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NETWORK REQUIREMENTS OF FUTURE ENERGY CONVERSION TECHNOLOGIES

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Abstract: Especially the introduction of intermittent electricity sources and the diffusion of distributed generation will make it necessary to improve the electricity network capacities and control mechanisms and will make the introduction of completely new dispatching philosophies necessary. The paper discusses the expected problems of the UCTE net introduced by the possible installation of 25 GW off-shore wind power in the North and Baltic sea. An up-grade of the transport capacities will become necessary to make the power available all over Germany. Control problems might especially arise, if a rapid shut down of the wind turbines in a storm situation would occur. The dispatching philosophy has to be changed from a demand driven to a supply driven philosophy, which distinguishes between renewable – primary – supplies and back-up – secondary - supplies.

Keywords: Dynamic modelling, Dynamic behaviour, Simulation, Wind speeds, Load Flows

1. INTRODUCTION

There is a lot of evidence that the future energy and especially electricity system will look completely different than the system looks today. Changes will be induced by the increased depletion of fossil fuels, the increased concern about environmental damages – especially climate change – and increasing political tension around the remaining attractive oil and gas reserves. A number of possible solutions are presented: more rational use of energy, energy savings and the introduction of completely new energy carriers like renewable and new nuclear energies.
New electricity sources will come increasingly into operation in the next fifty years. The characteristics of these source: unit size, spatial distribution, availability and so on might be completely different than of the power plants operating these days. The following paper will focus on the impacts of new generation technologies on the electricity network. This work is done in the context of a comprehensive study that will try to elaborate completely new supply systems and their interplay with the demand side. An intermediate step of this study is presented, namely a drastic increase of wind turbines in the German off-shore regions in the North and the Baltic sea. Plans exist to install up to 25 GW of wind power in the region. This installations could cover roughly 20% of the German electricity demand in the year 2030.

2. INSTALLATIONS AND REGULATIONS IN THE UCTE NET

Development and benefits of large electricity networks are discussed elsewhere [1, 2]. With an yearly electricity production of 2.205,6 TWh and a installed capacity of 515 GW (UCTE, 2002) the UCTE net covering Western and Central Europe is one of the biggest networks which is frequency synchronised

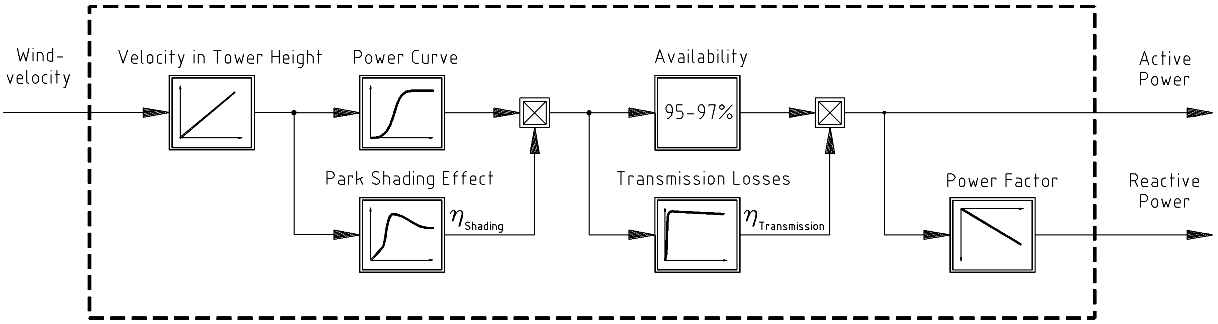

Figure 1: Simple wind park model

and voltage stabilised over the complete network. To guarantee voltage and frequency stability even with changing loads and power plant outages a general control procedure in three steps is agreed on. In case of an rapid increase of the load or an accidental outage the so called primary control is activated. A number of plants distributed over the complete network take part in this control measure. In a very short time up to 3.000 MW of extra power can be activated. This is mainly done by automatic changes in the steam cycle of fossil power plants which lead to an power increase. But this measure can only be kept active for a few minutes. Before this power gets lost again, the secondary control comes online. These are mainly very fast pump-storage hydro plants or specially designated thermal plants which operated not at full-load. In a third step power plants not yet online are activated and go on-line and replace the power plants activated by the secondary control. The UCTE network is divided in various control circles. While all partners in the network contribute to the primary control, the network provider in the control circle, where an outage happened, is responsible to supply the secondary and tertiary control. In the following study it is done as if the whole of Germany would be covered by one control circle.

3. SIMULATION OF FUTURE ELECTRICITY NETWORKS

3.1 Technical simulation with DIgSILENT

Basis for the following analysis is the software tool DIgSILENT PowerFactory [3], which is a computer aided engineering tool for the analysis of industrial, utility, and commercial electrical power systems. It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation optimisation. Modelling of the dynamic behaviour of all power system components down to very short time scales (milliseconds) is possible. The dispatching and control philosophy of various networks can also be adequately simulated with the help of a special block oriented programming language.

Within this tool the UCTE net is modelled using

- 1488 nodes
- 2401 transmission lines in the 380/220-kV-level
- 533 power plants
- 92 transformers
- 948 consumer loads.

Information on the

- production and consumption in the UCTE states
- distribution of produced power on the individual power plants and the individual plant types
- load-curves for high and low demand cases
- special conditions of the net
- international power flows
- dynamic of power plants and consumer loads

are available [4].

A description of the individual plant components for the conventional fossil, hydro and nuclear plants can be found elsewhere [5]. The simulation of wind power plants is done as depicted in Figure 1. Most important input parameter is the wind velocity in 10 m above the sea level. With the logarithmic elevator profile the velocity in tower height (100 m) is calculated. The wind-velocity-power characteristic is assumed to be like the characteristic of a Nordex N80 off-shore-turbine [6]. Impacts like shadings in the wind park and the power transmission losses are considered in efficiency curves. The availability of all plants in the wind park is expected with 95–97%.

3.2 Economic consideration: the optimal power plant scheduling

Operation of power plants is scheduled within the physics and engineering limits by economic consideration. A simple optimisation procedure was installed to model this decision process. Only fuel and variable costs were considered for the optimisation. Figure 5 gives a case for Germany, if 25 GW offshore wind and 20 GW of solar PV power were installed in addition to the existing power plants.

4. IMPACTS OF LARGE OFF-SHORE WINDPARKS IN GERMANY ON THE UCTE GRID

4.1 The German off-shore wind plans

Wind energy increased globally and a considerable fraction of this growth rate was achieved in Germany. The success of wind energy was promoted by two measure: first the so called 250 MW wind programme and than the "Stromeinspeisegesetz" which is now followed by "Erneuerbare Energien Gesetz". Wind energy is strongly promoted in Germany. Network providers are forced to buy the electricity from the wind power plants for a fixed price, namely for 8.5 Euro-cent/kWh. The limited number of favourable on-shore sites makes it necessary to go to off-shore locations in the long term if the growth rates stay high. A plan was elaborated to install in 4 phases up to 25 GW wind capacity off-shore till 2030 [7].

On the 11th of June 2001 the German government and the German utilities operating nuclear power plants signed an agreement for the phase out of nuclear power in Germany in the next decades. The agreement states a maximum of electricity that can still be delivered by nuclear power. Nonetheless it is reasonable to assume that in the next two decades most of the German nuclear generation capacity will be switched of an dismantled. One possible solution could be the installation of off-shore wind power, although it should be stated right from the beginning that off-shore wind power will be not able alone to replace base-load nuclear power plants. This will be discussed more in detail in 4.4.

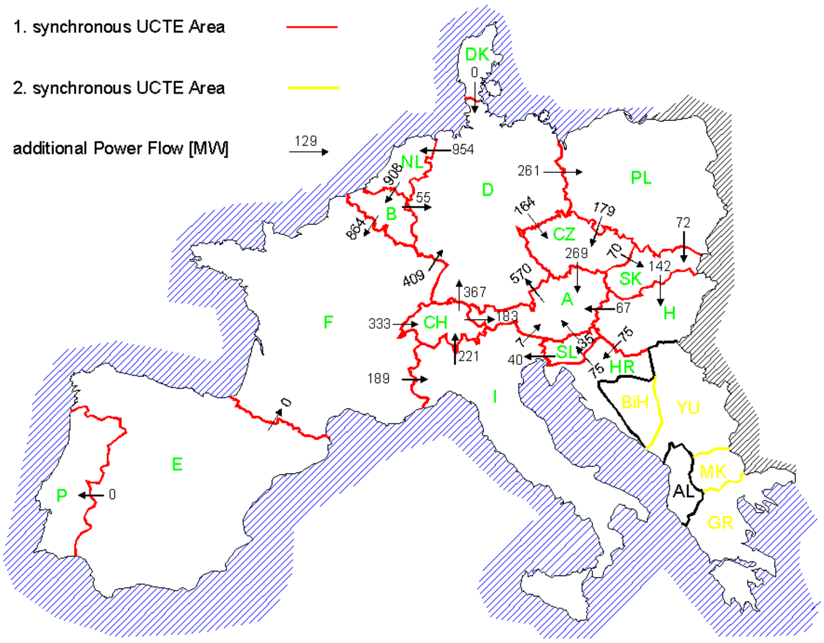

Figure 2: Additional power flow in Europe after feeding 7 GW wind power in North Germany

4.2 The missing transport capacities

In a first step the static electricity transport capacities are analysed. Basis for the analysis are the existing capacities of the 380-kV-transmission lines, see Table 1. Just for illustrative purposes Germany is divided in five supply areas (North, West, East, Centre, South).

Transport capacities from the region "North" to the rest are limited to roughly 13,32 GW. Just from this number it becomes obvious, that a production capacity of 25 GW will lead to problems if not a good fraction of the wind power is already consumed in the region "North". The case is if course more delicate since the transmission capacities are not solely reserved for the wind power. Two detailed investigations for a high load winter day and low load summer night very made. Wind velocities are assumed to be the average value for the respective month. It is now necessary to assume the power flows in the complete UCTE net. Power plants are on-line following the usual dispatching philosophy applied today. The investigations show that the winter day case poses the bigger problem, especially if it is assumed that electricity from nuclear power plants in the region "South" are replaced by the wind power. This is of course done on purpose, to understand the possible limitations of the network power needs to be delivered from the off-shore regions even to South-Germany. While in a base case without off-shore wind power plants the transmission capacities are only used up to 20 %, this increases considerable with 7 GW of wind power capacity in North and Baltic sea. Especially the line from the North to the West region would be used by more than 100 %, see Tables 2 and 3.

The wind power production does not only changes power flows in Germany but also in the other European UCTE partners. Figure 2 shows the impact of the wind power production in the north of Germany on the rest of the European UCTE net. Considerable power flows are delivered to the Benelux-countries.

Another negative side effect of the intense power flows are higher losses. The extra losses account for 470 MW, nearly 7 % of the wind power production.

The simulations show that already an installed capacity of 7 GW will lead to shortages of transport capacity in the Germany, if power needs to be delivered to South Germany. If all planed up-grades would be done this number would increase to nearly 20-25% of installed capacity. The at first intended 25 GW capacity needs completely new power lines.

Transmission Capacities [MVA]	North	East	West	Centre	South
North	-	5.580	1.380	6.450	-
East	5.580	-	-	8.890	2.760
West	1.380	-	-	15.340	1.390
Centre	6.450	8.890	15.340	-	13.630
South	-	2.760	1.390	13.630	-

Table 1 Transport Capacity in the German Grid

Line Loading [%]	North	East	West	Centre	South
North	-	8.2	14.8	8.7	-
East	8.2	-	-	10.5	6.6
West	14.8	-	-	18.4	6.3
Centre	8.7	10.5	18.4	-	6.6
South	-	6.6	6.3	6.6	-

Table 2 Line Loading without wind power

Line Loading [%]	North	East	West	Centre	South
North	-	15.2	106.8	53.4	-
East	15.2	-	-	2.8	24.3
West	106.8	-	-	12.0	29.4
Centre	53.4	2.8	12.0	-	19.3
South	-	24.3	29.4	19.3	-

Table 3 Line Loading with 7 GW wind power

4.3 The challenge for the net-stability

In chapter 2 the overall philosophy to guarantee the net stability in the UCTE net was presented. The question is, will the existing power plants, which take part in the net stabilisation, be sufficient to counterbalance possible changes in the output of the wind power or not. If the capacities will not be sufficient the question will be raised what kind of extra power plants need to be installed. Regular measurements of installed wind power plants show that in the year 2000 power changes stayed below 20 % in one hour [8]. Changes are expected to more pronounced in the off-shore case, since the geographical distance between wind turbines will be shorter.

The primary control in the UCTE net is able to counterbalance the loss of 3.000 MW on a second basis. If the changes in the hour range would not be larger that 20 % this should not pose a considerable problem, if 25 GW of installed capacity are assumed. The picture looks different if a rapid shut down becomes necessary. The question is, at which pace would a storm front pass over the North sea and would such an event not be predictable well in advance. For a quantitative examination a typical situation in winter and in summer was studied. In the winter case roughly 80 % of the installed capacity in the UCTE net was on-line. The wind velocity was assumed to be average velocity in January for the North and the Baltic sea. A drop of the wind velocity of 15 % was assumed to happen in a 10 min time period. This corresponded to a power drop from 14.770 MW down to 10.420 MW. This power drop let to a maximum change of frequency df = -170 mHz, depicted in Figure 3. The rapid shut-down of 1.000 MW nuclear power plant in Switzerland would lead to a frequency drop of 50 mHz. At a frequency drop of more than 1 Hz some loads are no longer supplied by the net. Similar assumptions were made for a low load summer night, but the problem here turned out to be less sever. In a second quantitative analysis it was assumed that the whole 14.770 MW capacity had to be switched of because of a storm. Obviously this needs not to be done at once, but at the time, when the storm front reaches the turbines. The time lack in between depends of the velocity of the storm front and the geographical distance of the wind turbines. In the simulation the wind capacity was switched of in four steps with a time delay of each 3 minutes. Figure 4 shows the effect of the net frequency and the Area Control Error (ACE).

4.4 New philosophies of dispatching

The variation in the power output goes from nearly zero during storms or large scale calms up to nearly full load. The rest of the power system needs to balance these fluctuations. Dispatching philosophies do

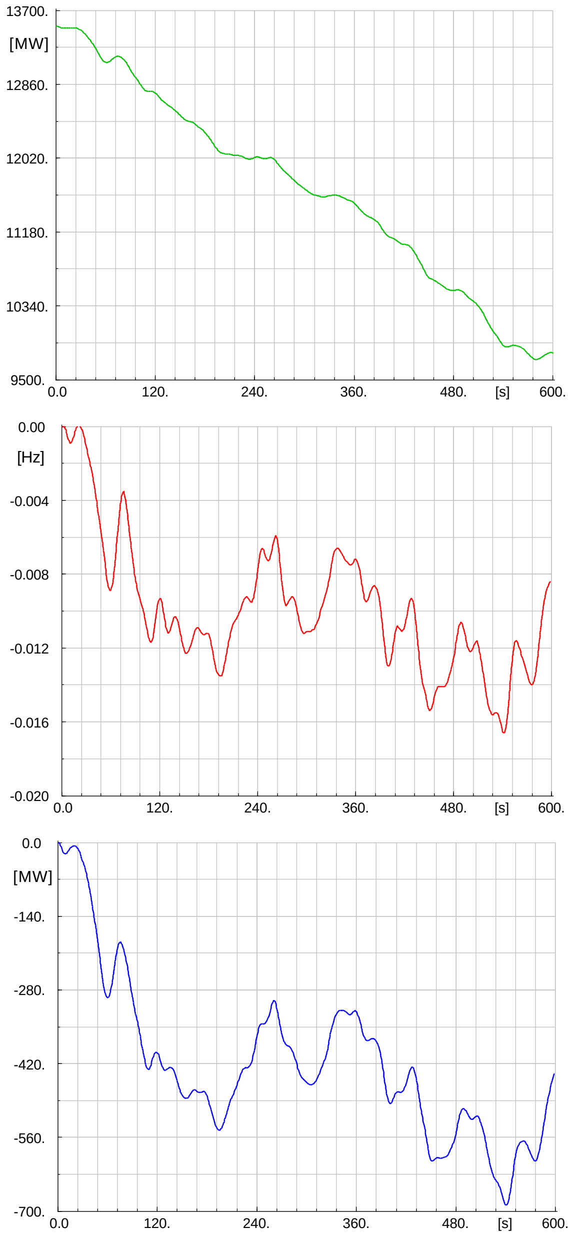

Figure 3: Power, Frequency and ACE during a drop of the wind velocity of 15 %

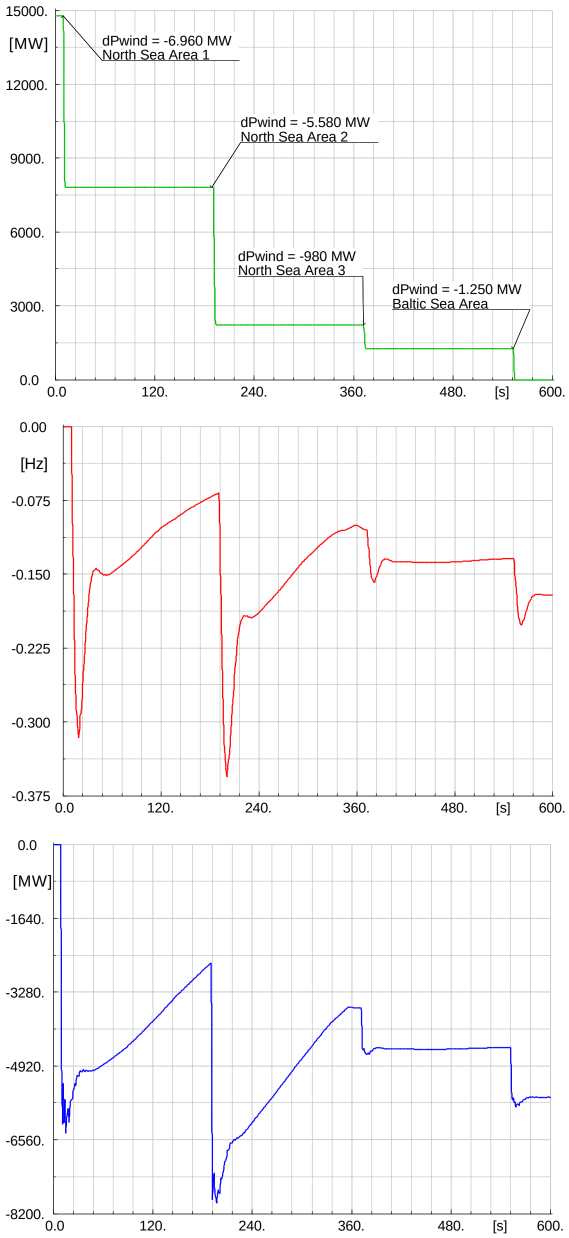

Figure 4: Power, Frequency and ACE during the wind capacity was switched of in four steps

depend on technological as well as on economic circumstances. In principle the load pattern is divided in a base, a middle and a peak load and different technologies are used to supply the three load categories. Liberalisation of the electricity markets might lead to changes in the way power plants are operated. Another change is expected by the strong linkage of electricity and gas market, volatility in gas prices might lead to very different competition situations of power plants using gas. The intensive introduction of intermittent renewable electricity sources and the increase of distributed generation might again lead to a change in the dispatching philosophy. An example is presented in Figure 5. Electricity from wind and solar PV is always used if available, while thermal power plants have to fill the remaining gap. Priority might be given to renewable technologies. The nuclear power plants have today still another large portion of the German energy production [9]. The concept of dispatching would then change from being demand driven as today to being more supply driven. The concepts of base, middle and peak load might be softened and be changes to primary supply and backup supply. This would of course have a very strong impact on the supply technologies. To study the various impacts a simplified DIgSILENT model was created. This made it possible to study various dispatching philosophies under various conditions over periods of weeks, under very different weather situations.

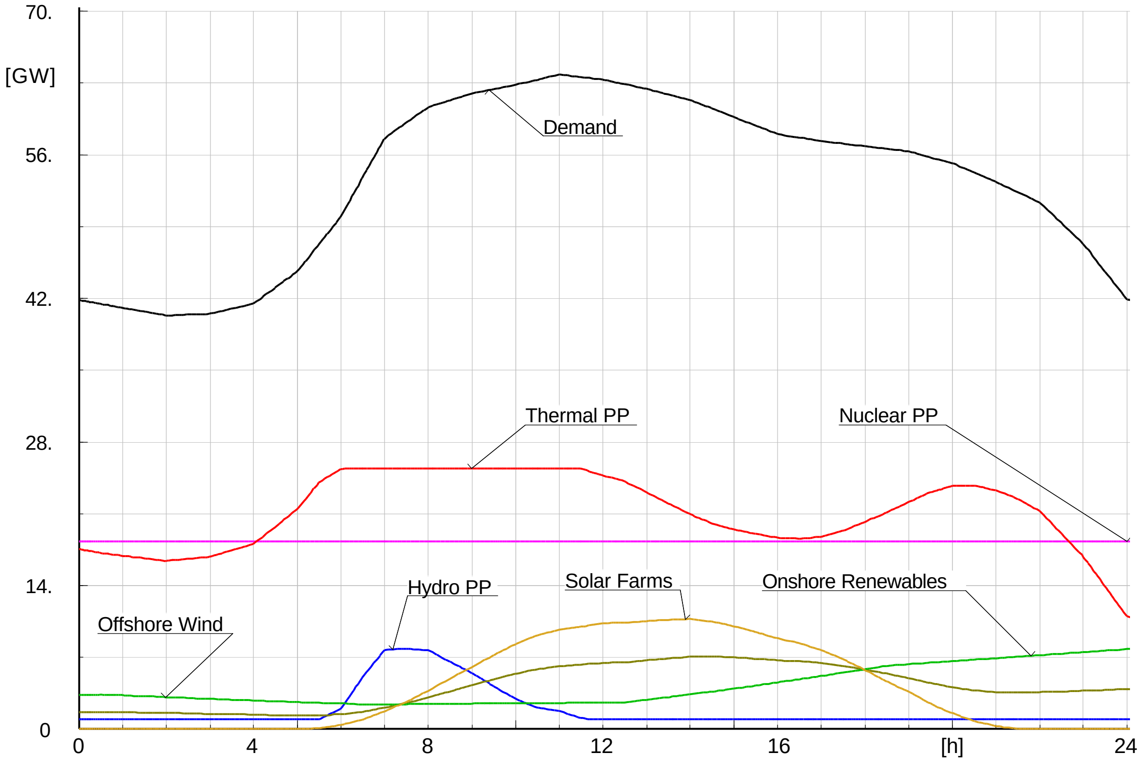

Figure 5: Power plant plan of application

5. CONCLUSION

The introduction of new intermittent electricity sources in the power market requires a revision of the complete power system. In case of the introduction of new off-shore wind capacities in the range of 25 GW in Germany, it will become necessary to strengthen the transmission capacity, to make sure that especially in case of storms no rapid shut-down of the wind-turbines becomes necessary and that a complete new dispatching philosophy is developed, which might make some of the base-load power plants obsolete.

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