Grid Code Requirements Concerning Connection and Operation of Wind Turbines in Germany

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Abstract—**This paper discusses issues of German grid codes relating to wind turbines. With the high utilization of wind power a simultaneous loss of several thousand MW wind generation became a realistic scenario in the German power system. Therefore, the main requirements concern the fault ride through capability of wind turbines. Accordingly, disconnection of wind turbines and wind farms above 15% nominal voltage at the grid connection nodes is not allowed. Besides, following network faults wind turbines have to supply a definite reactive current depending on the instantaneous voltage. Furthermore, they must return quickly to normal operation. The frequency range wind turbines have to tolerate is about 47.5-51.5 Hz. According to the wishes of German transmission grid operators large wind farms have to be treated in the future like conventional power plants.**

Index Terms—wind power, grid codes, renewable energy, power system dynamics, protection, reactive power control

I. Development of Wind Energy Utilization

THE German Federal Government and the German Bundestag promulgated in February 2000 an "Act on Granting Priority to Renewable Energy Sources" (Renewable Energy Source Act) [1] aiming at a considerable increase in renewably energy utilization in the next two decades. It has been updated in August 2004 [2] by keeping the overall targets. The Act is intended to contribute to the increase of renewable energy sources in the overall power supply to at least 12.5% by 2010 and to at least 20% by 2020. The major part of this increase should be covered by wind power. Pursuant to the Act, utilities are obligated to connect wind generators to their electrical grids, purchase their electricity and pay remuneration for the electricity purchased. Because the rules make investments in wind power profitable, the installed wind power capacity in Germany is increasing rapidly. Fig. 1 shows the development from August 2002 to October 2004. At the end of 2004 the wind power capacity approached 16 GW with the overall generating capacity of approximately 110 GW.

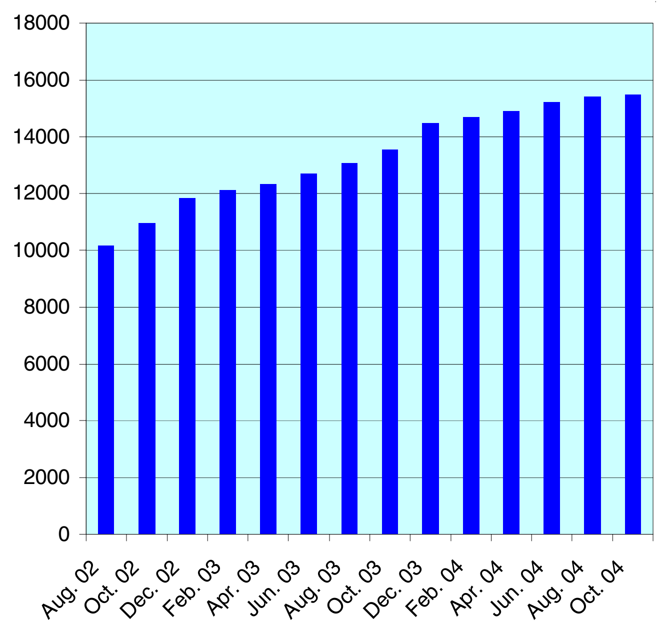

Fig.1 Development of the installed wind power capacity in Germany

Due to the uneven regional distribution of wind power installations (Fig. 2) the German utilities are concerned by wind power feed-in to varying degrees (Fig. 3). The most affected companies are E.ON and Vattenfall Europe Transmission (VE-T) whose share of wind power absorption is about 42% and 38% respectively.

Further increase of wind power generation will focus on offshore sites in the Nordic and Baltic See areas. Several wind farms with hundreds of MW, up to one GW in all, installed capacity are under planning in these regions. Such wind farms require connection to the 400 kV high voltage network and must be treated like conventional power plants. For increased wind exploitation, the new wind farms will be equipped with the new generation wind turbines in the range of 3-5 MW nominal power. New technical solutions are also required for connecting the large wind farms at a distance of 100-200 km offshore to the mainland.

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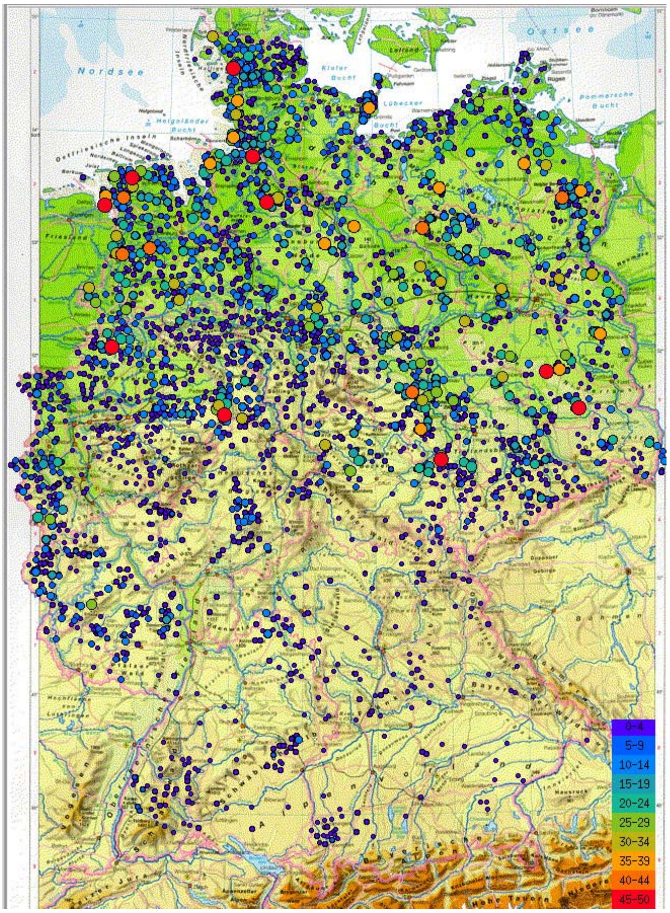

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Fig.2 Regional distribution of installed wind power capacity in Germany

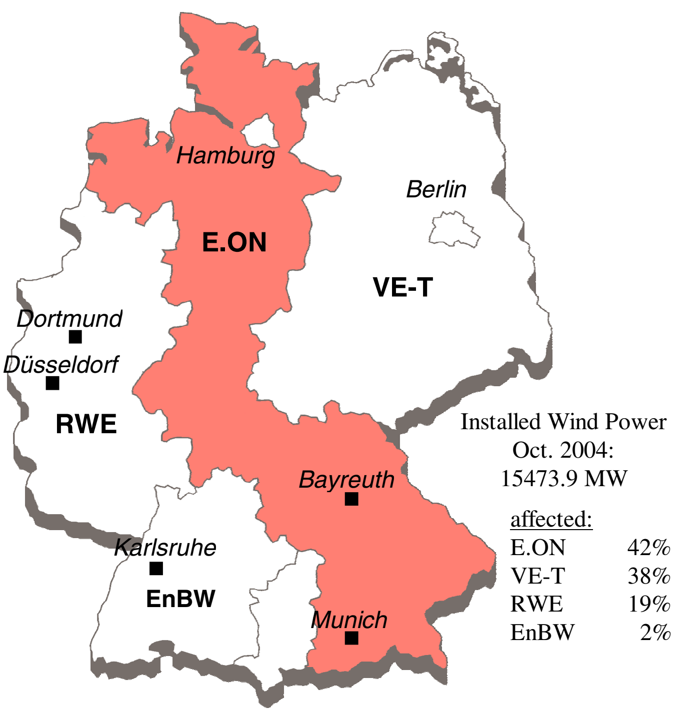
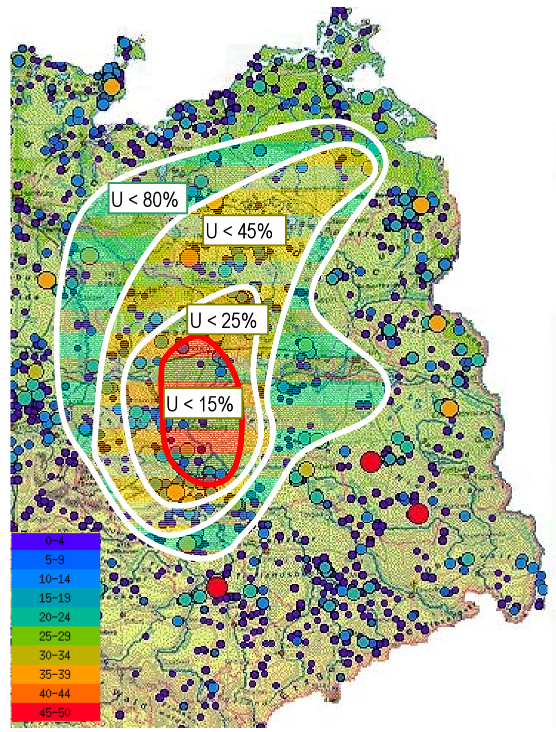


Fig. 3 Participation of German High Voltage Grid Operators in wind power feed-in

In the onshore area considerable increase is expected by refurbishing the old units.

Today, wind power feed-in may already lead to overloads in the 110 kV network. Therefore, further increase of wind power utilization requires investment in network infrastructure. Also the high voltage 220/400 kV network is not designed for transmission of wind power from the north to the south as proving to be necessary now. Therefore, German transmission grid operators are conducting comprehensive studies for identifying the necessary network measures and operational requirements to meet future challenges.



Affected wind turbines: * installed capacity
U < 80% → 2800 MW*(60%); U < 45% → 2100 MW*(45%)
U < 45% → 2100 MW*(45%); U < 25% → 1400 MW*(30%)
U < 15% → 1100 MW*(25%)

Fig. 4 Voltage breakdown during a three-phase short circuit

Already a standard short-circuit calculation reveals that following a three-phase short circuit a large amount of installed wind power capacity may be lost when previous rules are applied. Fig. 4 shows an example calculated in the VE-T network. In accordance with the previous practice, wind turbines were separated from the grid when the terminal voltage falls below 80%. In the past, requirements for wind turbines were focused primary on protection of the turbines themselves and did not consider the impact that this might have on the power system. However, with the increasing share of wind turbines on power generation and with connection of wind farms directly to the high voltage grid, loss of a considerable part of the wind generators cannot be accepted any more. Also operation with fixed power factor doesn't meet network requirements sufficiently. Rather, it is necessary

that wind turbines supply reactive power variably depending on network demand and the actual voltage level.
Therefore, German transmission network operators, first of all E.ON, released grid requirements on wind turbine connection and operation on the grid. VE-T published a grid code [3] where renewable energy sources are addressed in one document together with conventional power plants. In the meantime, E.ON consolidated its grid requirements also in one grid code [4]. Simultaneously, the association of German transmission grid operators, VDN, summarized special requirements concerning renewable energy sources operating on the high voltage network in a document [5] as an appendix to the existing general grid codes.

In the next chapter the authors will discuss special issues of German grid codes relating to wind turbines. The focus is on control and dynamic characteristics of wind turbines in response to network faults. Issues of power quality are not addressed in this paper.

II. Grid Code Requirements

Contrary to previous rules, wind turbines must be able to remain connected to the grid during and after network faults (Fault Ride Through capability, FRT). Fig. 5 shows the required settings of overvoltage and undervoltage relays installed in different network nodes.

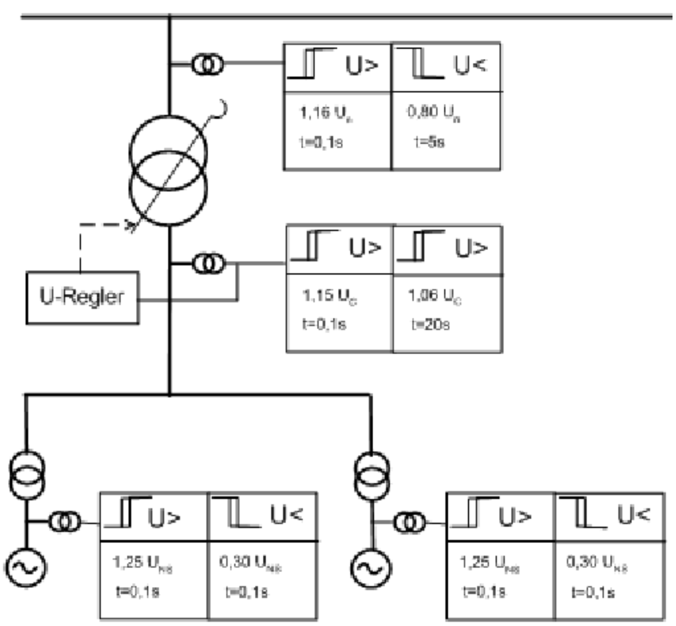


Fig. 5. Overvoltage and undervoltage protection relay settings [5]

The deepest voltage allowed on the generator terminal side is about 0.3 Un. It is assumed that the voltage at the network connection node in this case will reach approximately 15%.

The frequency band, which the wind turbine must be able to cope, is between 47.5-51.5 Hz. Fig. 6 shows the active power reduction allowed (6a) and the attendant voltage (operation) range (6b) depending on the frequency. Also the minimum time span for guaranteed operation under the various scenarios is shown in this figure.

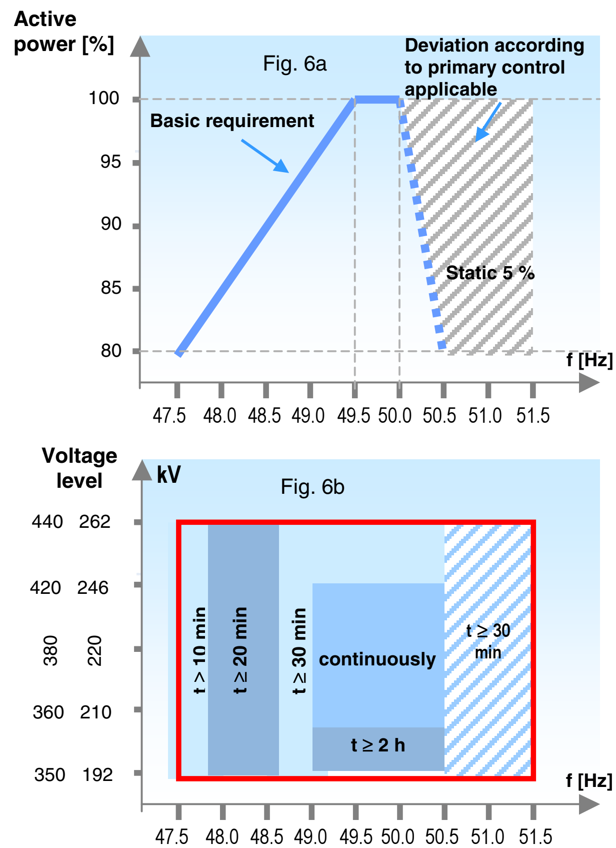


Fig. 6 Operating requirements depending on network frequency [3]

Wind turbines should be able to operate with different power factors in overexcited as well underexcited mode. Fig. 7 shows the required power factor range of VE-T depending on the voltage on the network side. Because of the differences in topology and loadings of the particular networks German transmission grid operators may define this diagram slightly differently.
How the corresponding reactive power will be generated is not specified in detail. It is possible to produce reactive power using the wind turbines itself. But in case of long distance connections between offshore wind farms and the grid, the transmission of reactive power may cause considerable losses and voltage drops. Therefore, more favorable is to use switchable shunt reactors near the grid connection point, in addition to a fixed one and to control the reactive power generated by the wind turbine within a smaller margin.

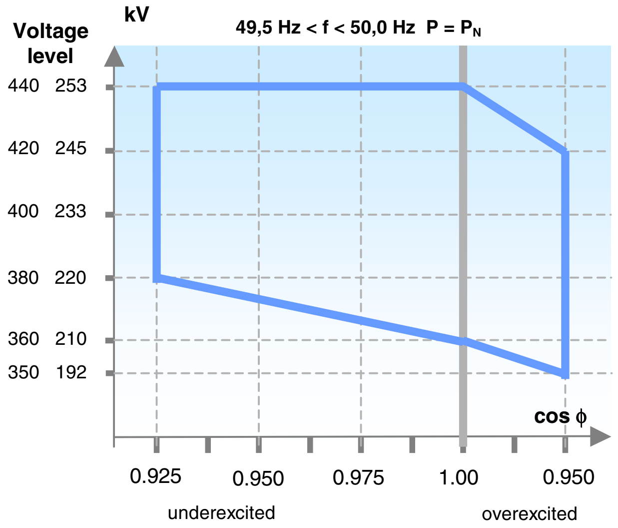


Fig. 7 Operating range within the coordinates of voltage and power factor [2]

Then, wind turbines are used only to provide reactive power continuously between discrete compensation ranges. However, step changes in reactive power input of (about) above 2.5% of the network connection transfer capacity in the 110-kV network and 5% in the 220/380-kV network is not allowed [4]. SVC offers more flexibility for reactive power control, but wind farm operators still hesitate to use it because of the higher cost. When the wind farm is connected to the grid through a DC link, the total reactive power must be produced on the network side. To ensure power supply at different voltages according to Fig. 7, it is usually necessary to control the voltage by a tap changer transformer.

According to the German grid codes, wind turbines should remain connected to the grid during network faults. This requirement became essential due to the fact that thousands of MW wind power was at risk of being lost, if the past practice of separating below 80%Un is allowed. Fig. 8 shows the new requirements where the lowest voltage that wind farms have to withstand is set at 15%.

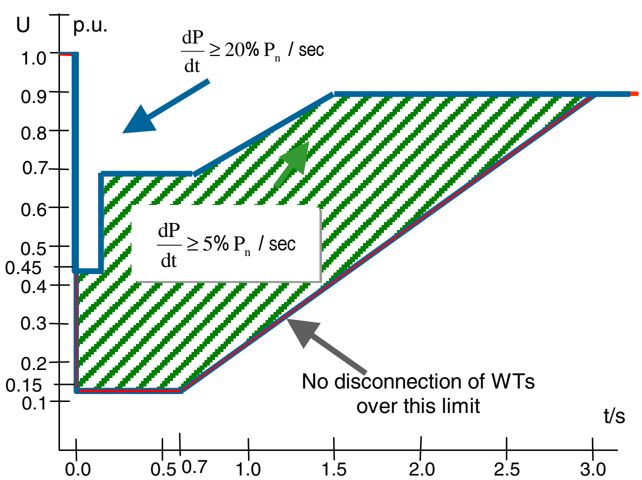


Fig. 8 Voltage limits at grid connection point during and following network faults [4]

Consider that this diagram should be applied to the grid connection node. At the wind turbine terminals the voltage dip will be less due to the expected voltage support by the turbines. Therefore, the undervoltage relay setting for the turbines is set to $0.3U_n$ as shown in Fig. 5.

Active power increase is also defined in Fig. 8, which is at least 5%, respectively, 20% P_n/s depending on the instantaneous voltage level.

Generators should supply a short circuit current, which ensures secure operation of protective devices and narrows the voltage collapse area. To support the network voltage primarily reactive power is required. Therefore, wind turbines must supply reactive current into the power system according to Fig. 9. In a small band of 10% around the steady state voltage, no requirements are defined. However, below and above this border, a reactive current equivalent to $2\%I_n$ per $2\%U_n$ voltage sag is required [4], [5]. Beside this, it has to be activated within 20 ms [4]. Return to normal operation is allowed after 3s, which corresponds to the lower border line in Fig. 8. In large wind farms reactive power is provided also by the cable capacitances and the shunt reactors used for compensation purposes. Therefore, for conformity with the grid requirements, , sometimes modifications are needed. So it is possible to adapt the reactive current / voltage characteristic to the particular network configuration. As an alternative, continuous dynamic voltage control may be introduced. However, all these measures have to meet at least the basic requirements as discussed above and have to be verified by dynamic simulation.

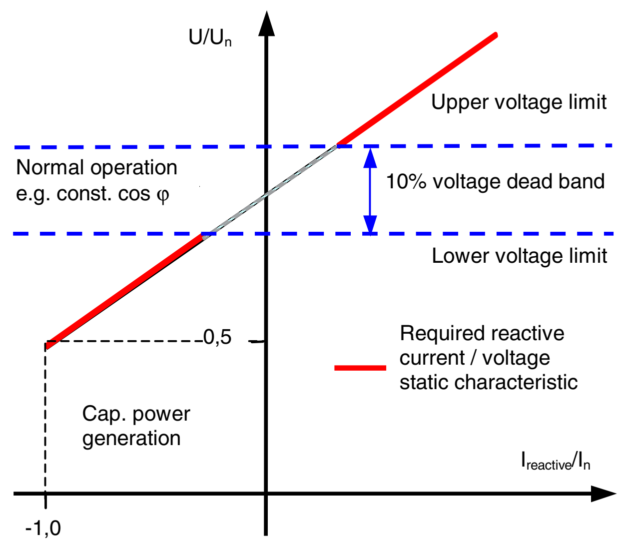


Fig. 9 Static characteristic for back up voltage operation [4], [5]

The technical implementation of FRT and voltage back up operation is not part of the grid codes. For this, different solutions are possible. Besides, the development in this field is still not completed.

In Germany Power System Stabilizer (PSS) are installed for damping of local and global interarea oscillations. With the substitution of conventional power plants by wind turbines it is essential that the oscillatory stability is not affected negatively. Therefore, the dynamic interaction of wind farms with the power system has to be proven by detailed dynamic simulations before implementation. In some cases active contribution towards damping of power system oscillations is required. As a further result of simulations, dynamic models for wind turbines and wind parks are provided to the utilities, which afterwards are used by grid operators for dynamic studies.

Because of temporary overloadings of selected overhead lines caused by wind power feed-in, E.ON established an obligatory active power management for wind turbines. According to this practice, wind power supply must be reduced to a defined degree in case of overloads for ensuring secure power system operation. For implementation, wind turbines and wind parks are equipped with communication technology and the corresponding control equipments.

III. Conclusions

In Germany the utilization of wind power for electricity production is increasing steadily and will reach 16,000 MW installed capacity by the end of 2004. To ensure grid conform operation German transmission grid operators released special requirements for renewable energy sources. Because wind turbines are providing a considerable part of the renewable energy the new requirements primarily focus on wind generators. The basic change in the rules concerns with the capability of wind turbines to remain connected to the grid during voltage dips caused by network faults. Beside this, it is required that wind turbines provide a back up voltage support and thus ensure proper operation of protective relays. Large offshore wind farms presuppose connection to the high voltage grid. Therefore, according to the German transmission grid operators they must fulfill requirements similar to that applied to conventional power plants. Further network studies have to be carried out for identification of network measures ensuring transmission of wind power within the grid.

IV. References

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V. Biographies

István 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.

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).