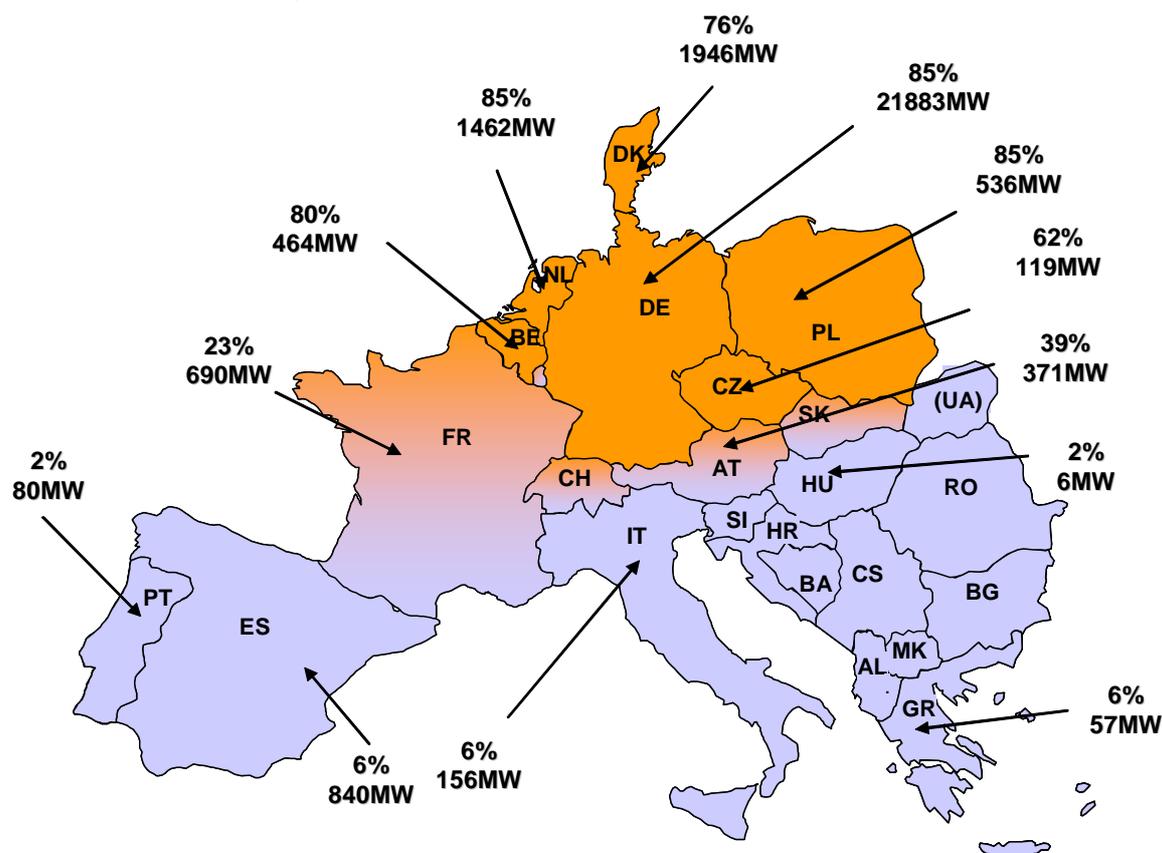


Figure 6: Wind Situation UCTE North

Wind Situation UCTE South: Maximum wind power production in southern UCTE countries (South-France, Greece, Italy, Portugal and Spain)

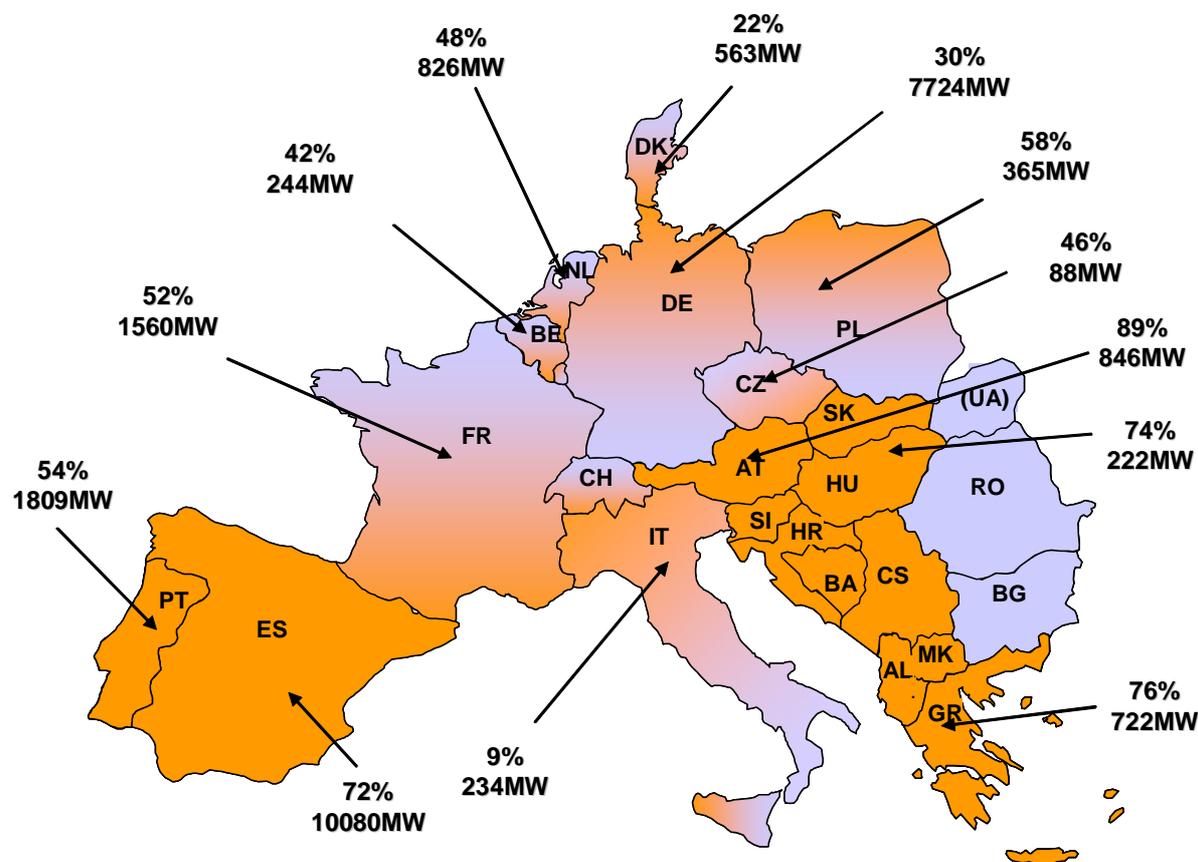


Figure 7: UCTE Scenario South

Using existing time-series of the wind power production, a point in time with the highest simultaneous wind power production in the northern UCTE countries was identified for UCTE Scenario North. For UCTE Scenario South the highest simultaneous wind power production in southern UCTE countries was identified.

For each country an individual level of wind power generation was then determined. In order to extrapolate the data into the year 2008, the expected wind power installed in each country in 2008 was used. In circumstances where no time-series of wind power production data was available, the wind power production was estimated from wind speed measurements of numerous weather stations in the countries.

The resulting wind situations (see Figure 6 and Figure 7) give realistic cases of strong wind power production in the north of the UCTE area as well as in the south of the UCTE area. The overall wind power production in wind situation UCTE North is 28,600 MW and in wind situation UCTE South 25,300 MW, compared to an installed capacity in 2008 of 56,500 MW in the UCTE area.

Wind situation Nordel

For the Nordel area one wind situation is studied. The case is calculated based on a time series analysis in which the 99 percentile of total wind power in the Nordel system is taken.

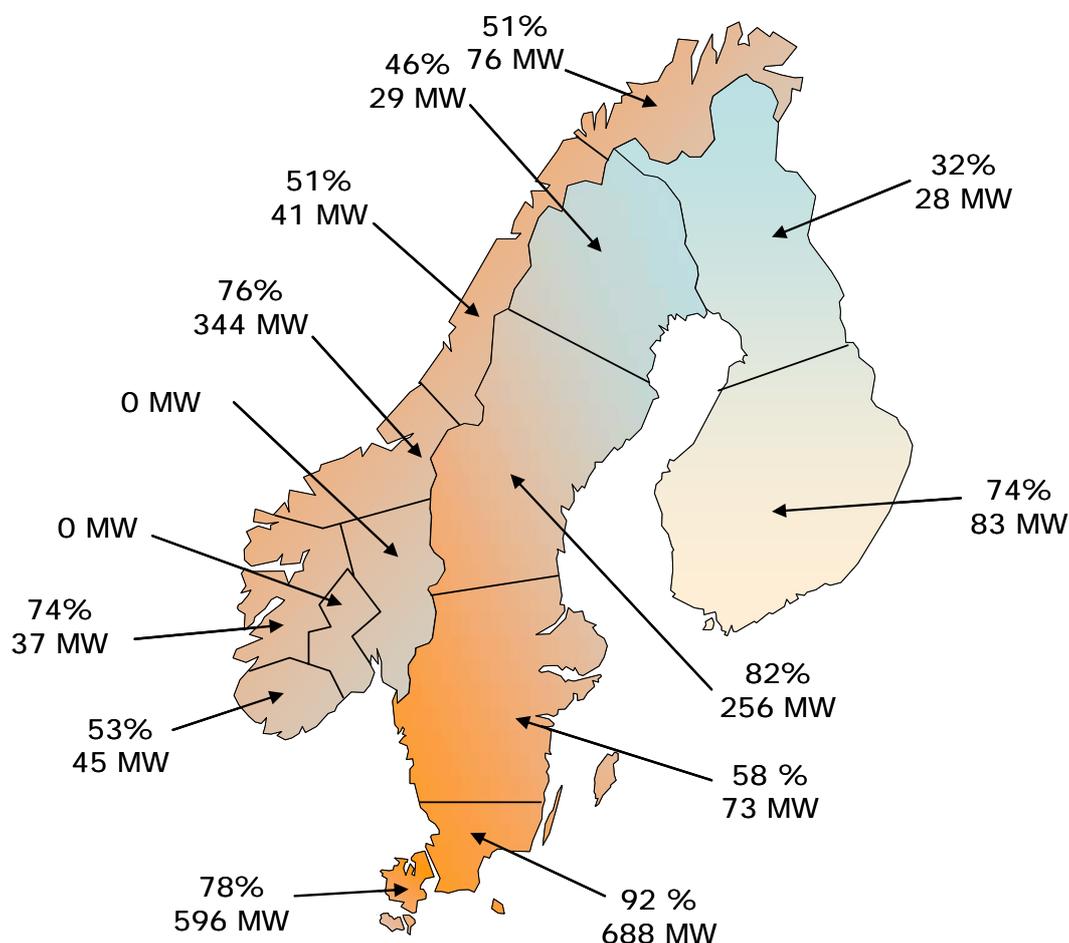


Figure 8: Analysed distribution of wind power distribution in synchronous Nordel. Production per cent of installed capacity and in MW.

This approach leads to a total wind power production in Nordel of 2 296 MW for the year 2008.

6.2 Methodology used in the adjustment of conventional power plants and exchange schedules

The output of the conventional power plants and the exchange schedules are adopted to achieve system balance with the additional wind power determined from the selected wind situation above. Adjustments are carried out according to a generalised generation priority. The generation priority serves as a ranking to reduce or increase the power generation from the power stations in response to the additional wind generation in the scenario. The exchange schedules are also adapted to reflect the impact of the new generation portfolio and increased wind generation in each country. If the available import/export capacities for the country are insufficient, the surplus/deficit power is distributed among other countries according to the generation priorities. If the export/import capacity is insufficient, the surplus power is then balanced within the country itself.

6.3.2 Base Case Scenario Nordel

For Nordel a simulated high load case without wind power is used as the reference. The high load case is calculated based on a typical dispatch in a year with normal inflow to the hydro power reservoirs.

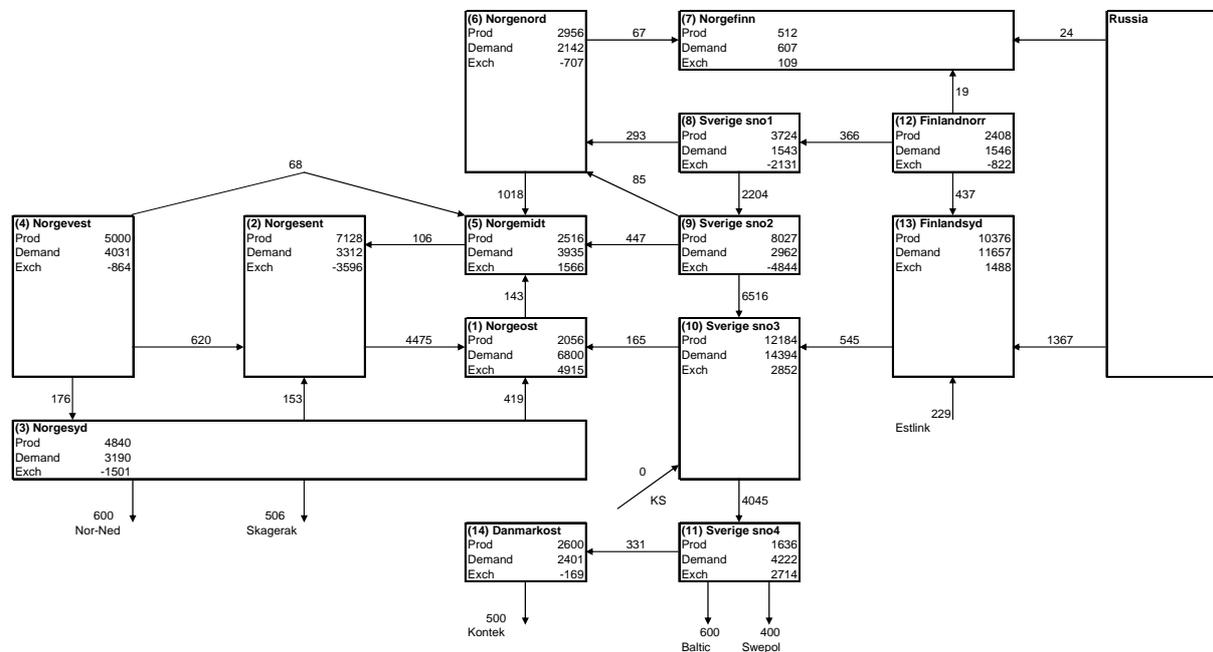


Figure 1 Power flow result of high load case without wind power.

The case shows a typical flow pattern in a peak load situation with export to the UCTE system.

6.4 Analysis of UCTE Scenario North

Wind UCTE Scenario North addresses situations where wind power generation especially in the northern part of Europe is high. High wind power generation in Northern Europe can have significant repercussions on the European electricity system as a whole. This is shown in Figure 10, where large changes to power generation due to the strong wind power generation can be observed.

It is significant that generally the countries with the highest wind power production and their neighbours are strongest affected by the changes in conventional generation, e.g. Belgium, Czech Republic, Denmark, France, Germany, The Netherlands and Poland. The reduction in power generation compared to the Base Case generally affects oil, gas and hard coal power plants.

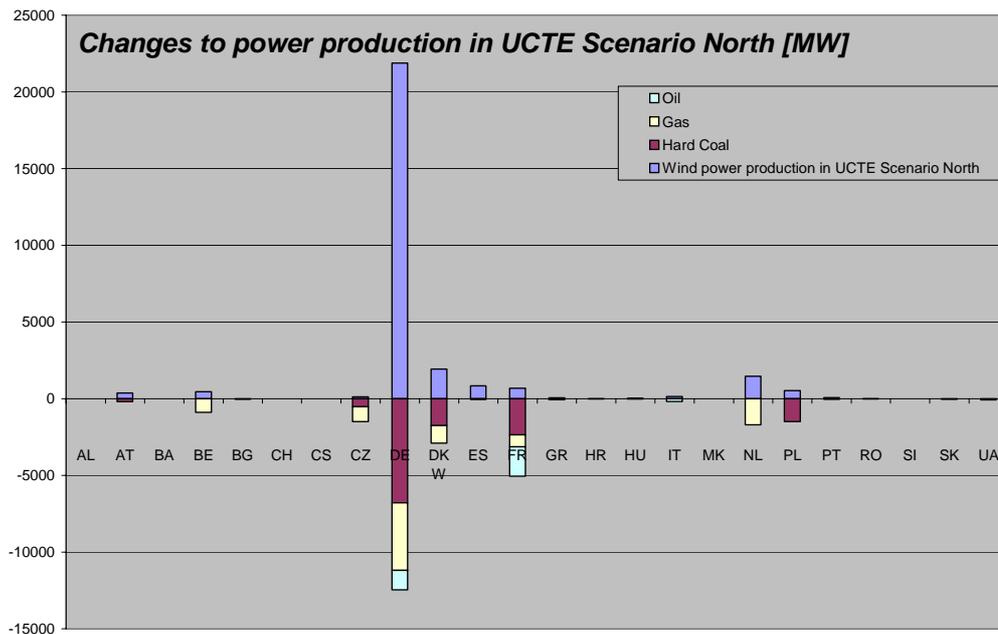
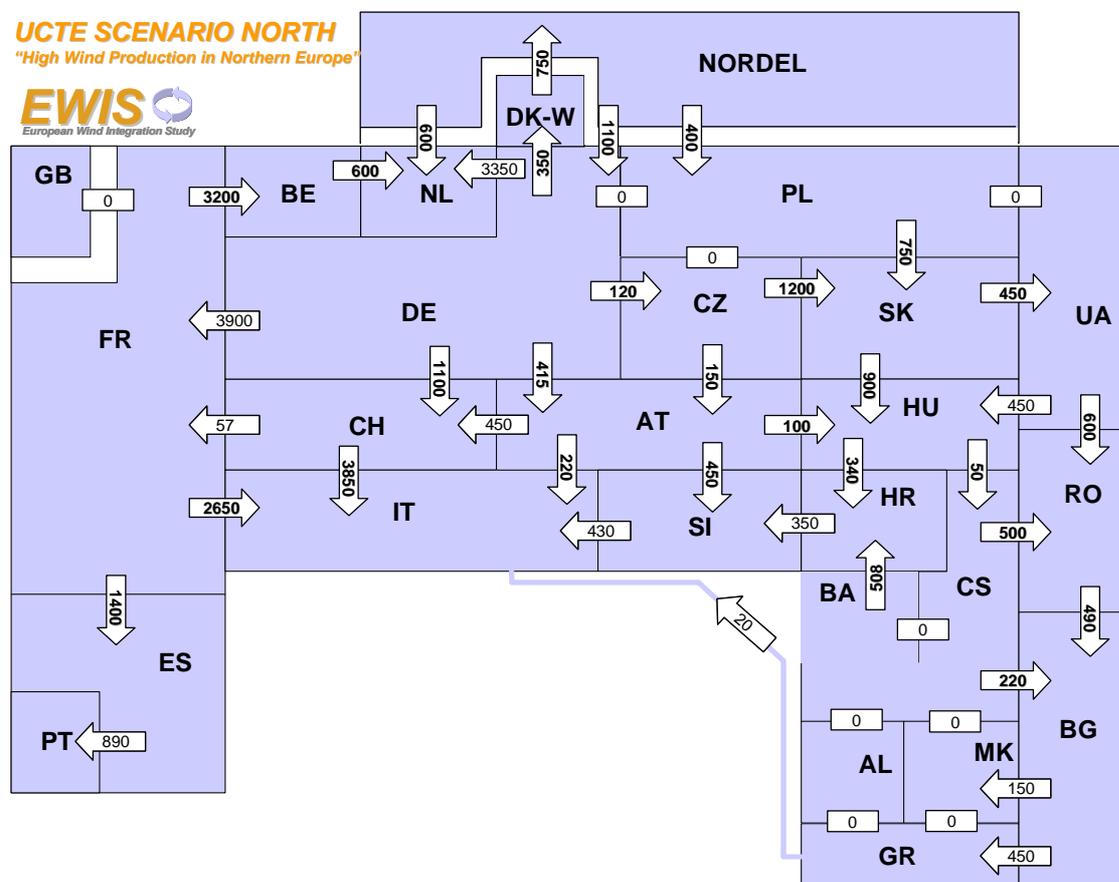


Figure 10: Changes in power production for UCTE Scenario North in comparison to the base case scenario

Figure 12 compares the exchanges between countries in the UCTE network (UCTE Scenario North vs. Base Case) while Figure 11 shows the exchange schedules.



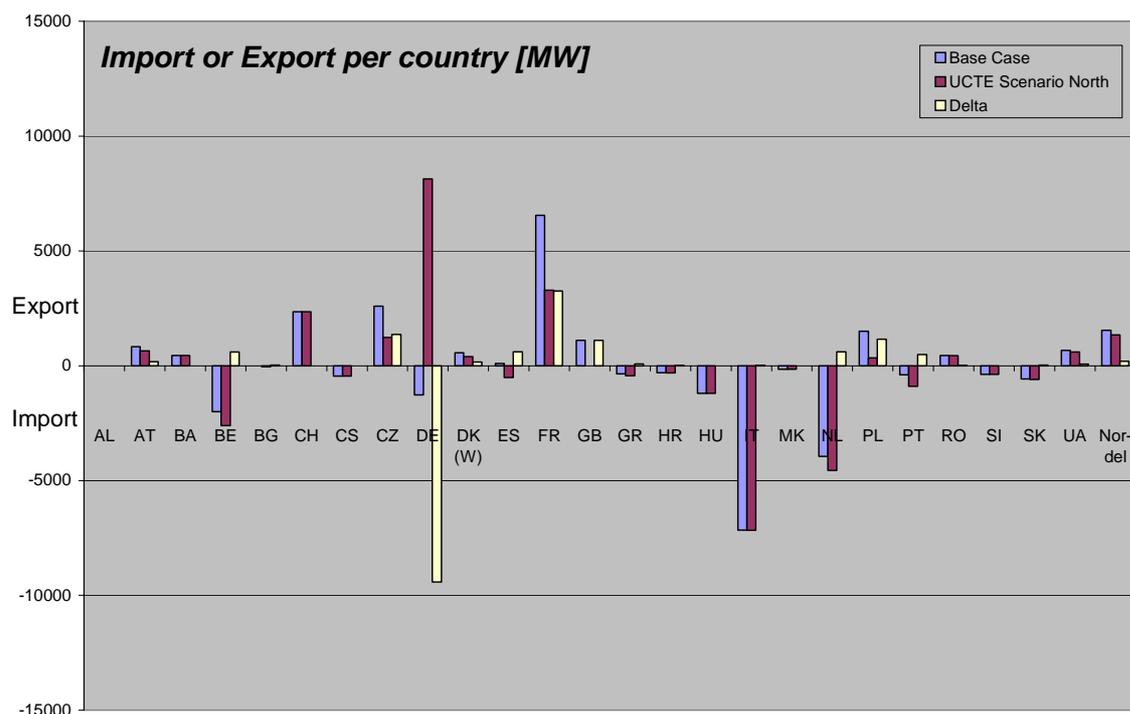


Figure 12: Comparison of scheduled exchange between base case and UCTE Scenario North

6.5 Analysis of UCTE Scenario South

Figure 13 shows the effects to conventional power production due to the wind power production. As in UCTE Scenario North, the largest changes in conventional power generation are in the countries with the largest wind power production or its neighbours. As expected, more countries in Southern Europe are now affected, e.g. Spain, France, Italy and Portugal. The exchange schedules of UCTE Scenario South are shown in Figure 14.

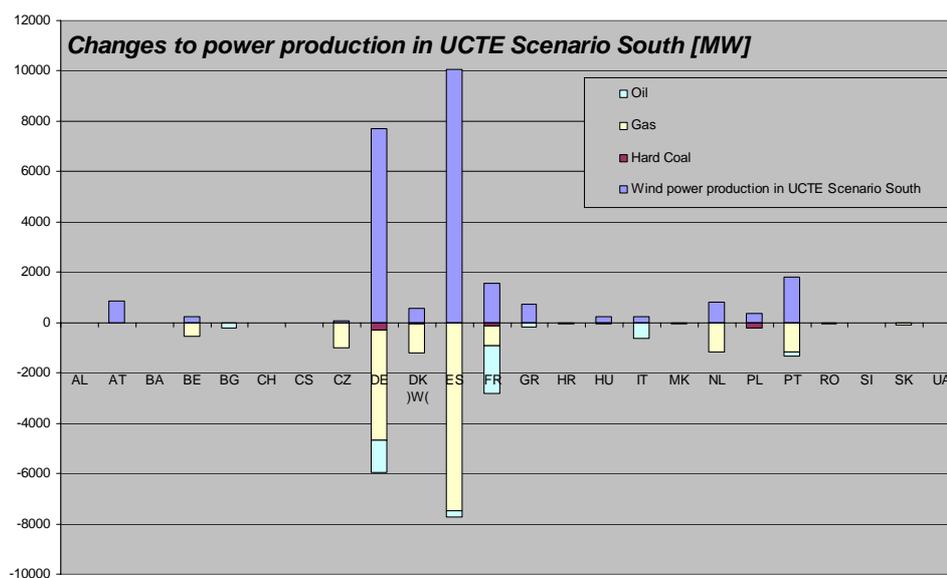


Figure 13: Changes in power production for UCTE Scenario South in comparison to the base case scenario

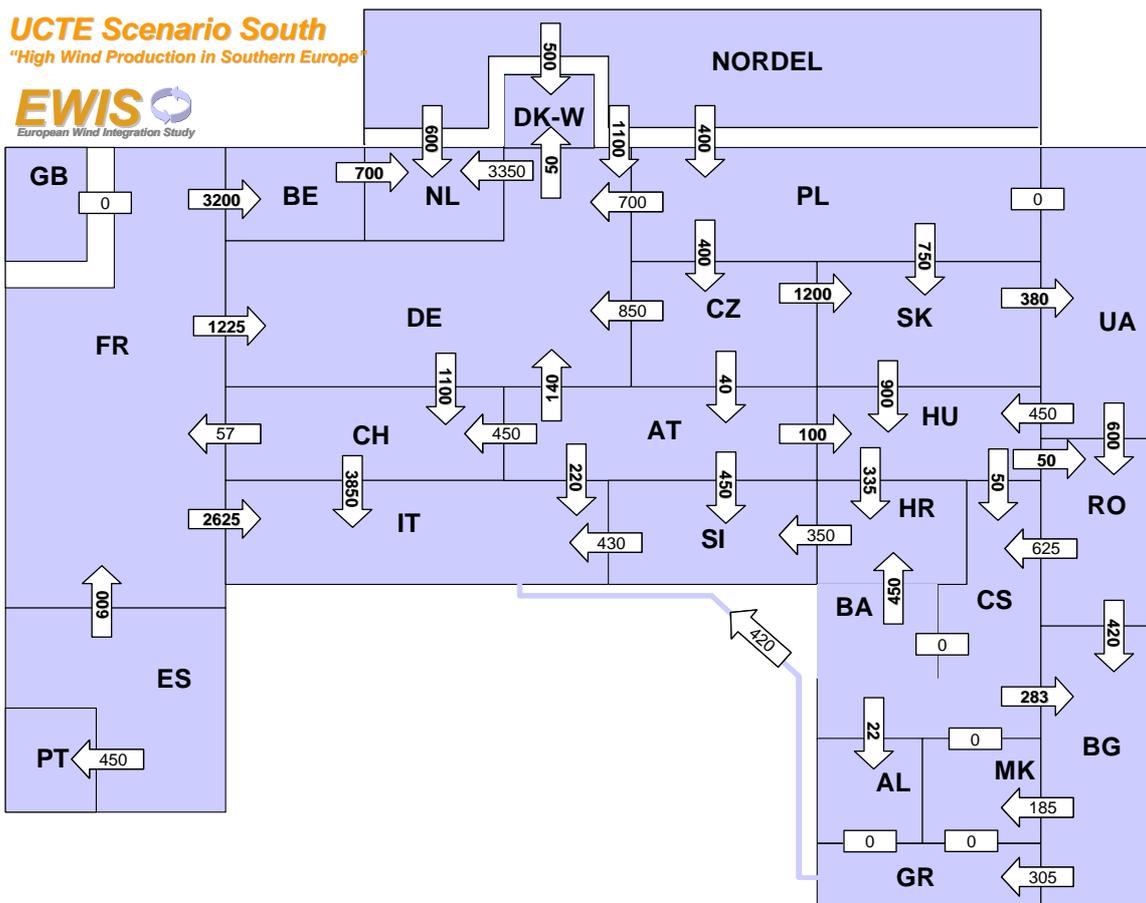


Figure 14: Exchange schedules UCTE Scenario South

Figure 15 shows the changes in import or export balance for the countries. Generally the changes in export and import in UCTE Scenario South compared to the Base Case are not as strong as in UCTE Scenario North. Due to the large installed wind power capacity, the northern European countries are showing, besides Spain, the strongest changes in exchange schedule, even so the scenario is a high wind scenario for southern Europe.

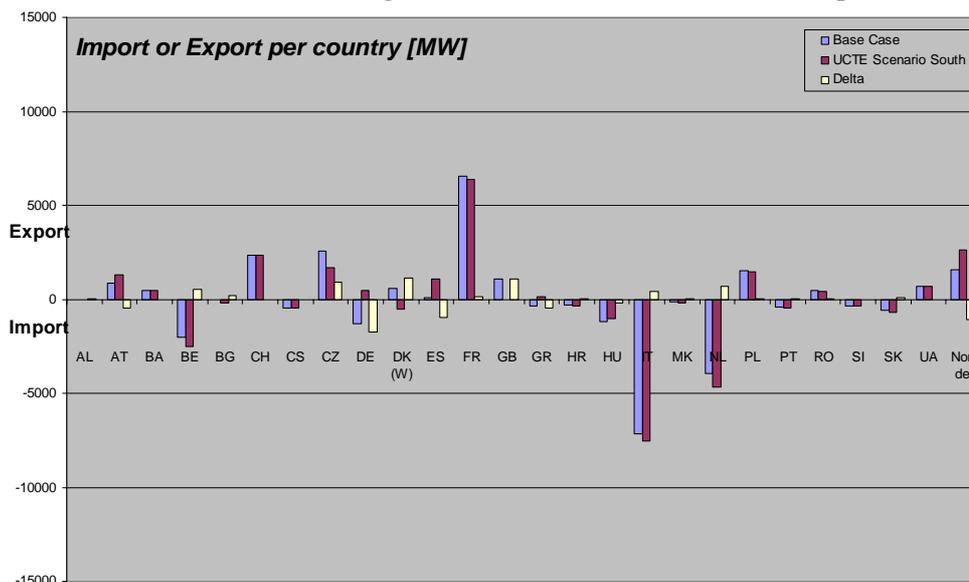


Figure 15: Comparison of scheduled exchange between base case and UCTE Scenario South

6.6 Analysis of the Nordel Scenario

The base case scenario is modified by inserting the 2 296 MW wind power as calculated by the time series analysis. The power flow after the redispatch is shown in Figure 3.

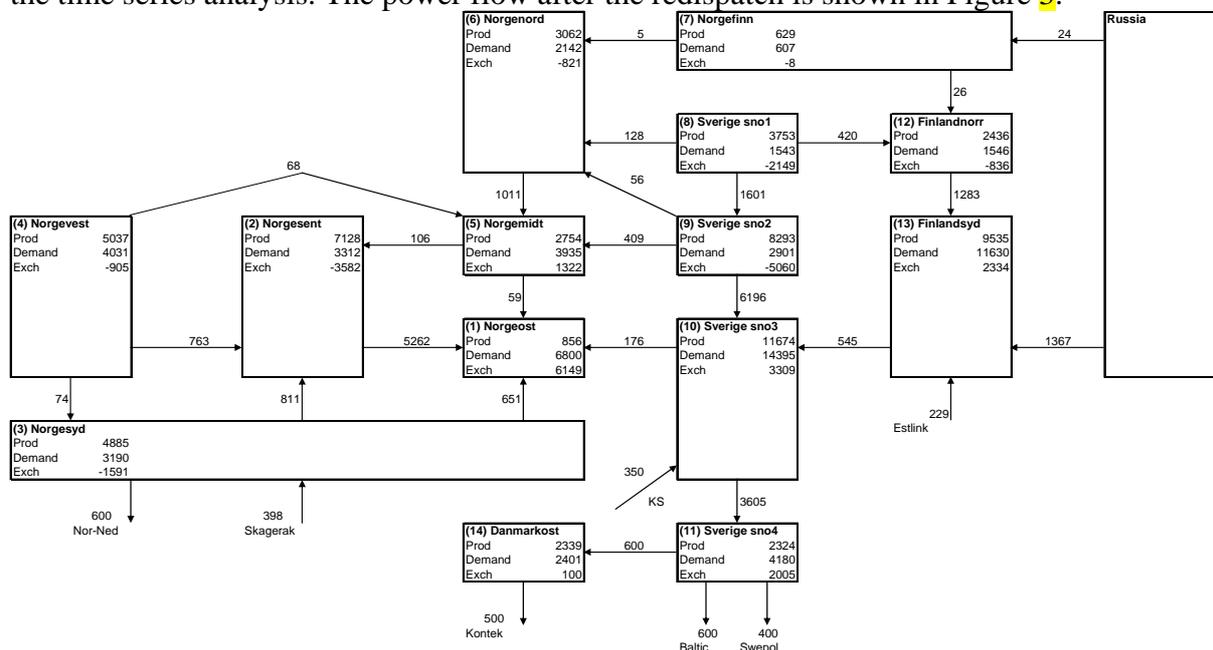


Figure 16: Power flow result of high load case with wind power.

Figure 17 shows the redispatch after inserting wind power in the base case. In total 3 550 MW hydro or thermal power is replaced as compared to the base case. Hydro power in East-Norway and in Central Sweden has been reduced by 1 780 MW. In Finland and East-Denmark the condensing power production (oil, hard coal and gas) is reduced by 760 MW and 1 130 MW respectively.

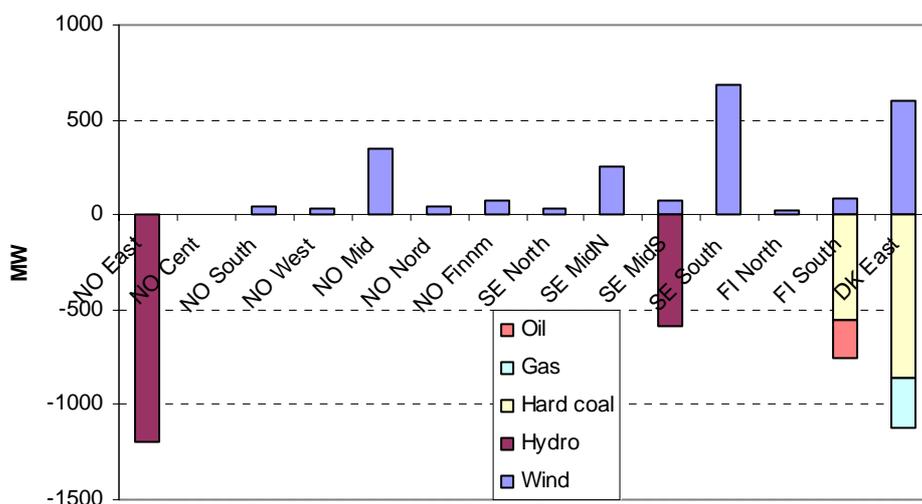


Figure 17: Changes in power production for Nordel in comparison to the base case scenario.

High wind power production in synchronous Nordel is also associated with high wind power production in the western part of Denmark. Therefore, the power flow on the HVDC links Konti-Skan and Skagerrak are changed by 1 250 MW towards Nordel.

Market simulation shows a very low correlation between wind power and exchange on the remaining HVDC lines between Nordel and the UCTE. This is due to structural differences between the power systems. Therefore, the flow is unchanged on the other HVDC lines.

7 POWER SYSTEM ANALYSIS

Wind power is different from conventional sources of energy due to three main reasons:

- prime mover, the wind
- location of resources with respect to load
- type of electrical machines.

Often regions with high average wind speed are located remote from centres of electricity demand and the power needs to be transported over large distances to the load. The grid is not yet developed for this transport, which can lead to congestions. Controllability and availability of wind power significantly differs from thermal or hydro generation because the primary energy source cannot be stored and is uncontrollable. 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 even complicate the long term balancing task, particularly at high wind power penetrations. In most grid codes, wind power producers are exempted for some or all ancillary services including frequency support, voltage support and fault ride through capability.

A reasonably priced and reliable electricity supply is an important location factor for the development of an economy. Thus, it is necessary to investigate the demands placed on the entire system for the generation and transmission of electrical energy, taking into account the integration of the increasing amount of electricity generated from RES.

Maintaining the current level of security and reliability of supply must be included here as an unconditional boundary condition. This gives rise to new challenges for the entire system and in particular for transmission system operators with regard to their system responsibility as far as a secure and reliable electricity supply is concerned.

The technical investigations regarding the integration of the capacities of RES within Europe as forecasted (Scenarios) in the study are based on the premises of unchanged reliability of Europe's electric power system and on maintaining secure and reliable interconnected operation with European partners. The technical criteria, analyses and also the evaluations are made under the following framework conditions and assumptions:

- Determination of the effects on conventional power plants in case of high wind power production

- Determination of the transmission system extension necessary for covering (N-1)-secure transmission
- Merit Order principle for all generating units (with or without existing priority rules for RES in some grid areas) as a result of the analysis of market aspects and present status.

The power system analysis comprises the following aspects:

- Deviation between scheduled exchanges (defined by the market, see previous chapter) and physical flows in case of low/high wind power in-feed
- Changes in power flow pattern induced by high wind power in-feed
- Risk analysis
 - Active grid losses (comparison between Base Case and UCTE Scenario North and UCTE Scenario South)
 - Global aspects on wind power integration
 - Cross border flows
 - Network congestions (N-1 contingency analysis)
- Risk mitigation
 - Network-related measures
 - Network reinforcement (overhead lines, phase shifter devices)
 - Reactive power compensation
 - New settings of existing phase shifter devices
 - Change of network topology by switching (corrective switching)
 - Market-related measures
 - Counter trading
 - Re-dispatch of generation units
 - Limitation of available transmission capacity on borders
 - Security management

7.1 Changes in power flow pattern

In case of UCTE Scenario North with high wind power production in northern Europe, where the most of the wind power capacity is installed, large deviations between scheduled exchanges and physical flows are detected (see **Figure 18**).

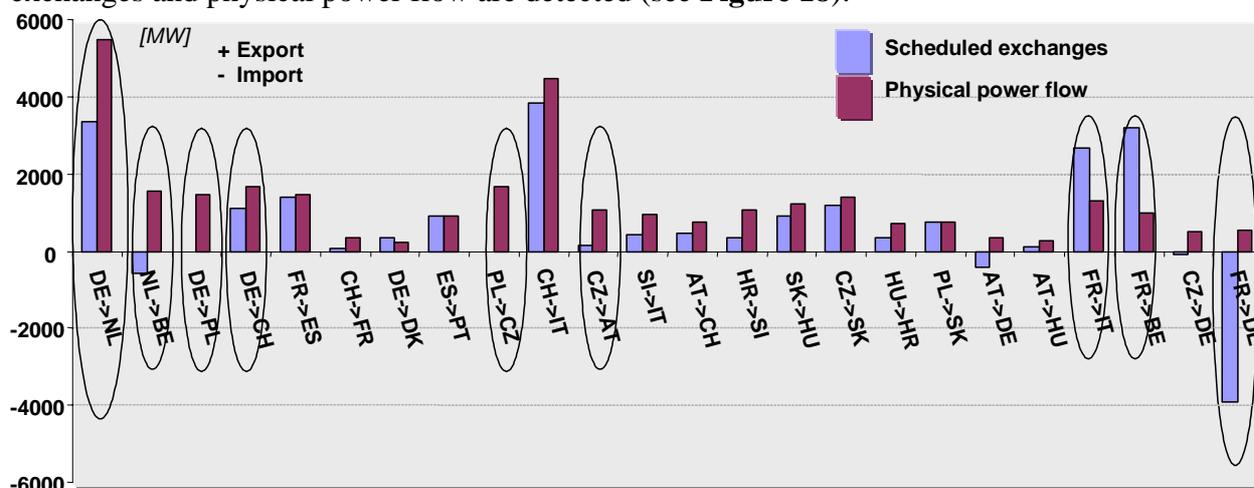


Figure 18: Physical power flows and scheduled exchanges of UCTE Scenario North

Large deviations of physical power flows from the exchange schedules occur especially on the axis Germany-the Netherlands-Belgium-France on the one hand and Germany-Poland-Czech Republic-Austria on the other hand. Although there is a large scheduled import from Germany to France in UCTE Scenario North, the physical flow is from France to Germany. A comparison of the deviations between Base Case (with low wind power production in northern Europe) and UCTE Scenario North (with high wind power production in northern Europe) shows, that the larger deviations of the physical power flow from the scheduled exchanges in UCTE Scenario North are related to the higher wind power production in northern Europe (see **Figure 19**).

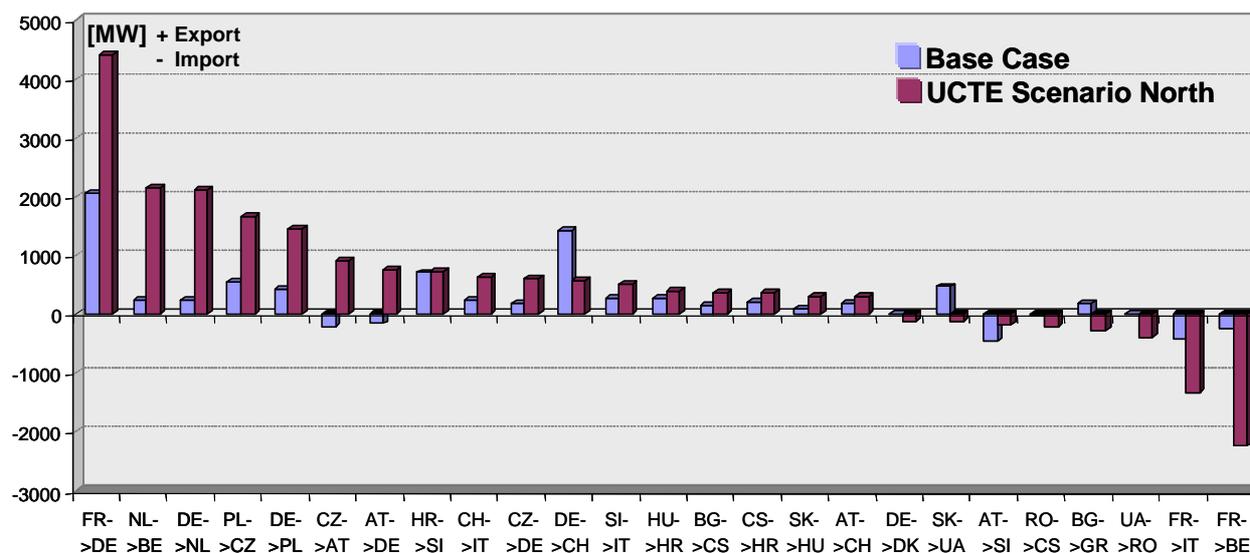


Figure 19: Deviations between scheduled exchanges and physical power flows

The main difference in import/export levels between the Base Case and UCTE Scenario North is the change from import to large export of Germany due to high wind power production as can be seen in (**Figure 20**).

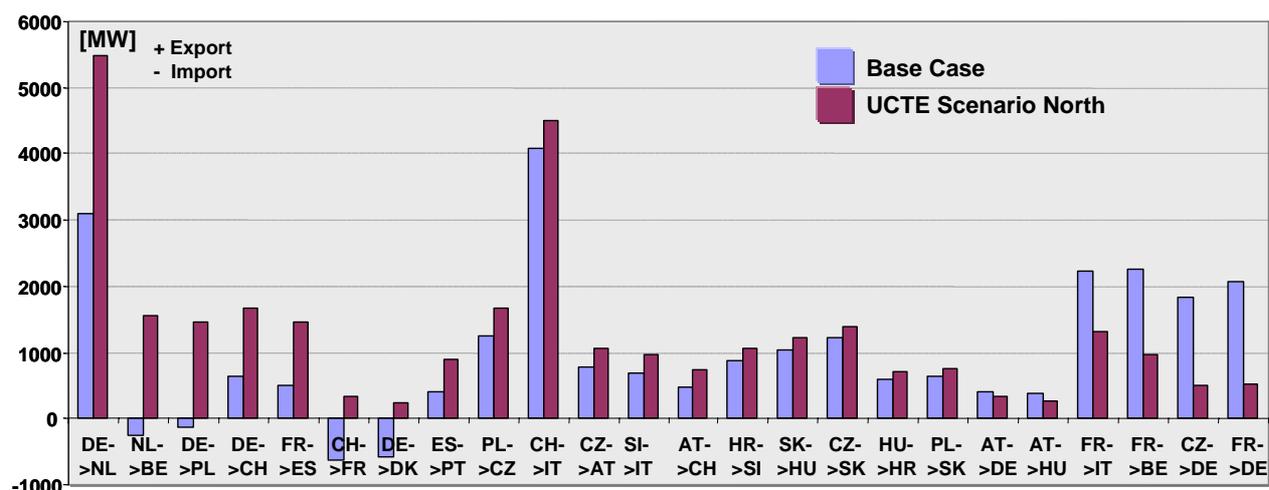


Figure 20: Comparison of physical power flows between Base Case and UCTE Scenario North

In case of UCTE Scenario South with high wind power production in southern Europe, where the most of the wind power capacity is installed in Spain, Portugal, France, Italy and Greece, smaller deviations between scheduled exchanges and physical power flow compared with UCTE Scenario North are detected (see **Figure 21**).

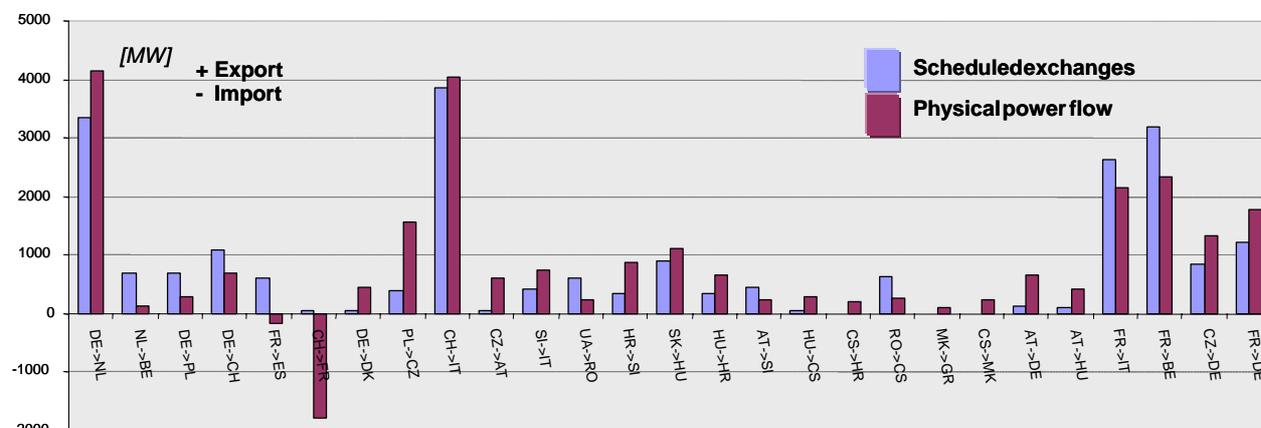


Figure 21: Physical power flows and scheduled exchanges of UCTE Scenario South

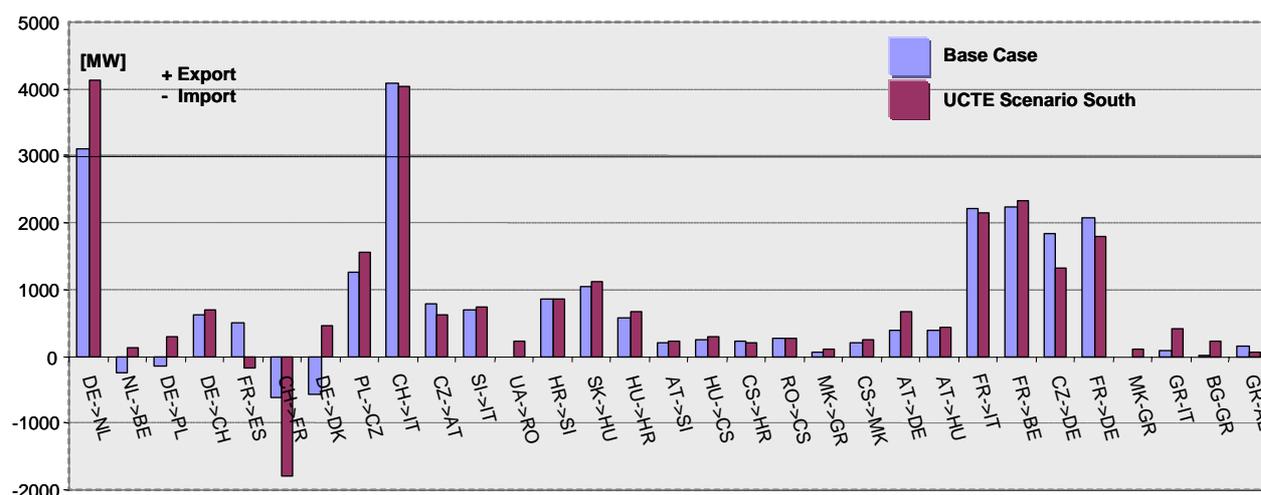


Figure 22: Comparison of physical power flows between Base Case and UCTE Scenario South

The main difference in import/export levels between the Base Case and UCTE Scenario South is the change from import to larger export of Spain to France due to high wind power production as can be seen in (**Figure 22**). This import could result in a decreasing damping of interarea-oscillations due to less PSS activated in Spain. The stability analysis to this issue will be investigated in the next phase of the project.

7.2 Base Case Power Flow Pattern

The Base Case describes the situation with low wind power production in Europe, especially in northern Europe.

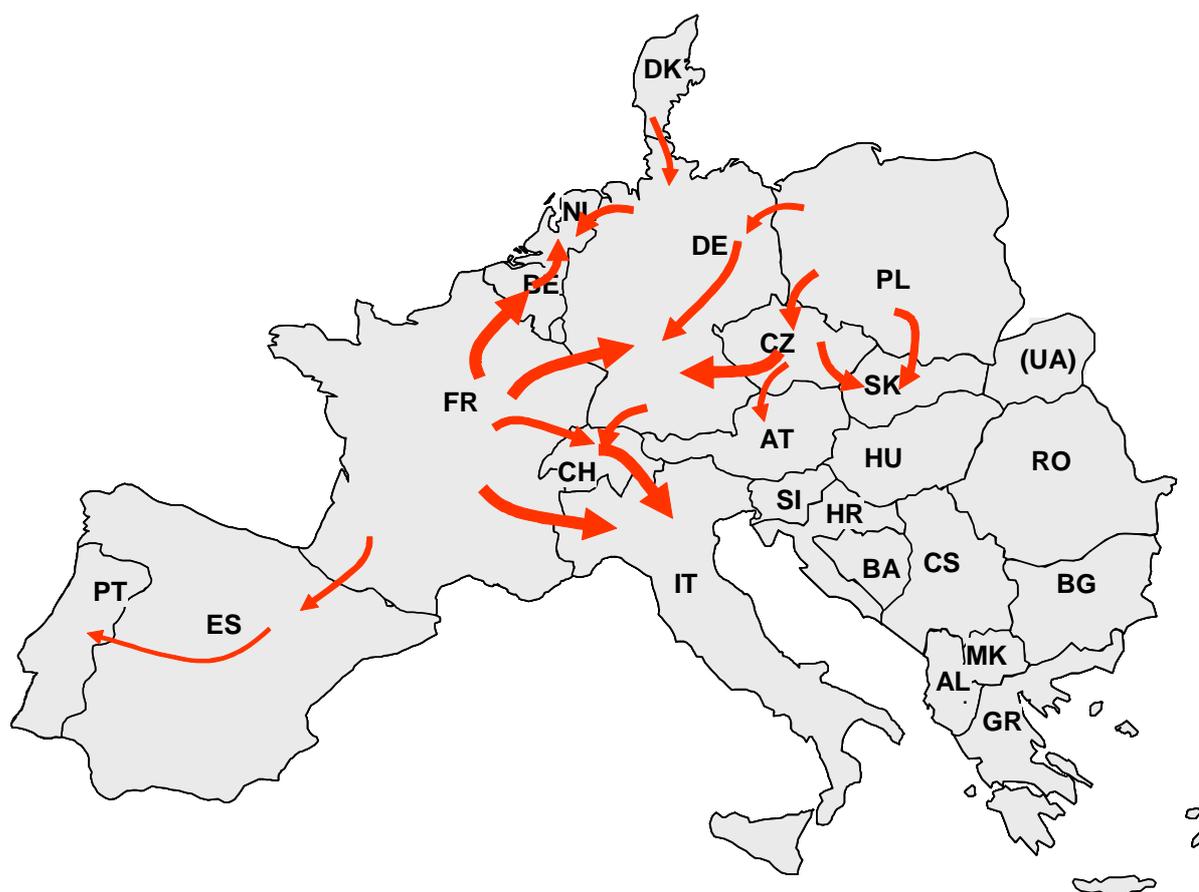


Figure 23: Main corridors of electrical power transmission in the Base Case

In case of low wind power production the main corridors of power transport are from

- France to Germany, Belgium, Italy and Spain
- France via Germany and Switzerland to Italy
- Poland to Germany, Czech Republic and Slovakia
- Czech Republic to Germany, Slovakia and Austria

Loop flow situations are only slightly developed in case of low wind power production in northern Europe (see **Figure 23**).

7.3 Resulting Power Flow Pattern

In case of UCTE Scenario North the main corridors of electrical power transport are going from the regions with high surplus of power production to the regions with surplus of power demand (see **Figure 24**). The surplus of power production in northern Germany due to the high wind power production is transmitted

- to southern Germany, further to Switzerland and Austria and further to Italy reducing the exchange from France to Italy via Germany and Switzerland
- to the Netherlands and Belgium
- to Poland and Czech Republic back to South of Germany and to Slovakia and Austria
- via Denmark to NORDEL.

The surplus of power production in France is transmitted to Belgium, Germany and Spain and further to Portugal and North Africa, where less power is produced at the same time.

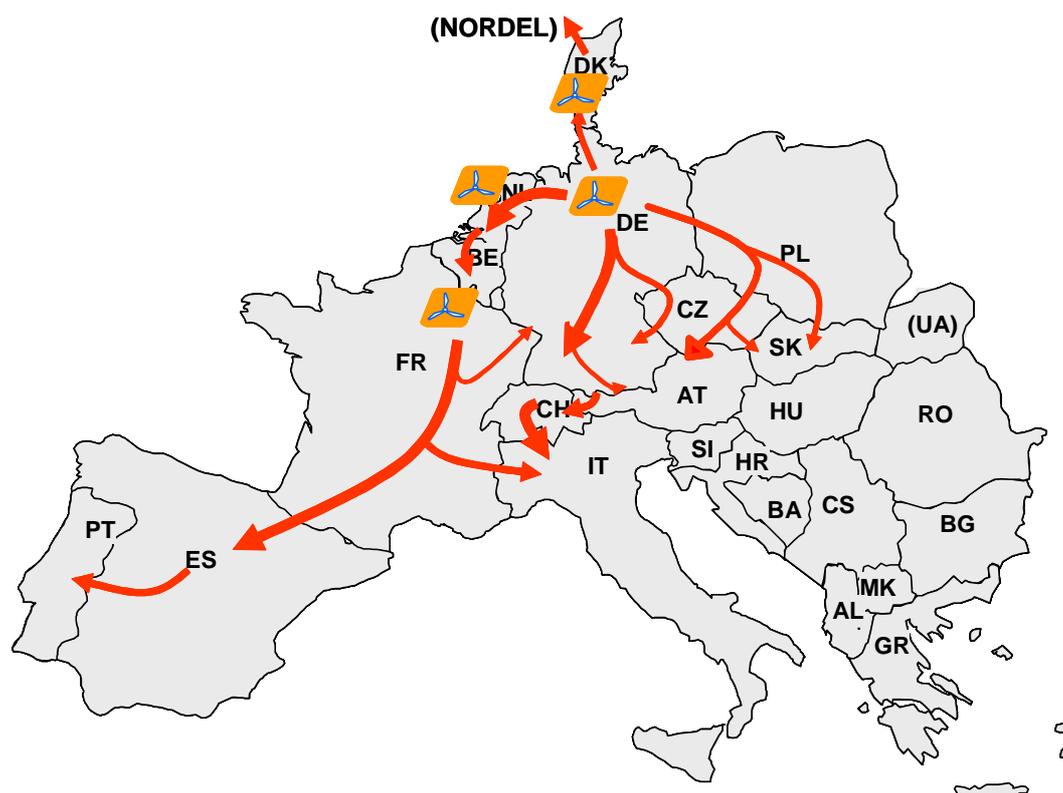


Figure 24: Changes of electrical power transmission in UCTE Scenario North

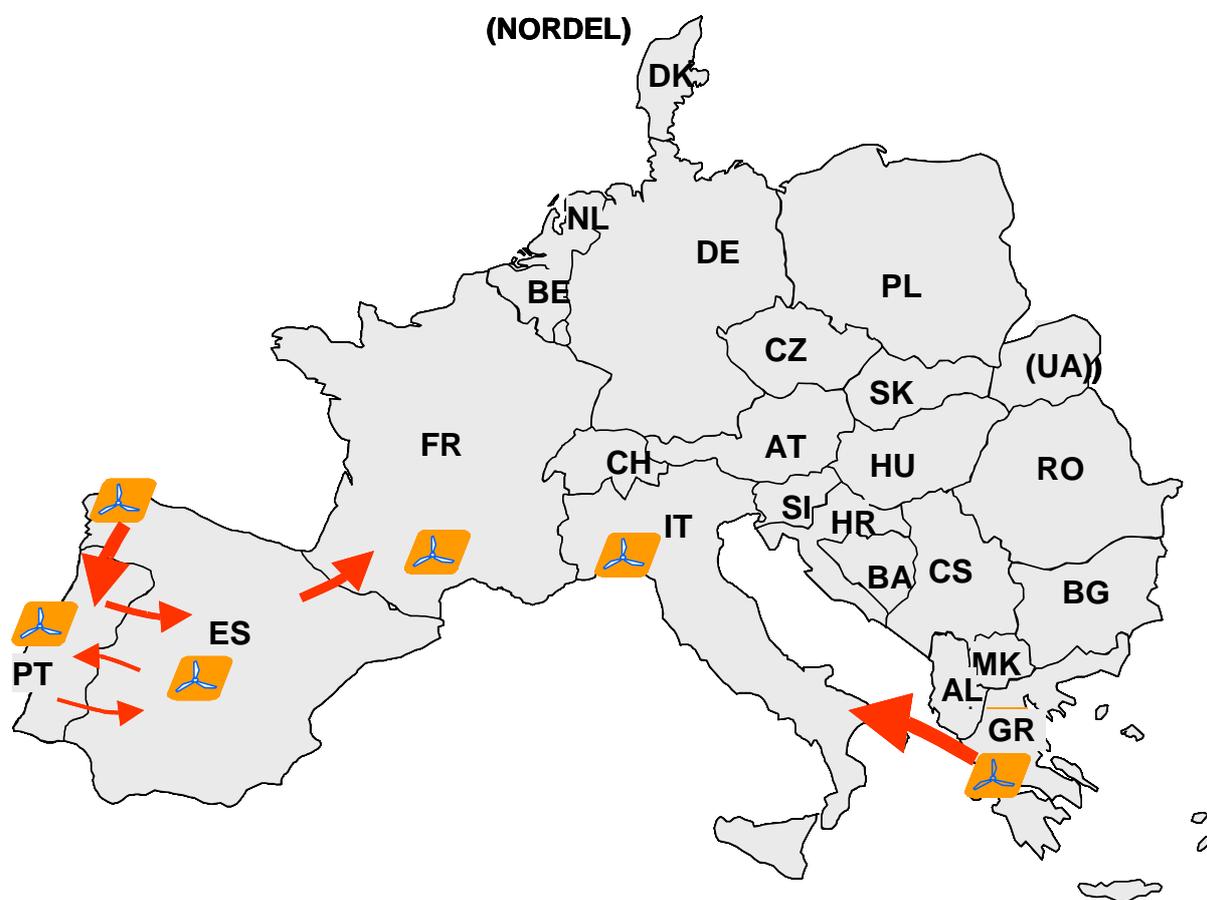


Figure 25: Changes of electrical power transmission in UCTE Scenario South

The growth of wind power generation has significant effects on the European electricity system as a whole. As stated in the previous sections, investigation shows that a concentrated and high wind power in-feed in northern Germany producing a high surplus of power production results in temporary large load flows inside Germany and through the neighbouring transmission systems in Benelux and Central Eastern Europe. These flows could affect system stability and available trading capacities increasingly.

In case of UCTE Scenario South, the surplus of power production in the Iberian Peninsula is transmitted to northern Europe via France and Switzerland. Furthermore, as a result of high concentration of wind power in the Spanish Galicia region, loop flows from Spain to North-Portugal and back to Spain are increased.

7.4 Effects on conventional power plants

The UCTE Scenario North which is developed according to the market model and methodology described above causes regional overloading of transmission lines in normal operation as well as in N-1 conditions especially within Germany. These results require measures in order to lead the system to a status with present level of security and reliability of supply.

These fundamental measures are firstly network-related measures distinguished between short-term operational measures for load flow control such as corrective switching and changing of settings of phase shifters and medium-term network expansion and network reinforcement measures. Although the TSOs instituted network expansion measures at an early stage, especially in the northern region, it is unlikely that they will come entirely into operation by 2008. The realisation of grid reinforcements will take several years due to the complex and lengthy authorisation procedure for transmission routes.

If the network-related measures are insufficient, market-related measures will be carried out according to their cost and effectiveness regarding the elimination of the congested transmission channel, i.e. re-dispatch of conventional power plants, counter-trading, etc. Complementary to these measures, a preventive measure of reducing short-term auction capacity on congested cross-border interconnections is also possible.

Herewith it is possible to react flexibly to expected critical grid situations caused e.g. by a high consumption of transmission capacity due to a forecast of high wind power in-feed. In Germany, a reduction of wind power generation to manage system security is only possible if the fundamental network- and market-related measures fail in the management of overloads and the maintenance of the secure operation of the power system (security management).

The German Renewable Energy Sources Act (21 July 2004) as national implementation of the Directive 2001/77/EC of the European Parliament and of the Council on the promotion of electricity produced from RES in the internal electricity market is the reason for that. It stipulates priority of connection of generating installations using RES to the general electricity supply grids, as well as priority of purchase and transmission of this electricity. This means that not only the generation landscape in Europe will change: conventional power generation has to be reduced in favour of renewable energy sources, leaving only the obligatory "must-run-units" in operation, but also a continuous control of wind power in Germany is not possible.

7.5 Risk Analysis

The objective of the steady state analysis is to investigate the necessary grid infrastructure (grid expansions, grid reinforcements) required to transmit RES energy to the point of consumption. Possible limitations of the transfer capacity of the interconnection lines due to dynamic problems will be investigated later.

Using the load flow model for the different synchronous regions (GB, Ireland, NORDEL and UCTE) the following topics are investigated for the different scenarios:

- N-1 contingency analyses
- Reactive power and voltage profile analyses
- Active grid losses (comparison between Base Case and UCTE Scenario North and UCTE Scenario South)

Both internal and cross border bottlenecks are identified.

All branches (lines and transformers) loaded more than 100% of their capacity are reported. In certain circumstances, branches with load close to 100% i.e. more than 90% are also reported. All nodes with voltages outside allowed limits are also accounted.

7.5.1 N-1 grid security

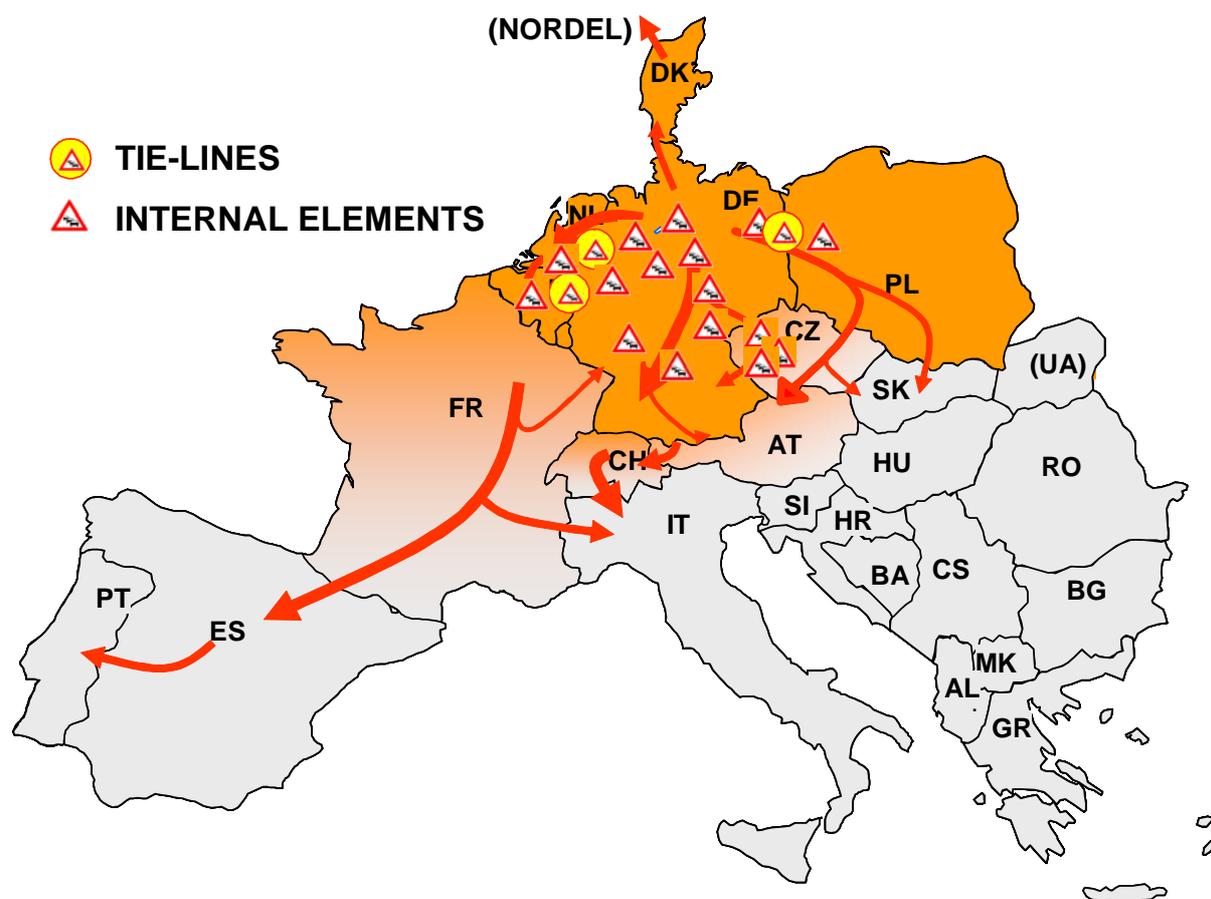


Figure 26: Detected bottlenecks during N-1 conditions of UCTE Scenario North

According to the security, operational and planning standards used by TSOs, highest importance is attached to the calculation of N-1 grid security based upon the electrical and physical realities of the network. This means, any probable single event leading to a loss of a power system element should not endanger the security of interconnected operation. The remaining network elements, which are still in operation, should be able to accommodate the additional load or change of generation, voltage deviation or transient stability regime caused by the initial failure.

Country	Circuit	N-1 Analysis Circuit loading (%)	Mitigation measures (2008)
BE	BDOEL 12 – BMERCA11 1	104	Use of new phase shifters on Dutch-Belgian border
BE	BZANDV11 – BZANDV31 1	122	
BE	BDOEL 11 – BMERCA11 2	104	
CZ	CHRD_11 – CREP_11	108	
CZ	CHRD_11 – CCHR_11	107	
CZ	CCHR_11 – CPRE_11	126	
CZ	CHRD_11 – CREP_11	105	
PL	TR 400/220kV KRA	110	Change of network topology on the German side
PL/DE	KRAJNIK – VIERRADEN	217 / 167 ^(1,2)	
DE	PASEWALK – VIERRADEN	182 / 139 ⁽¹⁾	
DE	HELMSTEDT – WOLMIRSTEDT	130 / 96 ⁽¹⁾	Reduced import from NORDEL and generation re-dispatch within Germany
DE	REMPENDORF – REDWITZ	115 / 82 ⁽¹⁾	
DE	PULGAR – VIESELBACH	115 / 77 ⁽¹⁾	
DE	STDE-KUMM-HAMN	143 / 84 ⁽¹⁾	
DE	WILS-DOLL	132 / 118 ⁽¹⁾	
DE	DOLL-LAND	124 / 103 ⁽¹⁾	
DE	GROH-WÜRGASSEN	123 / 102 ⁽¹⁾	
DE	OVEN-BECH	119 / 103 ⁽¹⁾	
DE	CONN-DIEL	116 / 106 ⁽¹⁾	
DE	GROH-WAHLE	110 / 75 ⁽¹⁾	
DE	CONN-UWES	107 / 94 ⁽¹⁾	
DE	GROSSKROTZENBURG – DETTINGEN	102	
DE/NL	DIELE – MEEDEN	106	
DE/NL	ROMMERSKIRCHEN – MAASBRACHT	104	Use of new phase shifters on Dutch-Belgian border
DE/NL	SIERSDORF – MAASBRACHT	103	
NL	DIEMEN - ENS	102	
NL	DIEMEN -LELYSTAD	102	
NL	LELYSTAD - ENS	118	
NL	ZWOLLE -ENS	106	

⁽¹⁾ Grid reinforcement measurements in preparation and partly realised are considered:

- New 380 kV double overhead line Krümmel – Schwerin (start of operation in 2007)
- New 380 kV double overhead line Halle/Saale – Schweinfurt (start of operation in 2008)

⁽²⁾ Considering the planned network expansion inside Germany (new 380 kV double overhead line Neuenhagen – Bertikow) overloads of the tie-lines between Poland and Germany do not occur any more. Until the realisation of this line, which is planned for 2009, a set of temporary operational measures can be taken in order to ensure operational security.

Figure 27: Bottlenecks during N-1 conditions of UCTE Scenario North

The loss of any power system element (generating unit, compensating installation, selected bus bars or any transmission circuit or transformer) must also not jeopardise the security of operation of interconnected networks as a result of limits of current, voltage magnitude, stability, etc. being reached or exceeded and accordingly cannot cause cascade tripping of installations with interruptions of supply.

For UCTE Scenario North bottlenecks on internal and cross border lines in northern Europe are detected. The overload during N-1 conditions varies from 100% to 180% (see Figure 26).

Cross-border bottlenecks

Without the use of phase-shifters, overloads of tie-lines are observed between Germany and the Netherlands, and Germany and Poland. By adjusting the settings of the phase-shifters in the Netherlands, Germany and Belgium to limit cross-border flows, the overloads of the tie-lines between the Netherlands and Germany can be reduced in 2008. Overloads near the Dutch-Belgian border can also be reduced with the use of phase-shifters in Belgium. The precise impact of these phase-shifters as well as their influence on neighbouring grids will be further analysed in later studies. The bottleneck between Germany and Poland is subject of bilateral investigations. Nevertheless, considering the already planned network expansion inside Germany (new 380 kV double overhead line between Neuenhagen and Bertikow) in UCTE Scenario North overloads of the interconnection between Poland and Germany do not occur any more. Until the realisation of this line, which is planned for 2009, a set of temporary operational measures can be taken in order to ensure operational security.

Internal bottlenecks

High wind power generation combined with high power production of conventional power plants with comparatively low marginal costs in the North of Germany and additional large import from NORDEL results in large North-South power flow in Germany. This causes several internal overloads during N-1 conditions. Internal overloads are also observed in Czech Republic, Poland, Belgium and the Netherlands for N-1 conditions in UCTE Scenario North. Investigated measures to eliminate these overloads are described in the detailed analysis.

N-2 security or rather N-1 with a maintenance outage will be further analysed in future studies.

7.5.2 Grid Losses

The grid losses in the extra high voltage grid (active power requirement) are extremely dependent on the required amount of transmission. Up to now its level was basically determined by load / demand. However, with the need to transmit wind energy, grid losses increase significantly depending on the extent of wind power infeed (see **Figure 28**).

An analysis of grid losses shows higher grid losses when there is high wind power generation in northern Europe. With the much higher wind power infeed compared to 2003, a distinct increase of grid losses is apparent in UCTE Scenario North. Compared to the Base Case (where there is less wind power generation), in UCTE Scenario North the active grid losses in Germany are doubled. In some countries, e.g. Poland and the Netherlands, there is a noticeable increase. The increase in grid losses must be compensated by the transmission system operators.

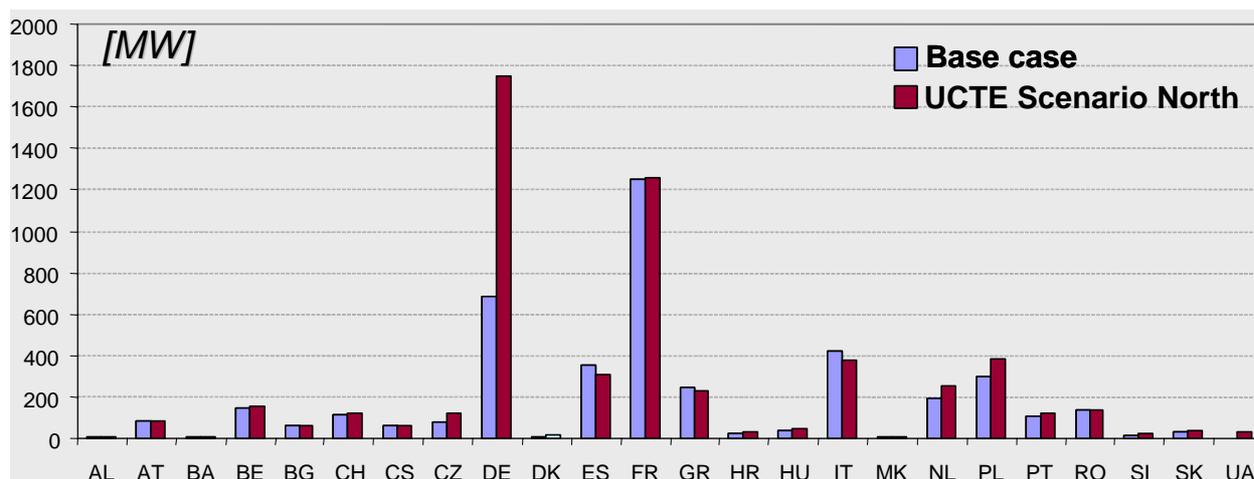


Figure 28: Comparison of active grid losses (overall system) between Base Case and UCTE Scenario North

In UCTE Scenario South, a significant increase of losses is also observed in Spain and Portugal. This increase is not apparent for Greece and France because of a lesser concentration of installed wind capacity.

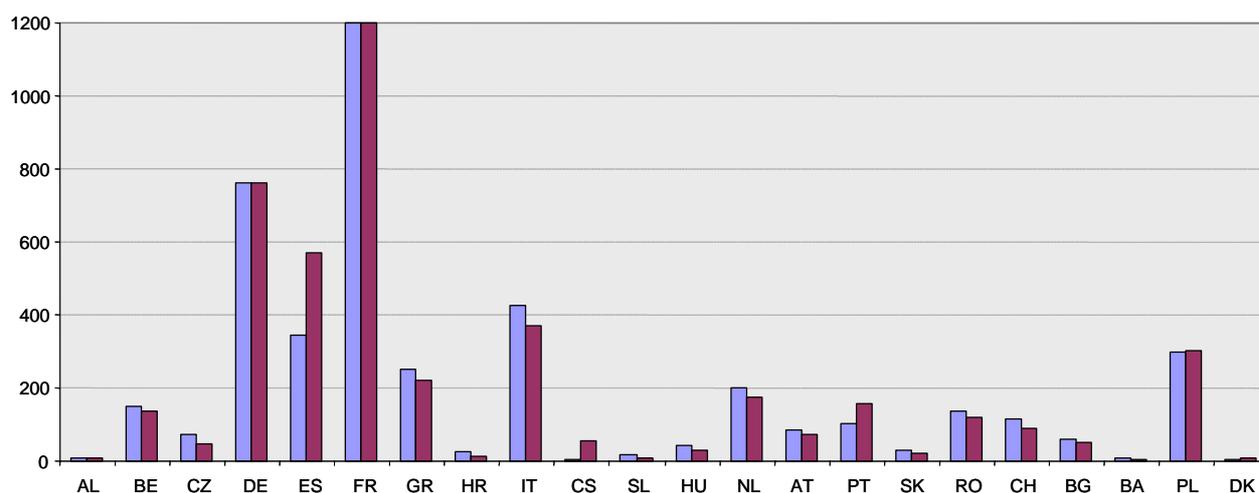


Figure 29: Comparison of active grid losses (ES, FR, GR, PT) between Base Case and UCTE Scenario South

7.5.3 Reactive Power Compensation

Wide-ranging transmission of wind energy leads to a higher load factor of the electric lines which thus consume more reactive power (see Figure 30).

This additional reactive-power demand of the transmission grid changes progressively (quadratic dependency) with the wind infeed. Because wind turbines are, at present, mainly integrated in the underlying distribution level (10 to 110 kV), the possibility of using these wind turbines for the provision of reactive power to offset the increasing reactive-power demand of the transmission system (above 110 kV) is very limited.

The variable reactive power available in conventional power plants is not designed for the additional reactive power demand of the transmission system. In addition, in several parts of the system with a high reactive-power demand conventional power plants have been taken out

of operation. Therefore reactive-power generation connected directly in the extra high voltage level must be provided by additional elements.

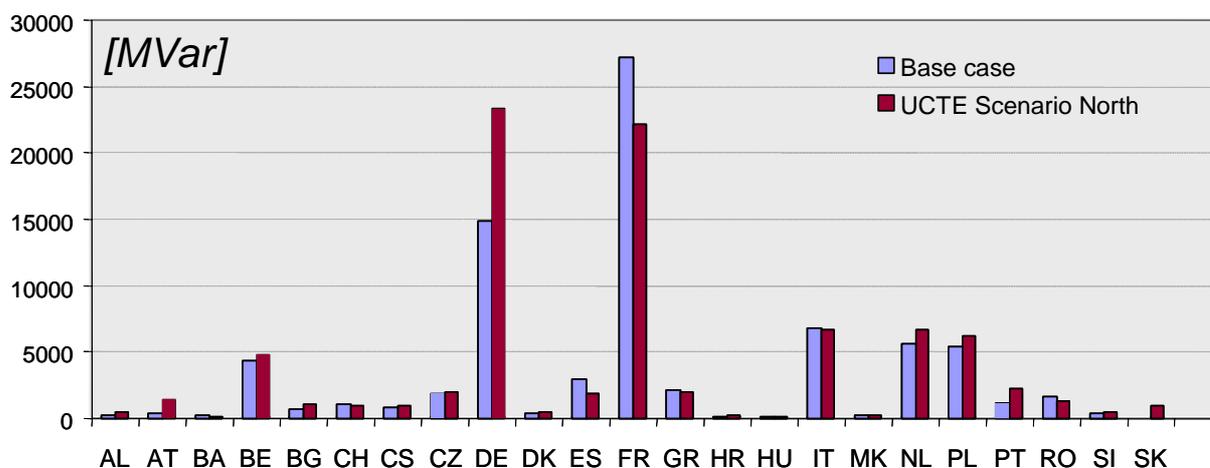


Figure 30: Comparison of reactive power demand between Base Case and UCTE Scenario North

Due to the high volatility of wind, it is also necessary to adjust the amount and frequency of the provision of reactive power in the extra high voltage grid. To ensure that the grid operation management can perform this task, sufficient devices must be installed for reactive power compensation (inductances/condensators). A capacity of up to 1,000 Mvar is used in the Northwest and central German grid regions, most strongly affected by transit of wind power.

7.6 Detailed power system analysis of affected countries (Main conclusions and summary)

A comprehensive investigation of each country was carried out and the detailed analysis of countries affected by the large integration of wind power in UCTE Scenario North is described in the following section.

7.6.1 Belgium

Belgium, together with the Netherlands, is situated between France and Germany. High transits through the Belgian transmission system are common. In the last years, a significant shift from the previously predominant south-north flow (i.e. from France via Belgium to the Netherlands) to a more important north-south flow (i.e. from Germany via the Netherlands and Belgium to France) was observed.

The Base Case Scenario illustrates a typical situation with south-north flows, with 2000 MW import into Belgium, and physical flows from France and into the Netherlands within the summer and winter NTC values. Although this base case cross-border flow is high, it is still less than that observed in real situations in recent years. There are no critical overloads for N-1 cases in the Base Case Scenario, whereas actual experience shows that critical N-1 situations do occur, especially in the summer months.

UCTE Scenario North, with high wind in Germany, shows a situation with high north-south flows, similar to actual situations that occur more often in recent years. The scheduled cross-border flow at the Dutch-Belgian border is well within the winter or summer NTC values. However, with an observed north-south loop flow of 2350 MW, the scheduled Belgian-Dutch flow of 600 MW is replaced by a physical Dutch-Belgian flow of 1750 MW, very close to the summer NTC value of 1900 MW.

The 380/150 kV transformer at Zandvliet, near the Dutch-Belgian border, and the lines from Doel (near the border) to Mercator (more centrally located) are highly loaded after outages in the grid. The percentage of permitted loading depends on the use of winter or summer transmission capacities. Topological measures are available to reduce the high stress on the system, although the increase in short-circuit level is a concern. A more fundamental countermeasure will be available with the 3 phase shifter transformers planned at the Dutch-Belgian border for 2008.

However, an even more extreme north-south flow has been observed in recent years. Dispatcher action and coordination with neighbouring TSOs has been necessary to re-establish N-1 security.

Change in active grid losses is negligible. Extra capacitors are planned to allow a higher level of import, but these do not fundamentally alter the high reactive power transits. These are dependent on the voltage levels set in Belgium and the neighbouring countries. A coordinated planning of voltage levels is required to limit reactive power transits.

7.6.2 The Netherlands

The Dutch transmission network is connected to the transmission networks of Germany and Belgium. In the Base Case Scenario the import of the Dutch system amounts 3300 MW. The physical cross border flow from Germany to the Netherlands and from Belgium to the Netherlands are well within the range of the indicated NTC values. No lines are overloaded (for n-1 cases) and no significant voltage drops have been found.

The investigated UCTE Scenario North is characterized by an adapted generation pattern with a high infeed of wind power compensated by a reduction of power output of conventional power plants and a maximum use of the scheduled available cross border capacity. This results in a high north to south flow. For the Dutch power system, UCTE Scenario North results in an increase of import up to a total of 3950 MW. The physical border flow from Germany to the Netherlands increases by 2700 MW up to a total of 5700 MW, while the physical border flow from the Netherlands to Belgium increases by 2000 MW up to a total of 1750 MW.

The resulting loop flow from Germany via the Netherlands to Belgium amounts 2350 MW. The physical border flow from Germany to the Netherlands is above the NTC value indicated for the winter of 2005/2006.

While investigating the (n-1) security constraints, several high loaded and slightly overloaded lines were found. It concerns all 380-kV tie-lines from Germany to the Netherlands and the internal 380 kV lines from Zwolle via Ens to Diemen. Breaching of (n-1) security is mainly caused by the high loop flow.

7.6.3 Czech Republic

Czech Republic is mainly exporting country and thanks to its location also bears significant transit and loop flows. In base case north-to-south direction of flows prevails and there are no overloaded elements at N-1 contingency analyses.

In scenario north, high infeed of wind power on the north, reinforces loop flows and also changes their pattern. Analyses of N-1 security criterion found 4 cases of N-1 contingency, which lead to overloaded elements (2x Hradec-Reporyje, 1x Hradec-Chrast, 1x Chrast-Prestice). Change of grid losses, which must be compensated by TSO, is approximately 16MW which represents change by 22%. In scenario south no overloads in contingency analyses were identified. Losses drop down by 28 MW.

In base case and both scenarios analyses show need for voltage compensation at 4 buses, and particularly in scenario north voltage at 220kV bus CSOK_21 rises to 111%. Voltage regulation need is within the currently available reactive power compensation capacity.

Due to experienced volatility of pattern and magnitude of power flows resulting from wind power infeed changes, higher TRM must be maintained for secure operation of the grid.

7.6.4 Germany

In the Base Case Scenario, the German system is modelled with very low level of wind power generation. In this scenario, Germany imports from all neighbouring countries, except the Netherlands and Switzerland. However, for UCTE Scenario North, a large North-South power flow is observed due to the additional import from NORDEL and the high wind generation in Germany, in particular in the North. This results in overload of several internal transmission circuits in Germany (up to 180% in the 220-kV system) during N-1 conditions.

In addition to corrective switching and the use of phase-shifters, power exchange with NORDEL and conventional generation in northern Germany need to be adjusted in order to eliminate the detected internal overloads. First results of load flow studies show that the overloads during N-1 conditions caused by large North-South power flow can be eliminated by halving the import from NORDEL in combination with a large reduction of conventional generation in North/East Germany.

This reduction is balanced by increasing the production of other conventional power plants with comparatively higher marginal generation costs in areas without overloads, mainly in the West and South of Germany. These measures ensure that the North-South power flows of UCTE Scenario North are within acceptable levels and the system security is maintained. When the network extensions identified in the dena study for the time horizon 2010 are considered, the overloads during N-1 conditions can be eliminated or at least largely reduced. The new 380-kV double overhead line between Halle/Saale and Schweinfurt will be in operation by the end of 2008 to prevent overloading of existing lines in eastern Germany. As a consequence, the amount and costs of market-related measures which are necessary to manage system security can also be reduced significantly. It should also be noted that the new 380-kV double overhead line between Krümmel and Schwerin, will also be in operation in 2008.

It is also observed that the phase shift transformers in Germany, the Netherlands and Belgium have an impact on reducing the cross border flows and internal overloads. Without these phase shift transformers, the tie lines between Germany and the Netherlands are overloaded. Using these phase shift transformers, the power flow from Germany to the Netherlands is reduced to 5,100 MW, maintaining all tie-lines loaded below ca. 70%.

Due to low level of voltage in certain regions in Germany, additional reactive power (approx. 1,000 Mvar) is also required in North and central Germany.

7.6.5 Greece (UCTE Scenario South)

Scenario B, with high wind power production in South Europe does seem to bring special problems to Transmission System. This scenario supposes about 720 MW produced in Greece by Wind Parks which is slightly more than the 530 MW which are now installed in Greece and produce instantly more than 450 MW. In any case the Greek Transmission System has been planned to afford such level of Wind Production. Thus, no problem is expected to occur in Greek Transmission System due to expected wind power production in year 2008. Analysis proved that all power flows in N and N-1 situations are under thermal limits, while voltage profiles are kept between their normal operation limits. Reduction in active grid losses is also considerable (from 251 MW in Base Case to 222 MW in scenario B).

7.6.6 Poland

In the Base Case Scenario, all network voltages and circuit loadings are at the permissible level. Model of Polish power system does not reflect the real winter peak power demand, and potential voltage problems do not occur.

Grid congestions occur in Scenario A, where a double circuit line Vierraden-Krajnik is loaded up to 118% of permissible value, without network outages, and 208% when the one circuit is switched off. In case of an outage on an internal 400 kV line in south western Poland the power flow on the tie-lines in the south of Poland is reduced leading to overloading (120%-130%) on the tie-lines in the north of Poland. Switching off generating units in Poland may result in increased power flow from Germany to Poland. Significant amount of power that flow into Krajnik station is transferred from 220 kV to 400 kV and further to northern part of Poland. In the analysed scenario in n-1 contingencies, at the flow of exceeding 900 MW, switching off a transformer in Morzyczyn station (which is close to Krajnik) causes overloading of transformer in Krajnik (110% of rated value) and switching off 400 kV line Slupsk - Zarnowiec leads to increase in loading of transformer in Slupsk up to 100% of nominal value.

Due to high loop flow through Polish system, tie lines to Czech Republic and Slovakia are already heavily loaded at only 700 MW scheduled exchange to Slovakia. Value of loop-flow exceed 1700 MW and causes also increasing active power losses by 100 MW. On the other hand cross border physical flows from Poland to Slovakia and from Poland to Czech Republic are close or slightly exceed the NTC values given by neighbouring TSO's (CEPS and SEPS). It shows that results obtained from scenario A indicate necessity of reduction NTC to avoid congestion in this region. Although a possible installation of phase shifters on the 220 kV line Vierraden – Krajnik will limit the power flow on this line, it increases the loading of the 400 kV double circuit line Hagenwerder – Mikulowa, but loop flow remains on the same level. The results obtained confirm observed and recorded phenomena of increased power flow from Germany to Poland due to increased wind generation in Germany. For the

scheduled export of 700 MW reliability requirements are not fulfilled in Scenario A. As a cross border bottleneck should be treated not only a double circuit 220 kV line Vierraden – Krajnik but all tie lines between Germany and Poland. Reinforcement of only double circuit 220 kV line Vierraden – Krajnik is insufficient.

On the whole, there is a threat of overloading the 220 kV line Vierraden – Krajnik and high loop flows which lead to grid congestion and limitation of border capacities for market. Physical cross border flow exceeds the NTC value on the polish south profile. Due to limited countermeasures in polish system there still is a need to find effective solution to reduce power flow on all tie lines between Germany and Poland. This issue is subject of bilateral investigations.

Proposed changed generation pattern in Germany causes that power flow from Germany to Poland decreases (by ca. 200 MW) but still reduction of the loading 220 kV lines Vierraden - Krajnik is insufficient in some n-1 cases.

The solution that prevents overloading of the 220 kV line Vierraden – Krajnik in normal operation situations with high wind power generation in the north of Germany can be managed by corrective switching on the German side.

7.6.7 France, Spain, Portugal (UCTE Scenario South)

The Base Case scenario shows a typical situation of import from France to the Iberian Peninsula. In UCTE Scenario South, this typical flow pattern is reversed and the surplus of production due to the high wind conditions is transmitted to northern Europe through France. However, such a pattern at the French and Spanish border is not foreseen as problematic. In addition, loops flows from Spain to North-Protugal and back to Spain are significantly increased compared to the Base Case situation, as a result of high concentration of wind generation in the Spanish Galicia region.

In Portugal, a n-1 security analysis focused on 220kV and 380 kV grids revealed only one overload (flow on line PPICOT21-PBEMPO22 exceeding thermal limit after a contingency on PPICOT21-PD.INT2). The constraint is eliminated by an adequate generation adjustment. Such a situation also appeared in Spain (overload of EPSMIG21-EAGUAY21 in case of contingency on EPSMIG21-EAGUAY21 and vice-versa), the constraint being removed the same way.

Calculations have also shown a significant increase in losses for Spain (about 70%) and Portugal (50%). On the other hand, losses are unchanged in France as a result of lesser concentration of wind capacity.

7.7 Risk Analysis for the Nordel Scenario

Loadflow analysis has been performed on the base case and the case with wind power. Wind power affects the power flow in the system by replacing other generation sources but due to the limited wind power capacity in the Nordel power system for the year 2008, no significant impact can be seen.

No significant changes to grid losses or voltage are visible.

Wind power production brings new challenges for the system operators. Unlike conventional power production, the output of wind generators is variable and for long time in advance insufficiently predictable. These two aspects require new solutions to enable system operations, especially when wind power penetration levels rise. The two major risks that currently are experienced by the TSOs are

- Large power flows that lead to congestion in the grid and especially in the grids of other control areas
- Reduction of available system reserves

These two risks have a high probability of occurrence as well as a big impact on system performance when wind power penetration levels rise.

8.1 Main properties of wind power production affecting system operation

In several countries priority dispatch of wind power production is legally imposed. It removes the responsibility for balancing from wind power suppliers and gives it to the TSOs in these countries. Control of wind power output is only allowed in case of emergency. In Germany, Portugal and Greece there is no market mechanism to control wind power generation. The complete wind power feed in is given to the transmission system where balancing is done by the TSOs.

In Denmark the fluctuation of the wind power has contributed to the commissioning of an Automatic Generation Control for Denmark West, which activates ± 140 MW, to take care of small and quick deviations. The bigger and longer deviations are handled in the balancing market.

Wind power forecast, being important for system operation, started more than ten years ago, with the continued increase in the number of wind farms. The tools that have been developed are mainly used either for planning purposes, in order to estimate the future output of a wind park, or for online daily use in dispatch centres. Most of the currently established forecasting tools are of short-term nature. The prediction time ranges from 1 hour to several days ahead. However, longer prediction times go with higher errors. Several model families are in use and under permanent development. Most of them are based on numerical weather prediction (NWP). The NWP also called meteorological model gives as output the wind speed and the wind direction as well as other meteorological data. These forecasts are converted into electrical power forecast.

Under conditions of high penetration rates of wind energy, imperfect control and imperfect forecasting lead to an increasing balancing need in the control areas. The impact of wind affects the volatility of market prices. In some control areas it even may happen that the wind power production exceeds the total load in a control area.

Wind farms behave differently from conventional power plants with respect to grid stability. In case of a fault in the grid causing a voltage drop, conventional power plants normally continue to generate electricity providing short circuit power and voltage control. Older wind power plants supply only little reactive power and short-circuit power and may cause stability problems. As an example in Germany, the Grid Code requirements were modified in 2001,

2002 and at the beginning of 2006 due to the results of the Dena study. New installations have to have common fault-ride-through-capability and voltage support. In addition to this monitoring systems are required for each wind farm to prevent voltage collapses due to reactive power consumption. Other countries are in the process of such amendments on Grid Codes as well.

8.2 Major risk of large power flows that lead to congestion

Generally wind is concentrated in remote areas and the power needs to be transported over large distances to the load. The grid was not designed for transport from remote areas with high concentration of wind power, which leads to congestions on some locations. The impact of such transport may affect the grid in a neighbouring country and loop flows can occur. These loop flows can be unexpected and in some cases are uncontrollable.

Every member state has a different risk profile for these large power flows in the grid. In **Figure 31** the risks are rated per country as they are expected to be experienced in 2008.

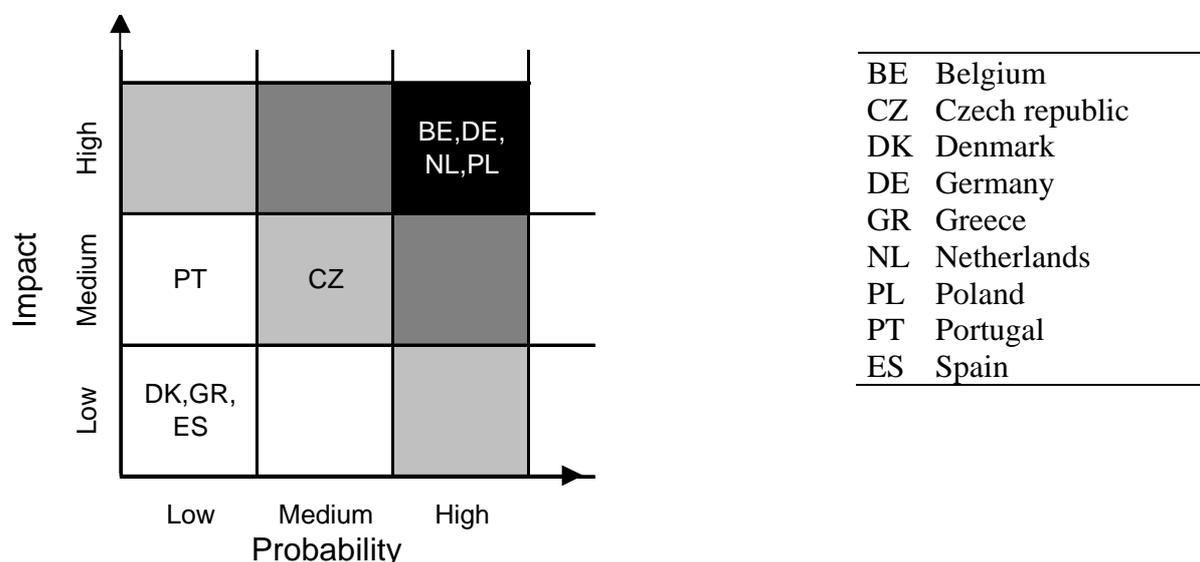


Figure 31: Congestion on the transmission grid due to large wind induced power flows

The following countermeasures were taken in the most affected countries to mitigate the risks:

- Reducing available cross-border capacity for the market
- Generation re-dispatch inside the power system,
- Changing of the network topology (including phase shifter tap settings).

In the case of Portugal measures taken have proven effective in reducing the impact.

8.3 Major risk of reduction of available system reserves

Wind farm production means a new challenge for balancing electricity production and consumption, mainly for those TSOs with a large share of such production units. Balance management has to compensate mainly for the imperfect forecast of production and consumption. These two sources of imbalances have different characteristics. Due to the large share of wind production in some countries, their impact on balance management is already evident.

High wind penetration in combination with low contribution to system reserves from wind power plants may lead to a reduction of available regulation and reserve power. In Figure 32 the risks are rated per country as they are expected to be experienced in 2008.

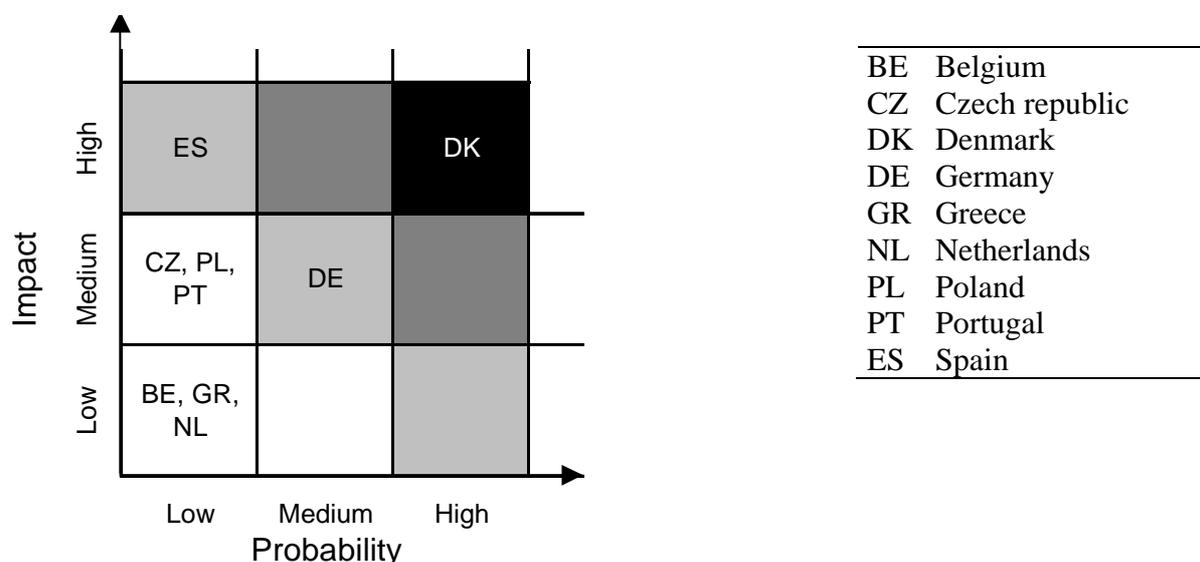


Figure 32: Risk matrix concerning reduction of system reserves

In Denmark the conventional system reserves have reduced in the last ten years due to the wind power production and the reduction of number of conventional power plants.

A system reserves market has been created as a countermeasure in order to activate the local Combined Heat and Power (CHP) plant as well as increasing demand side management.

As an example, the Dena study in Germany showed the future situation expected in Germany. The forecast errors for the wind energy feed-in give rise to an additional requirement for regulating and reserve power capacity provision for guaranteeing the system balance. Despite an assumed improvement in the predictability for the wind energy in-feeds, the required regulating and reserve power capacity increases disproportionately as the installed wind energy capacity increases. Due to the dependency of the wind-related regulating and reserve power capacity requirement on the level of the predicted wind in-feed, the regulating and reserve power capacity required for the following day can here be defined as a function of the forecasted wind energy in-feed level, taking into account optimisation aspects. This provides an average “day ahead“-regulating and reserve power capacity. However, the power stations must be collectively configured in order to provide the required maximum regulating and reserve power capacity at all times. In 2015

- in addition up to 7 GW of positive regulating and reserve power capacity is needed, of which on average 3,2 GW has to be contracted “day ahead”. In 2003, the corresponding values were 2,1 GW maximum and 1,2 GW on average.
- in addition up to 5,5 GW of negative regulating and reserve power capacity is needed, of which on average 2,8 GW has to be contracted “day ahead”. In 2003, the corresponding values were 1,9 GW maximum and 753 MW on average.

8.4 Analysis for further investigations regarding risk mitigation

The mitigation of the previously described risks is very complicated due to the fact that grid codes, market regulations and support schemes of EU Member State differ. There is no single level playing field for TSOs, regulators and market participants. Mitigation methods for operational risks must at the same moment be activated across countries; coordination therefore is a key requirement.

Besides the presented results and risk mitigation methods further investigations regarding risk mitigation, especially for the time horizon 2015, are proposed for phase II of EWIS. These investigations are split up in four dimensions:

- Political analysis
 - Political support and priority for grid reinforcement and expansion
- Legal analysis
 - Harmonisation of rules within regulations
 - Improvement of Grid Code requirements for wind power plants
 - Identification of legal barriers
- Market and business analysis
 - Adjustment of market rules for balancing purposes
 - Integration of balancing market
 - Harmonisation of the regional market design
 - Coordination by TSOs on a regional and intra-regional level
- Technical analysis
 - Sharing of wind power forecast information
 - Possibility to control wind power plants
 - Usage of large scale energy storage
 - System automatics for emergency control and demand side management
 - Consideration of the offshore integration of wind power

9 CONCLUSION

With most European countries planning to increase the installed wind power, it is expected that installed wind power in Europe will grow from 41 GW in 2005 to nearly 67 GW in 2008. The European Wind Integration Study (EWIS) covers all relevant technical, operational and market aspects related to the integration of large scale wind power in Europe.

With the special regulatory situation stipulating priority of connection, purchase and transmission of wind and other renewable energy in some countries in Europe, the generation landscape will change. Conventional power generation has to be reduced in favour of renewable energy sources. Continuous control of wind power is rarely possible and a reduction of wind power is only permissible if other fundamental grid- and market-related measures are insufficient to manage network congestions and maintain secure operation of the power system.

The expansion of variable wind power generation has significant effects on the European electricity system as a whole. In order to determine the major impact of the expected wind power on the operation and security of the European transmission network, two realistic scenarios for the year 2008 were developed in EWIS. The first scenario focuses on high wind power production in northern UCTE countries and low wind power production in the southern UCTE countries, while the second scenario represents a complementary situation where the high wind power production is in southern UCTE countries.

Investigation results showed that the high concentration of wind power in northern Germany is producing large power flows through Germany and the neighbouring transmission systems in Benelux and Central Eastern Europe, increasingly affecting system stability and trading capacities. Detailed analysis of the scenarios reveals overloads of transmission lines in normal operation as well as under N-1 conditions. The identified risks should be reduced by risk mitigation methods within the scope of both medium-term system planning and system operation. For the time horizon 2008, the fundamental medium-term measures comprise installation of additional phase-shifters and reactive power compensators and the realisation of network extensions and reinforcements as planned. Operational measures are grid-related load flow control such as corrective switching and changing of settings of phase-shifters. If necessary other market-related measures have to be carried out according to their cost and effectiveness on the congested transport channel, i.e. re-dispatch of conventional power plants, counter-trading, etc. A preventive measure such as reducing the short-term auction capacity on congested cross-border interconnections is also possible. If the network-related and market-related risk mitigation measures are insufficient security management measures, i.e. the reduction of wind power generation, have to be taken.

Harmonized grid code requirements should also aim to better adapt the grid requirements of wind turbine, as well as introducing extended and more specific control and protection rules. To maintain power system stability, it is essential to prevent the loss of large amount of wind power generation following grid faults. Therefore, fault ride through behaviour, wind turbines voltage control and additional system automatics based on frequency characteristic, are necessary.

10 OUTLOOK

In recent years, TSOs repeatedly addressed the necessity of a thorough examination of RES integration, especially wind power, on a European level. So far no reference study at a pan-European level exists as a complement of several investigations performed in different sectors and/or at national level.

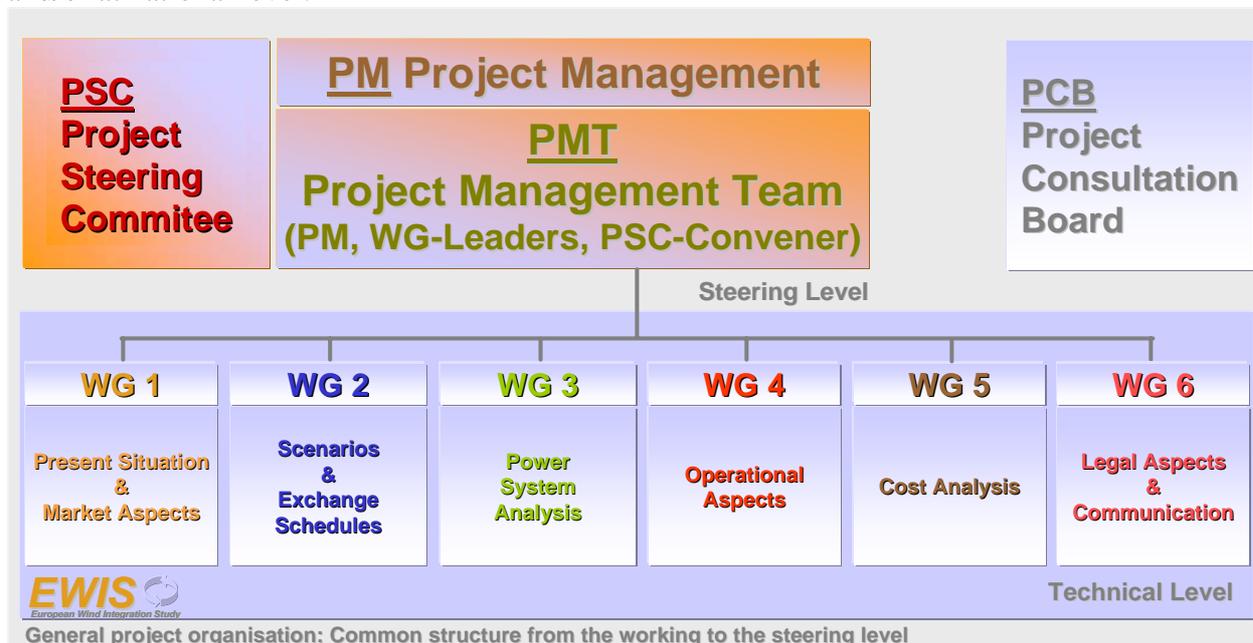


Figure 33: Organisational structure of EWIS project for Phase II

The EWIS project, coordinated by European TSOs, fills this gap as unique project gathering both technical and market as well as legal aspects in the four main synchronous electricity systems in Europe. The final objective of the full study is to obtain the necessary information for the technical and operational measures for risk mitigation and the secure operation of the European electricity grid, identified by steady-state and dynamic investigations on electricity grid models established within the study. Market and regulatory aspects will also be taken into consideration. This project is launched by ETSO and UCTE and also involves European Regional Associations of TSOs, NORDEL (Nordic TSO Association, UKTSOA (United Kingdom TSO Association), ATSOI (Association of TSOs in Ireland). A Consortium of 16 Transmission System Operators (TSO) from 14 countries, (with one TSO acting as a coordinator) representing the four main synchronous electricity systems in Europe, will provide a specific support. External stakeholders will also be invited to join a Consultation Board based on the needs of the study and the respective commitments about an active participation (e.g. European Commission, EURELECTRIC, EWEA ...)

Based on different developed scenarios for the time horizons of 2008 and 2015, the final results will comprise not only the necessary requirements for the further increase of wind capacities in national/regional generation mix in terms of system reliability, but also measures to counteract identified limitations, assessment of the costs of such measures, and consequences of existing, medium and long term issues related to the integration of wind power. Furthermore, the final results will comprise stability assessments and impacts, and give recommendations of harmonised grid code requirements for wind turbines to ensure a successful integration of wind power into European electricity grids while maintaining system security and stability.