# Advanced Grid Requirements for the Integration of Wind Turbines into the German Transmission System

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In Germany the installed wind turbine capacity already reached 18 GW. By the year 2020 a total wind power capacity of nearly 50 GW is expected, which is more than 50% of the German peak load. The implementation of this strategy will result in a very pronounced spatial concentration of in-feed from wind energy in Northern Germany. Firstly, more and more electrical energy must be transported over greater distances. Secondly, it is necessary to at all times guarantee to maintain the equilibrium between the electricity taken from the system by power consumers and electricity generation fed into the grid. This requires a new method of operating and adaptations in the power stations and the transmission system. According to the results of the dena-Study and the application of the previous Grid Code to different large wind farm projects, the German utilities decided to revise the existing rules for connection and operation of wind turbines on the transmission grid in advance to the necessary grid enforcement which will be realised before 2015. In the following the main aspects of the new requirements will be described with focus on the new and innovative issues.

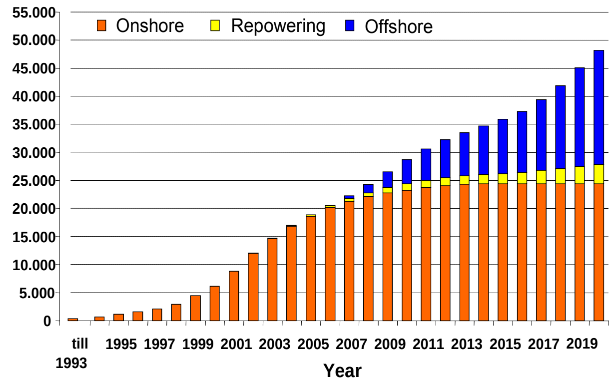


Figure 1: Expected wind power generation by the year 2020 and Pan-European aspects on wind power integration

In many countries in the world energy policies are focused on the increased utilization of wind energy due to the fact that wind power can provide a considerable input to electricity production. For the present status of grid operation the expansion of intermittent wind power generation in some EU Member States has significant repercussions for the European electricity system as a whole. For example: The concentration of wind power in Northern Germany is already producing huge load flows through the neighbouring transmission systems in Benelux and Central Europe. These spontaneous flows reduce system stability and increasingly affect trading capacities. In the future wind power increase will be realized mainly offshore where wind farms with several thousand megawatts should be built. Figure 1 shows the expected wind power in-feed points in the northern part of Germany and as a result the dominating power flow directions within the grid.

Most of the wind turbines are connected to the medium voltage grid. However, the expected large offshore wind farms will always be connected to the 400-kV network. Due to the required bundling of cable routes wind power in-feed will be concentrated to selected, strong 400 kV nodes. However, for security reasons the capacity of 400 kV stations is limited to 3000 MW.

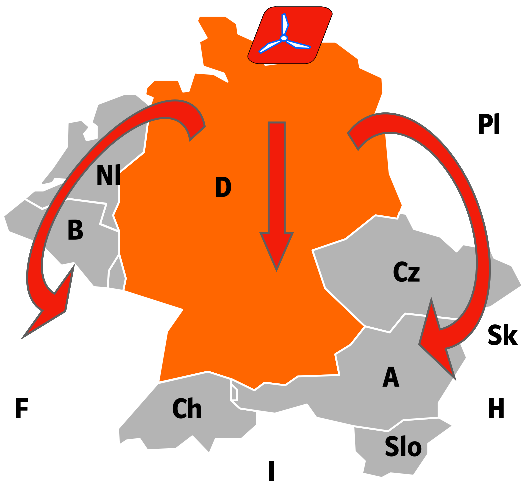


Figure 2 Physical flows in case of high wind penetration

Another concern focuses on the transportation of wind power to the load centres in the South for which new lines are indispensable in the near future. Despite several improvements, wind power forecast is still fraught with uncertainty. Therefore power system operation with increasing wind power penetration is becoming more and more difficult. Besides, the substitution of conventional

power plants by wind turbines and the unidirectional power flow in the grid may impact system stability considerably.
It is obvious that for secure power system operation wind turbines have to meet grid requirements. In Germany the first Grid Code for wind turbines was introduced in 2003. However in 2005 German transmission grid operators, together with wind turbine manufactures and several research institutes conducted detailed investigations about further development of wind power utilization in Germany and the consequences on system stability, operation and grid extensions. The results of this so-called "dena-study" underline the need for updating the existing Grid Code. The main concerns are:

- Fault Ride-Through (FRT) requirement to keep wind turbines on the grid during faults by introducing new technologies.
- Even in case of tripping wind turbines have to guarantee reconnection and continuation of power generation in the shortest possible time.
- Wind turbines have to provide ancillary services like voltage and frequency control with particular regard to island operation.
- Definition of technical standards for grid connectivity and operation of large offshore wind farms.
- The establishment of mechanisms for ascertaining and continuous monitoring of the fulfilment of grid requirements
- Establishing intelligent system protection devices to ensure a minimum loss of wind power and to guarantee fast recovery of normal operation.

After the year 2015, the wind power share on the German electricity production will increase considerably also due to the intended shutdown of nuclear power plants.

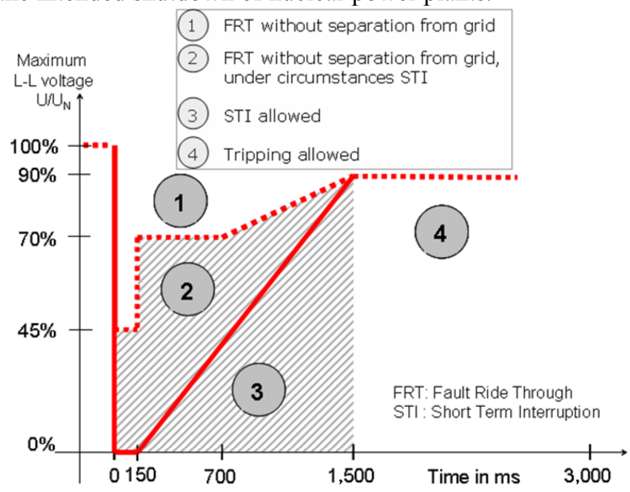


Figure 3: Fault Ride Trough - Short Time Interuption (STI) behaviour

As a result, the stability margin of the system is going to be less, affecting the security of the whole European power system. The European UCTE system is designed to withstand 3000 MW sudden generation losses. Therefore the substitution of conventional power generation by wind requires some new methods applied to wind turbines and wind farms for further secure system operation. On the one hand wind turbines have to provide some services still offered by conventional generators, and on the other hand, new features of modern wind turbines such as control and FRT properties have to be utilized for maintaining system security.
Special focus is directed to the old wind power plants built before 2003 and not capable of fulfilling Grid Code requirements. The objective is to enable these plants after a minimum retrofitting to withstand voltage dips and thus to avoid tripping following network faults.The main differences to the old grid code can be summarised as follows:

- Zero voltage for about 150 ms at grid connection point has to be considered in the future.
- The total duration of the low voltage period referred in the Grid Code is reduced to 1.5 s.
- STI is introduced and always required when low voltage period is shorter than 1.5 s and FRT is not possible without tripping
- Wind turbines have to ensure that after FRT power generation continues within the shortest possible time. For this purpose, the required minimum power gradients are defined

According to the new Grid Code voltage support is required when the terminal voltage exits the dead band of 10% around the current operating point.

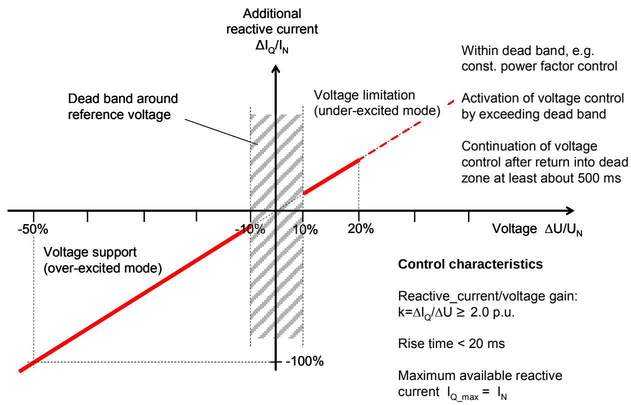


Figure 4: Voltage control requirements

The minimum reactive current/voltage gain required is 2.0 p.u. A reactive current of 1.0 p.u. will be supplied at voltages below 50%. Furthermore, the rise time required for this control is less than 20 ms. To ensure variable voltage support during normal operation utilities can require continuous voltage control too as practised by conventional synchronous generators. Fast continuous voltage control guarantees also maximum available reactive current in-feed during faults and some smoothing of voltage flicker may be caused by the fluctuating wind power. Large offshore wind farms are candidates for continuous voltage control. Besides, wind farms have to provide a contribution to stabilizing power system electromechanical oscillations that require the design of voltage controller taking power system stability aspects into account.

Following major disturbances power system may experiences large excursions in voltages and frequency. Beyond specific limits, system stability can not be guaranteed and generators as well as consumers may risk damage. In this case disconnection from the grid seems to be the best strategy. According to the new Grid Code wind turbines have to stay on grid within the frequency range of 47.5 Hz and 51.5 Hz. Beyond these limits separation without any time delay is required. However, wind turbines have to reduce power in-feed already at frequencies about 50.2 Hz as shown in Figure 5.

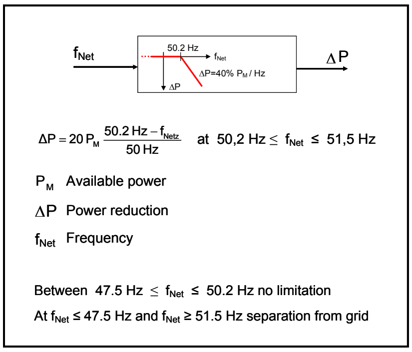


Figure. 5: System Automatics and system monitoring

In order to obtain system security aspects monitoring systems must be taken into account. These so called system automatics will disconnect generation units with reactive power consumption in case of low grid voltage selectively in order to prevent voltage collapse.

When the voltage falls below 85% of the grid nominal voltage and the reactive power flow is directed to the wind farm, i.e. the wind farm is consuming reactive power, the wind turbines have to be disconnected after 0.5 s delay. The conditions of this rule are referring to the connection points. However, disconnection has to be taken at the wind turbines directly in order to ensure fast restoration. The voltage considered is the maximum line to line voltage at the connection point. Taking into account the direction of reactive power flow, the conditions also provide for monitoring of the voltage support requirements.

Assuming that the voltage at the wind turbine terminal nodes falls further below 80% of the minimum permanently allowed voltage (i.e. 690 V x 0.95 x 0.8 = 525 V), disconnection of wind turbines is required in time steps of 1,5 s, 1,8 s, 2,1 s and 2,4 s. In each time step 25% of the wind farm units have to be tripped if the voltage doesn't increase again about 80% in the meantime. The grid code contains also requirements concerning backslide relations of the voltage relays too. Besides, it is recommended to build voltage and frequency functions in one joint relay.

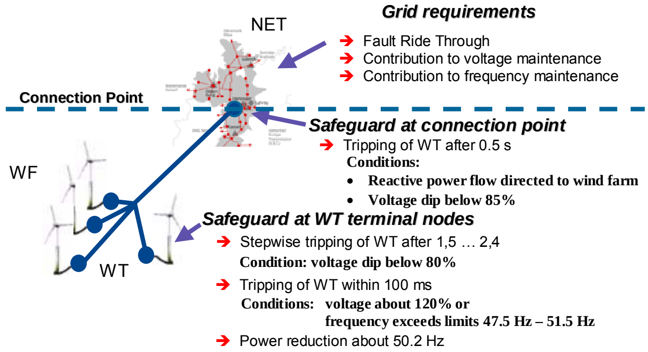


Figure. 6: Frequency dependent generation management

After disconnection, due to violation of voltage and frequency limits, resynchronisation can take place not until the voltage increases again to about 105 kV in 110-kV-networks, to about 210 kV in 220-kV-networks and to 370 kV in 380-kV-networks. In this case the maximum power gradient allowed is about 10% per minute of the contracted grid capacity. In the subsequent protection switching actions, wind farms might remain separated from the grid. However, stable operation of islands presupposes that the balance between generation and consumption as well as voltage and frequency control capabilities of the remaining generator units. Because of power balance is unlikely to be maintained within the island and wind turbine usually can not provide the required control service, separation from the grid is recommended. Wind turbines as a rule will be tripped by voltage and frequency relays due to violations of the corresponding limits. However, when the circuit breakers are connecting the wind farm to the grid trip, shut down signals have to be sent to the wind turbines too. Then, island operation has to be terminated within 3 s.

The changes and extensions included into the new E.ON Netz Grid Code aim, on the one side, at better adaptation of grid requirements to wind turbine capabilities and, on the other side, at the introduction of extended more specific control and protection rules. For maintaining power system stability, it is indispensable to prevent the loss of considerable wind power generation following grid faults. Therefore, the new Grid Code changed the FRT requirements taking into account realistic grid behaviour and also innovative FRT solutions of modern wind turbines. To ensure power system stability retrofitting of old wind turbines without FRT capability is necessary. For this purpose, some suggestions are made by the German utilities. Voltage control by wind turbines will become more important in the future because of conventional generators, which currently providing this service, will be replaced by wind power.

According to studies carried out considering the prospective increase of wind power and the reduced share of conventional generators [2], just simple line faults may endanger the security of the whole European power system in the near future. Three phase short circuits will result in voltage dips in wide areas of the network as shown in Figure 7 for a section of the German grid. Subsequently, old wind power plants without any FRT capabilities will be tripped and thus the system will experience loss of a large amount of generation capability. In case of the most likely single line to ground faults, system security may be guaranteed by alignment of voltage protection relays evaluating the maximum line to line voltage for developing corresponding decisions. Furthermore, a time delay of approximately 250 ms would protect tripping also for three phase short circuits. However, the technical feasibility of the proposed measures is still not proven by the manufacturers.

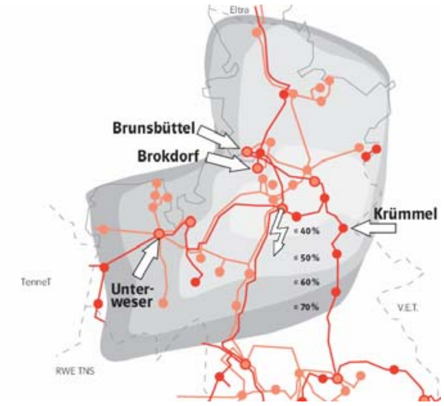


Figure 7 Voltage dip during a three phase short circuit in the German grid

Due to the German energy policy considerable increase in utilization of wind energy is expected in the next decade. However, the transport and distribution of wind power will alter the capacity limits of the German grid and will result in new congestions. With increasing share, wind turbine behaviour during faults and also in normal operation will become significant. In accordance with the results of the dena study available since April 2005, modification of the existing rules for wind turbines are necessary. The proposed changes and extensions discussed in this paper aim, on the one side, at better adaptation of grid requirements to wind turbine capabilities and, on the other side, at the introduction of extended more specific control and protection rules. For maintaining power system stability, it is indispensable to prevent the loss of considerable wind power generation following grid faults. Therefore, the new FRT requirements consider more realistic grid behaviour and also innovative FRT solutions for modern wind turbines. To ensure power system stability retrofitting of older wind turbines without FRT capability is necessary. For this purpose, some suggestions are made by the German utilities which are currently under examination by wind turbine manufacturers. The implementation of the described measures will improve and stabilize wind turbines behaviour and results in decreasing loss wind power following disturbances.

A European wide study on wind integration, which was repeatedly addressed in recent years, is set to launch (phase I with the time horizon of 2008 has been already started). In spite of several investigations performed in different sectors and/or at national level no reference study at a pan-European level exists so far. The EWIS project made by TSOs will fill this gap as unique project gathering both technical and market / legal aspects in the four main synchronous electricity systems in Europe. The overarching goal of the present study project is to address especially the network issues arising from large scale wind power plants, particularly relevant to European TSOs and to make proposals for a generic and harmonized European-wide approach towards wind energy issues.

## BIOGRAPHIES

**Udo Bachmann** (1952) received his grad. Engineer degree in electrical power grids and systems from the Leningrad Polytechnic Institute /Russia in 1977. After his studies, he worked in Berlin in the field of development and management by renewal and reconstruction of power grid protection. From 1980 to 1983, he joined the Department of Electrical Power Plant and Systems of the Leningrad Polytechnic Institute again, where he received his Ph.D. degree in 1983. Since 1983 he worked in the National Dispatch Center as Engineer and senior specialist in the field of management of grid protection from system view. During the last 15 years he is responsible both for steady state and dynamic stability computation and short circuit computation as well as network reactions in the Vattenfall Transmission Company (former VEAG Vereinigte Energiewerke AG).

**Istvan Erlich** (1953) received his Dipl.-Ing. degree in electrical engineering from the University of Dresden/Germany in 1976. After his studies, he worked in Hungary in the field of electrical distribution networks. From 1979 to 1991, he joined the Department of Electrical Power Systems of the University of Dresden again, where he received his PhD degree in 1983. In the period of 1991 to 1998, he worked with the consulting company EAB in Berlin and the Fraunhofer Institute IITB Dresden respectively. During this time, he also had a teaching assignment at the University of Dresden. Since 1998, he is Professor and head of the Institute of Electrical Power Systems at the University of Duisburg-Essen/Germany. His major scientific interest is focused on power system stability and control, modelling and simulation of power system dynamics including intelligent system applications. He is a member of VDE and IEEE.

**Wilhelm Winter** received the M.Sc. degree and the Doctor degree in Power Engineering from the Technical University of Berlin in 1995 and 1998 respectively. From 1995 to 2000 he was with Siemens, working in the department for protection development and in the system planning department. He was involved in large system studies including stability calculations, HVDC and FACTS optimizations, Modal Analysis, transient phenomena, real-time simulation and renewable energy systems. .He was responsible for the development of the NETOMAC Eigenvalue Analysis program. Since 2000 he has been working at E.ON Netz, responsible for large system studies, system dynamics and the integration of large scaled wind power.