

Advanced requirements for thermal power plants for system stability in case of high wind power infeed

I. Erlich, *Senior Member, IEE*, J. Löwen, J. M. Schmidt, W. Winter

Abstract— This paper reveals requirements for generation units necessary to maintain system stability in the German power system penetrated by large scale integration of both onshore and offshore wind turbines and new thermal power plants concentrated in the north of Germany. Currently the installed wind turbine capacity is in the range of 20 GW but the sum of wind power infeed will increase with a large gradient.

Several thousand MW fossil fuel fired units located near the North Sea coastline are currently in the planning phase or even under construction. This concentration of synchronous machines leads to loss of stability margin in the case of severe short circuits near the large units.

Fast valving is a technology applicable to thermal units, involving rapid closing and reopening of steam valves. It is a proven and widely used technology which can be utilized in the new thermal power plants in Germany. With this technology, reduction of stability limit, resulting from a concentrated plant construction near the coasts, far from the huge load centers, can be equalized.

Index Terms - Grid Code, wind power, thermal power plants, fast valving, power system stability.

I. INTRODUCTION

THE Federal Government is significantly promoting the development of renewable energies and is aiming to expand them further. By 2010, the proportion of electricity consumption covered by renewable energies is supposed to rise to at least 12.5% and by 2020 to at least 20%. By 2050, further significant increase is expected. The efficient integration of wind power stations both on- and offshore and future thermal power plants in northern Germany into the electrical interconnected power system is necessary in order to achieve greater use of renewable energies. Due to this, investigations concerning the connection of new power

I. Erlich is with the University Duisburg-Essen, Germany (e-mail: istvan.erlich@uni-due.de).

J. Löwen is with E.ON Netz GmbH, Bayreuth (e-mail: Jakob.Löwen@eon-energie.com).

J. M. Schmidt is with E.ON Netz GmbH, Bayreuth (e-mail: JoergMichael.Schmidt@eon-energie.com).

W. Winter is with E.ON Netz GmbH, Bayreuth (e-mail: Wilhelm.Winter@eon-energie.com).

generation in the north of Germany and additional requirements not only for wind power generation and for new power plants but also for system security aspects in case of high transit flows from north to south are necessary.

The development of strict rules, involving a contribution to voltage stability by reactive power infeed in case of low voltage or requirement of the fault ride through ability simplifies the integration of wind power into the power system. In addition to the high wind power infeed in the north of Germany, many conventional power plants with a nominal power of several thousand MW are intended to be arranged near the coastline of North Sea. This concentration of conventional power plants and wind power infeed far the large load centers, in the middle and the south of Germany, may lead to stability problems in post-fault conditions in case of a failure near the synchronous machines. Caused by high active power infeed of the mechanical energy, stored during the voltage drop until clearing of the short circuit, a loss of synchronism may occur. In accordance to the process to adapt the behavior of modern generation units such as wind turbines started in 2001, new power plants have to support system stability of the future transmission grid.

II. WIND POWER DEVELOPMENT

Currently the installed wind turbine capacity is in the range of 20 GW, consisting only of onshore wind farms. The first offshore wind farm grid connection is expected in 2009 and the sum of wind power infeed will increase with a large gradient.

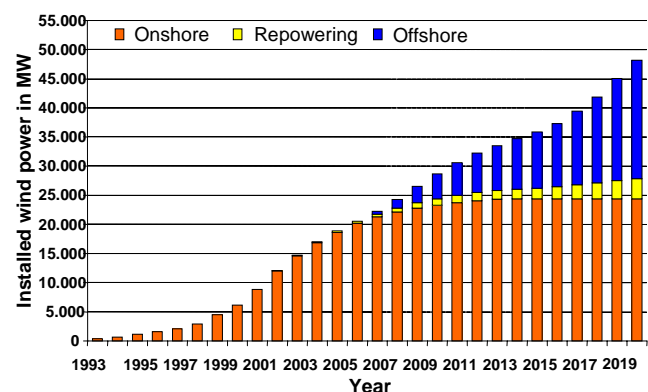


Fig. 1 Development of wind power utilization in Germany [1]

Detailed estimations of installed wind power capacity until 2020, split into onshore, onshore-repowering and offshore capacity developed in the DENA Grid Study 2005 [1] are shown in **Fig. 1**. Presently most of the wind turbines are connected to the medium voltage grid and onshore wind parks are connected to the 110kV grid, but the upcoming large offshore wind farms will be bundled and connected to the 380-kV network.

Beside the local concentration of wind power infeed in northern Germany, the huge power flows resulting in 2020 are shown in **Fig. 2**.

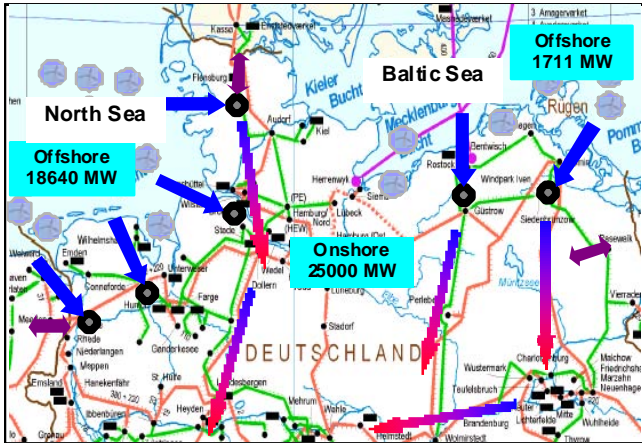


Fig. 2 Expected wind power generation by the year 2020 [4]

The final results of the DENA Grid Study 2005 [1] reveal that the integration of wind power into the German transmission system for the time horizon 2015 requires

- Extension of the transmission grid (850 km overhead lines)
- Advanced requirements for wind turbines
- Measures for reactive power compensation
- Measures for upgrading old wind turbine installations

The enhanced requirements for wind turbines were identified by the University Duisburg-Essen and released as grid code of E.ON Netz in 2006 [2] and fed into the Transmission Code 2007 [3].

III. GRID CODE

In Germany the first Grid Codes for wind turbines were introduced in 2003. The results of the DENA Grid Study, mentioned above, underline the need for updating the existing Grid Codes. Special focus is directed to the old wind turbines erected before 2003, which not capable of fulfilling the 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 [4].

The main concerns of the Grid Code [2, 4]:

- Keeping wind turbines connected to the grid during faults, recommended as Fault Ride-Through (FRT) requirement
- Even in case of tripping, wind turbines have to reconnect and continue power generation with short delay but with priority of voltage support
- Wind turbines have to provide ancillary services like voltage and frequency control with particular regard to island operation.
- Establishing intelligent system protection devices (safeguard)

Wind turbines have to withstand not only unbalanced faults but also three-phase short circuits near the grid connection node. **Fig. 3** shows this FRT requirement which allows a short time interruption (STI) depending on the time dependent voltage development.

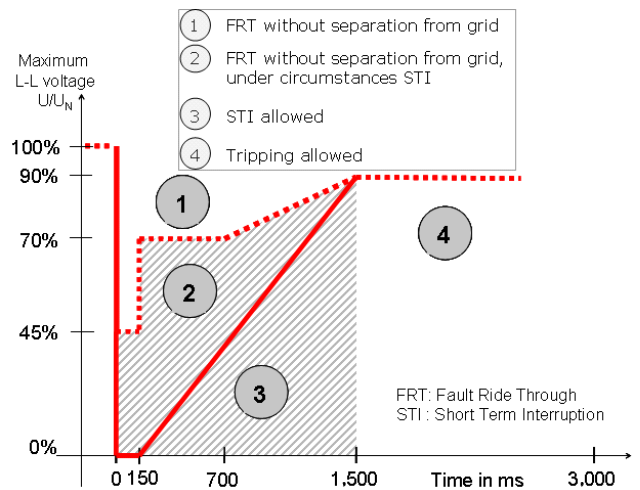


Fig. 3 Definition of FRT requirements [2]

Conventional synchronous generators are usually equipped with exciter and voltage control and they are able to supply high short circuit currents to the fault during considerable time intervals. High generator short circuit currents keep the voltage within the grid high and thus the low voltage area caused by the fault is reduced. In consequence, less consumer, wind turbines or other distributed generator units are affected. However, many conventional power plants will be replaced by wind power in the future. Therefore, wind turbines have to provide voltage support during faults and, to some extent, also during normal operation. According to the new Grid Code voltage support is required when the terminal voltage exceeds the dead band of 10% around the current operating point. The minimum reactive current/voltage gain required is 2.0 p.u. According to this, a reactive current of 1.0 p.u. will be supplied at voltages below 50%, shown in **Fig. 4**. Furthermore, the rise time required for this control is less than 20 ms [2] [4].

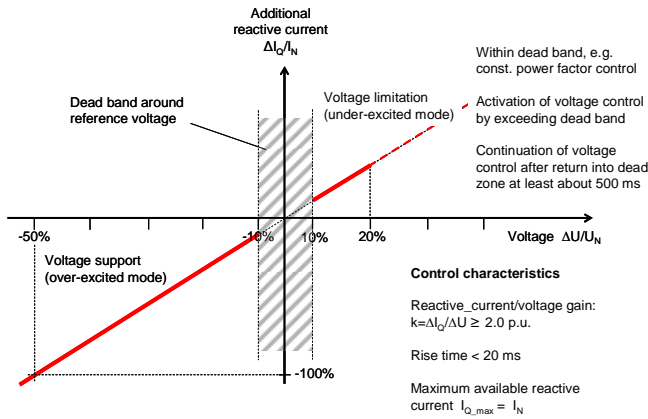


Fig. 4 Characteristic of voltage control [2]

Avoiding voltage collapse within the grid requires intelligent protection devices and schemes, which separate wind turbines selectively from the grid, even when their contribution to system behaviour is going to be adverse.

At least with the request for connection, wind farm operators have to provide evidence of the fulfilment of these requirements for their specific connection. For single wind turbines it may be sufficient to present a certificate, but large wind farms always need to be investigated by simulations which include steady state as well as dynamic studies. Besides, fulfilment of the grid requirements will be monitored continuously in the future [4].

Facing the beginning of the grid connection of large offshore wind farms, special connection rules for offshore wind farms to the onshore grid have just been issued [10].

IV. CONVENTIONAL PLANT DEVELOPMENT

Due to conventional power plant pool innovation in Germany expected during the next decades, several thousand MW fossil fuel fired units are currently in the planning phase. The majority of these power plants requesting to connect to the E.ON Netz control area are near the coastline. These sites enable a convenient supply of imported hard coal to be delivered by large cargo ships.

Fig. 5 gives an overview of the nodes with high concentration of hard coal fired plant projects near the North Sea coast in Germany and clearly shows that an overlap of offshore wind farm power flows with conventional unit power flow will occur.

Caused by high transit due to distance between renewable and concentrated conventional power generation in the north and the large loads in the south, the system stability limit is reduced. Despite the construction of new overhead lines and enhanced system performance of wind turbines, upgraded performance for thermal units becomes necessary.



Fig. 5 Areas of new power plants in E.ON Netz control area

If a severe short circuit occurs in northern Germany, more synchronous machines transients overlay and enhance the risk of losing synchronism. Thus, these stability measures in thermal units have to counteract the stability reduction in the region with concentrated infeed of thermal units.

V. FAST VALVING

The stability criterion focusing on accelerating power during fault and decelerating power after fault clearing is known as the equal area criterion. Regarding the P-δ-diagram of a synchronous machine, the mechanical power accelerating the machine unit (F_B) is set into relation to the decelerating power (F_V) after fault clearing. Fig. 6 shows transient performance of a unit after a 3-phase fault cleared before exceeding the critical clearing time with constant turbine power. Unstable performance of a unit is shown in Fig. 7. Due to the fact that accelerating area (F_B) exceeds decelerating area (F_V), the rotor angle exceeds the rotor angle stability limit (δ_{grenz}) and the generator gets further accelerated. [5]

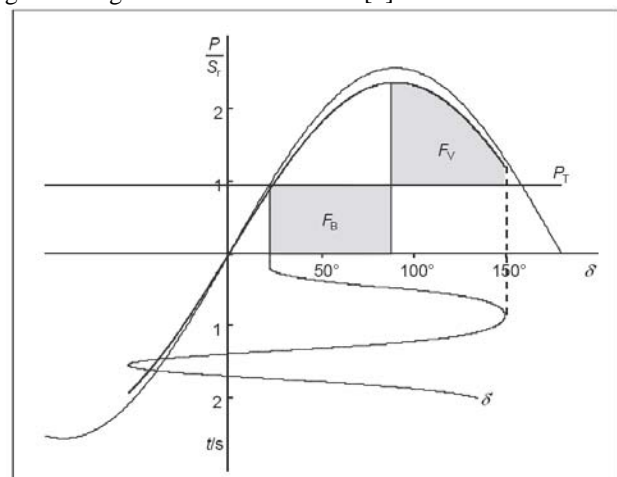


Fig. 6 Equal area criterion and stabil angle curve after 3-phase fault (stability limit) [5]

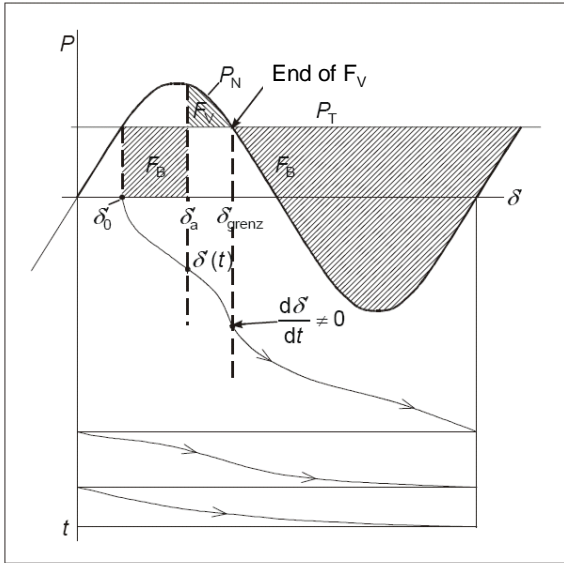


Fig. 7 Equal area criterion and instabil angle curve after 3-phase fault [5]

A proven method to maintain synchronism without generator tripping is the rapid reduction of mechanical power for a defined time period to keep the generator acceleration in an acceptable range, recommended as fast valving. The effect of fast valving on system stability is similar to the utilization of generator tripping or breaking resistors. Compared to other measures, implementation of fast valving in new power plants is relatively cheap. Although the effect of fast valving is significantly lower than generator tripping, fast valving can be preferred, regarding mid-term voltage and frequency stability in case of generator tripping.

Fast valving is a technology applicable to thermal units, involving rapid closing and opening of steam valves. Although the benefit of fast valving on power system stability has been known since the 1930, a deep technical discussion, publication of papers and the implementation of fast valving in power units has been started initially in the 1960 [6].

The activation of fast valving can be triggered by different measurement values like the relation of electrical power and mechanical power. Beside this, generator acceleration detection relays or a system automatic detecting severe disturbances or line-losses or can be applied.

Fast valving is acting directly on the steam valves by omitting the speed turbine control and enables a rapid control of the mechanical power produced by the steam turbine which is submitted to the generator. Thus, fast valving leads to a reduction of the accelerating power. A turbine model of a fossil fuel power plant including valves is shown in **Fig. 8** [6].

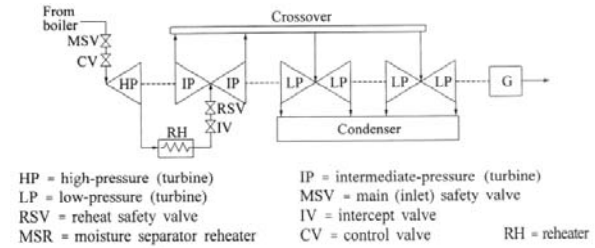


Fig. 8 Configuration of a tandem-compound single reheat steam turbine fossil-fuel unit [6]

If fast valving is realized only for the intercept valves, about 70% of the total unit power can be controlled. Larger power reduction can be obtained by integrating both main governor valves (control valves) and intercept control valves into the fast valving automatic [7].

To avoid a loss of synchronism caused by a deceleration, the duration of the steam interruption has to be adjusted. If the reopening time is adjusted too long, an enhancement of the backswing of the generator or a swinging of one generator against another may occur. Also the severity of the disturbance should be regarded by the fast valving controller to achieve a reaction, fitting to the triggering event [8]. A method combining rapid temporary reduction with a sustained reduction in turbine power is referred as *sustained fast valving* [6] and can be a useful selective reaction on a power system which is weaker due to tripping of network elements after fault clearing.

Detailed system studies aiming to adjust a fast valving controller for generator and system stability, including interactions of generators are required.

The impact of fast valving on system stability strongly depends on the speed of closing and reopening, which is determined by the governor system utilized. A common practice is the utilization of fast-acting hydraulic valves arranged to dump oil from spring-loaded actuating cylinders of the intercept and control valves. This facilitates rapid valve closure in 0.08 to 0.4 seconds. Reopening of the valves after rapid closure is delayed for approximately 0.3 to 1.0 seconds due to restoration of oil to the hydraulic cylinder. Reopening time usually is in the range of 3 to 10 seconds. If applications require faster reopening, special technology with hydraulic accumulators can be applied [6].

The nuclear power plant Olkiluoto/Finland is one of the latest examples of an utilization of fast valving. At EPR (European pressurized water reactor) Olkiluoto generating unit FIN 5 with a nominal active power of 1600MW, the stability margin after severe faults will be enhanced by fast valving.

VI. SIMULATION RESULTS

For the calculation with the PSS/NETOMAC software tool, an IEEE Controller model using fast valving is implemented. Fig. 9 and Fig. 10 show the block diagram of TGOV 3 and the valve position after triggering fast valving. With TGOV3 triggering of fast valving depends on the relation of electrical power and mechanical power of the generator and takes place when a limit of deviation between electrical and mechanical power is exceeded.

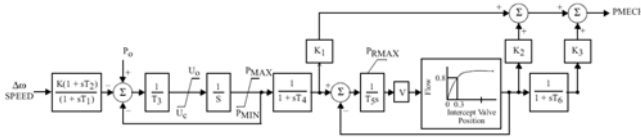


Fig. 9 Block diagram of IEEE Governor TGOV3 [9]

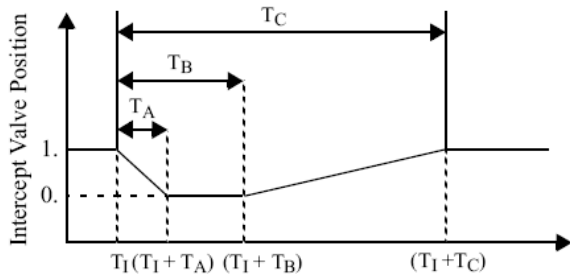


Fig. 10 Valve position after triggering fast valving [9]

Calculations have been conducted with plant models connected to a grid equivalent, with a model containing the area from North Sea coast to large loads centers in the center and south of Germany and with an dynamic UCTE model.

Diagrams presented in Fig. 11 show the electrical power of the generator and the rotor angle of a hard coal fired thermal unit without fast valving after a three phase fault near the connection point. During the calculations shown in Fig.12 fast valving is activated and triggered when the deviation between electrical and mechanical power exceeds 0.6. In addition to the values mentioned before, mechanical power submitted to the generator and valve position are also plotted.

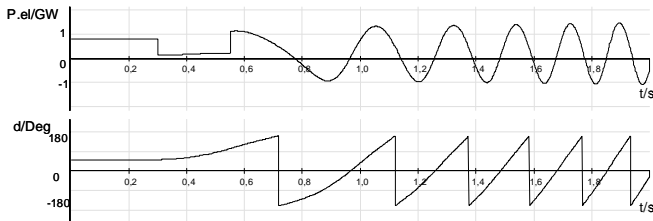


Fig. 11 Diagram of plant quantities after severe disturbance with constant turbine moment

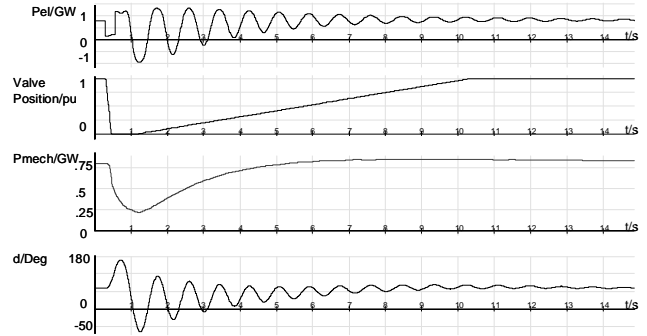


Fig. 12 Diagram of plant quantities after severe disturbance with fast valving controller TGOV 3

VII. CONCLUSIONS

Foreseeable developments in the German power grid during the next years lead to further requirements for conventional power plants to avoid system instability after severe faults occurring near the region with high concentration of power plants. A voltage drop in case of a short circuit influences many plants concentrated in the north of Germany. Transients occurring during heavy load on transit lines may cause a loss of stability and synchronism. This loss of stability arises from the transients of the conventional power plants in combination with the loss of a network element after fault clearing. To integrate the new power plant projects without a decrease in stability of the generators and the interconnected system, a reduction of transients without post-fault disconnection is necessary.

Calculations confirm the need of further measures to maintain system stability to avoid a reduced stability margin and the risk of losing stability.

Fast valving is a proven and widely used technology which can be utilized in the new thermal power plants in Germany. With this technology, reduction of stability limit, resulting from a concentrated plant construction near the coasts far from the huge load centers can be equalized.

VIII. REFERENCES

- [1] Deutschen Energie-Agentur GmbH (dena) „Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020“ Germany 2005
- [2] Netzanschlussregeln Hoch- und Höchstspannung, E.ON Netz GmbH April 2006
- [3] „TransmissionCode 2007“ Netz- und Systemregeln der deutschen Übertragungsnetzbetreiber, 2007
- [4] I. Erlich, W. Winter, A. Dittrich “Advanced Grid Requirements in Germany on Connecting and Operation of Wind Turbines in Power Systems” IEEE summer meeting Montreal 2006
- [5] B.R. Oswald „Skript Stabilität“ Institut für Energieversorgung und Hochspannungstechnik Universität Hannover, 2005
- [6] P. Kundur „Power System Stability“, McGraw-Hill Inc., 1993

- [7] J. Machowski, A. Smolarczyk J. W. Bialek "Power System transient stability enhancement by co-ordinated fast valving and excitation control of synchronous generators" CIGRE Symposium "Working Plants and Systems Harder", London, 7-9 June 1999, paper 200-06
- [8] R. Patel, K. V. Pagalthivarthi "Artificial neural networkbased turbine fast valving for enhancement of Poser System transient stability" Journal of ELECTRICAL ENGINEERING, VOL. 57, NO. 1, 2006, 3-11
- [9] PSSE "Program operation manual" Power Technology Inc.
- [10] Anforderungen an seeseitige Netzanschlüsse an das Netz der E.ON Netz, Stand 01.04.2008

development of the NETOMAC Eigenvalue Analysis program. Since 2000 he has been working at E.ON Netz, responsible for system studies, system dynamics and the integration of large scaled wind power.

IX. BIOGRAPHIES



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.



Jakob Löwen (1950) received his Dipl.-Ing degree in Power systems and grids from University of Moscow/ Russia in 1977. After his studies, he worked in Russia for SO EES (System operator IPS/UPS) as an engineer, responsible for Protection and emergency control automatics in high voltage grids from 1977 to 1991. Since 1994 he has been working as grid planning engineer at Bayernwerk AG and E.ON Netz GmbH, Germany. He is responsible for power system stability, short circuit calculations, unsymmetrical faults, neutral-point connection and the development of the grid code for

wind turbines.



Jörg Michael Schmidt (1982) received his Dipl.-Ing degree in Power Systems Engineering from the Clausthal University of Technology (Germany) in 2007. During his diploma thesis he investigated on System Automatics in HV and EHV grid to avoid voltage collapses. Since 2007 he has been working at E.ON Netz GmbH, Germany as Grid Planning Engineer. Beside grid connection of new conventional power plants, he is responsible for dynamic modelling, simulation of transient

phenomena and power system stability.



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