Overview of German Grid Issues and Retrofit of Photovoltaic Power Plants in Germany for the Prevention of Frequency Stability Problems in Abnormal System Conditions of the ENTSO-E Region Continental Europe

Jens. C. Boemer[1], Karsten Burges[1], Pavel Zolotarev[2], Joachim Lehner[2], Patrick Wajant[3], Markus Fürst[3], Rainer Brohm[4], Thomas Kumm[5]

***Abstract*-- In recent years, electricity production from distributed renewable energy generators in Germany increased significantly due to the German Renewable Energy Sources Act. Photovoltaic power plants have shown the highest growths rates in 2009 and 2010. About two thirds of photovoltaic power plants in Continental Europe are connected to low voltage networks. Related grid codes allow for distributed generation only to operate within frequency ranges that are in many cases extremely close to nominal frequency. At an abnormal system condition the frequency of a region may increase above those thresholds and distributed generators would disconnect within immediately. The paper investigates the related potential frequency stability problem and analyses mitigation measures.**

***Index Terms*—distributed generation, frequency stability, photovoltaic power plants, power systems, retrofitting**

I. Introduction

Recent years have seen a great increase in renewable energies in Germany, particularly through the promotion of the Renewable Energy Sources Act (EEG) [1]. By the end of 2010, for example, approximately 80% of cumulative installed photovoltaic (PV) capacity, i.e. about 14 GW, was connected on the low voltage level (Fig. 1). PV power plants with a rated capacity of up to 10 kWp accounted for about 50% of all low-voltage connected PV power plants put into operation in the recent years. However, these plants contributed only 10-15% of the annual PV capacity installed (Fig. 2). The boom of PV in Germany was related to economies of scales in the production of PV power plants which allowed for more than 50% decrease of the respective feed-in tariffs in the years 2005-2011 (Fig. 3).

The grid integration challenges for PV in Germany are:

- Upgrading and extension of distribution networks
- Maintenance of frequency stability
- Real-time control of PV power plants ≤ 100 kWp

The paper is based on a study that was jointly commissioned by the four German transmission system operators (Amprion, TenneT, 50 Hertz Transmission, and EnBW Transportnetze), the German Solar Industry Association (Bundesverband Solarwirtschaft, BSW) and the Network Technology and Operation Forum of VDE (Forum Netztechnik/Netzbetrieb, FNN).

[1] J. C. Boemer and K. Burges are with the Power Systems and Markets group at Ecofys Germany GmbH, Stralauer Platz 34, D-10243 Berlin, Germany (e-mail: J.Boemer@eocfys.com, K.Burges@ecofys.com).

[2] P. Zolotarev and J. Lehner are with the Institute of Combustion and Power Plant Technology (IFK) at the University of Stuttgart, Pfaffenwaldring 23, 70569 Stuttgart, Germany (e-mail: pavel.zolotarev@ifk.uni-stuttgart.de, joachim.lehner@ifk.uni-stuttgart.de)

[3] Patrick Wajant and Markus Fürst are with EnBW Transportnetze AG, Ohmstraße 4, D-73240 Wendlingen, Germany (e-mail: p.wajant@enbw.com, m.fuerst@EnBW.com).

[4] Rainer Brohm is with the German Solar Industry Association (Bundesverband Solarwirtschaft e.V., BSW-Solar), Stralauer Platz 34, D-10243 Berlin, Germany (e-mail: brohm@bsw-solar.de, www.solarwirtschaft.de)

[5] Thomas Kumm is with Network Technology and Operation Forum of VDE (FNN), Bismarckstr. 33, D-10625 Berlin, Germany (e-mail: thomas.kumm@vde.com).

II. Background and Characteristics of the Study

This paper focuses on the frequency stability challenge. With the installation of distributed generation (DG), these power plants and the power distribution system have gained an increasing relevance for transmission network operations.

Before a transitional arrangement was introduced by the VDE|FNN e.V. in April 2011 [4] along with the associated equipment standards alteration of DIN V VDE 0126-1-1 [5], low voltage generation plants were required to be switched off immediately if system frequency increased to 50.2 Hz [6]. This requirement was introduced in 2005/2006 when the generation of electricity from PV systems still proved to have a negligible influence on the electrical system. Since, PV systems with a cumulative capacity of at least 12,700 MW connected at low voltage level have been installed.

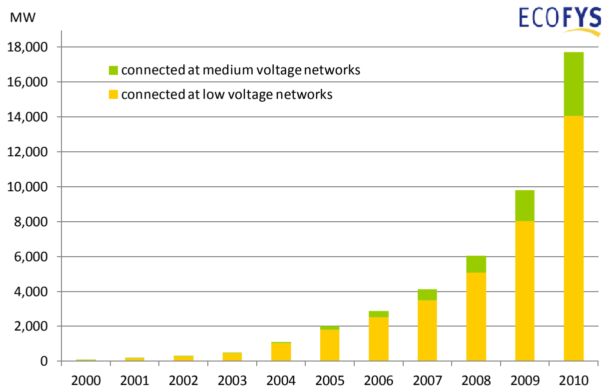

Fig. 1. Cumulative installed PV capacity in Germany 2000-2010 differentiated by voltage levels. Source: [2], [3]

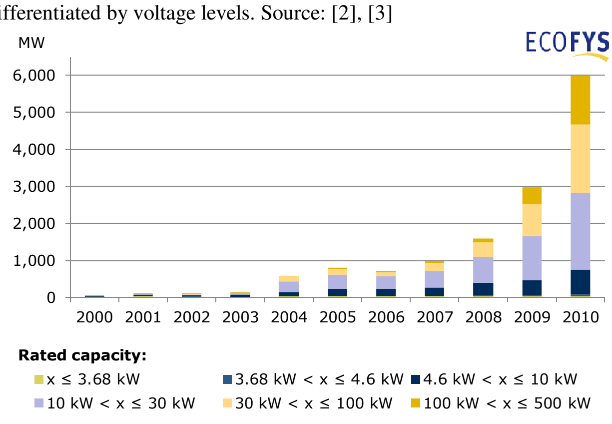

Fig. 2. Annual installed low voltage connected PV capacity in Germany 2000-2010 differentiated by rated power plant capacity. Source: [2], [3]

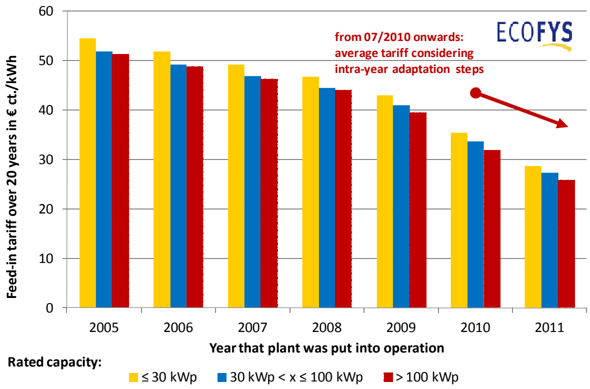

Fig. 3. Development of feed-in tariffs for PV power plants in Germany 2005-2011.

In a worst case scenario, up to about 9,000 MW[1] of power from PV systems would disconnect from the network if system frequency increased to 50.2 Hz. Reaching a system frequency value of 50.2 Hz during normal operations is as yet quite unlikely (Fig. 4). However, future energy trade will likely become increasingly important, and with it the hourly occurring deterministic frequency deviations up to values of about 50.1 Hz. If the market trading schedule is not shortened from 60 min. to, for example, 15 min., the frequency deviations will increase at the hours, moving closer to approaching the critical threshold of 50.2 Hz [7].

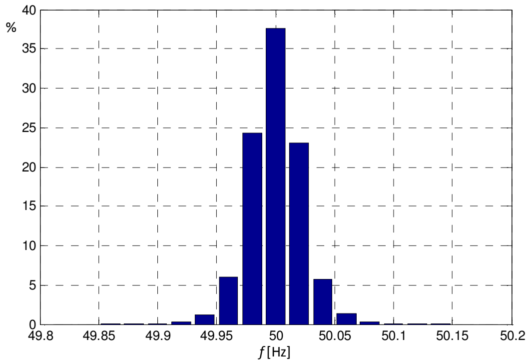

Fig. 4. Histogramm of network frequency in Continental Europe in 2010. Source: IFK

Any unexpected large-scale disturbance followed by an abnormal system condition would today, however, already pose significant risks. In such a case, the frequency would increase *due to an oversupply of electrical power* in those regions that exported to other networks before the occurrence of the disturbance. An example of this is the European power grid failure in 2006 [8] and the blackout in Italy in 2003 [9]. In both cases, Germany belonged to an exporting network region in which the frequency value increased to 50.2 Hz. The European grid is only designed for a sudden loss of 3,000 MW of generating capacity. If similar disturbances were to occur on sunny days with the current PV capacity during high supply from those PV systems, then their power infeed would be lost. Already today, PV systems in Germany exceed the value of 3,000 MW by several times on sunny days.

[1] assumed 70% coincidental in-feed from 12,700 MW relevant capacity

Thus, there is a high probability of a large-scale failure to the electrical supply in those parts of Europe that would be affected by this phenomenon.

With this in mind, it is necessary to take measures for reducing the impact on network operations and network stability in case of higher frequency levels:

- Short-term measure for new plants: transitional rules for PV systems (from April 2011 until VDE-AR-N 4105 has been enforced) [4]
- Medium-term measure for new plants: requirements for generation facilities in accordance with VDE-AR-N 4105 (the latest from 1.1.2012) [10]
- Medium-term measure for PV existing systems: retrofitting (probably between the years 2012 and 2014)

The short- and medium-term measures for new plants on the low voltage network are already under the technical rules set by the Forum network technology/network operation in the VDE Association (VDE|FNN). The medium-term measures to upgrade existing facilities that are already in operation can only be defined through the statutory regulatory framework.

A joint initiative comprised of the four German transmission system operators (TSO), the distribution network operators, the German Solar Industry Association (BSW-Solar), including representatives of various PV inverter manufacturers and the VDE|FNN has been working together toward the development of a sustainable solution to these existing facilities since 2010. This initiative is framed within the system security working group of the 'platform for future networks' by the Federal Ministry for the Environment (BMU), the Federal Ministry of Economics and Technology (BMWi) and the Federal Network Agency (BNetzA). The European Network of Transmission System Operators for Electricity (ENTSO-E) also gives priority to finding a solution in order to guarantee stable operation of the Continental Europe (CE) network region [11].

The consulting firm Ecofys and the Institute of Combustion and Power Plant Technology (IFK) at University of Stuttgart have been commissioned by the joint initiative accompanied by BMWi, BMU and the Federal Network Agency to investigate whether and to what extent a technical upgrade of PV equipment inventory is necessary and possible. The VDE|FNN also initiated the additional investigation of the impact that a retrofit of existing PV installations would have on distribution network operations, examining in particular the temporary operation of sub-networks with so-called emergency standby power systems.

The results and recommendations presented in section III and IV are of particular relevance, given the fact that from April to May 2011, Ecofys conducted a broad industry survey involving the distribution network operators, the manufacturers of inverters for PV systems, the manufacturers of emergency standby power systems, and the manufacturers, designers and operators of wind turbines and installers.

III. Results

The fundamental results of the study conducted by Ecofys and IFK shows that it is indeed necessary to retrofit a significant proportion of the existing PV plants which switch off when system frequency increases to 50.2 Hz.

A. *Countries and energy sources concerned*

The analysis has shown furthermore that also other DG, e.g. wind power plants, and especially other countries in Continental Europe, e.g. Denmark, Italy and maybe also Belgium, France have to take comparable measures in the future. An overview on the over- and under-frequency thresholds in those countries is shown in Fig. 5 and differentiated by energy source in Fig. 6. Besides over-frequency values, also adaptation of under-frequency values of DG are necessary: especially since loss of generation would worsen the power imbalance in these cases.

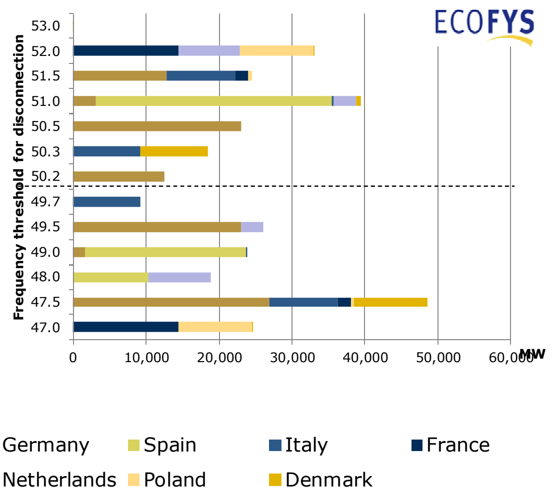

Fig. 5. Over- and under-frequency thresholds and corresponding installed generation capacity in seven countries of CE. Source: EUROSTAT, energymap.info, CNE.es, own investigations & assumptions.

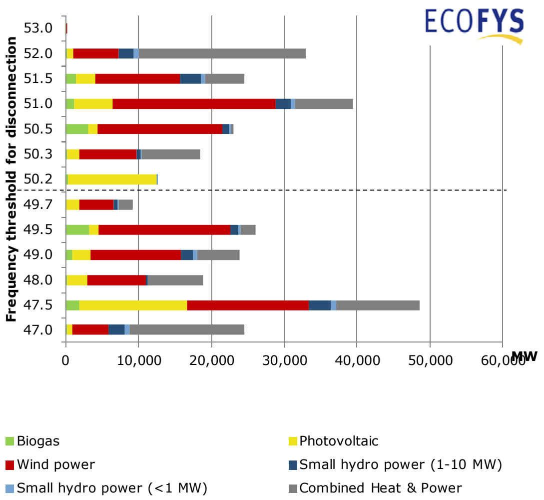

Fig. 6. Over- and under-frequency thresholds and corresponding installed generation capacity in seven countries of CE differentiated by energy source. EUROSTAT, energymap.info, CNE.es, own investigations & assumptions.

B. *Analysis of existing PV power plant registry*

The analysis of the assumptions and outcomes of the system modeling studies performed by IFK has shown that a remaining installed capacity of concerned PV power plants of 3,500 MW in Germany is acceptable. Based on the publicly available PV power plant registry [2], [3] a sensitivity analysis was performed (Fig. 7).

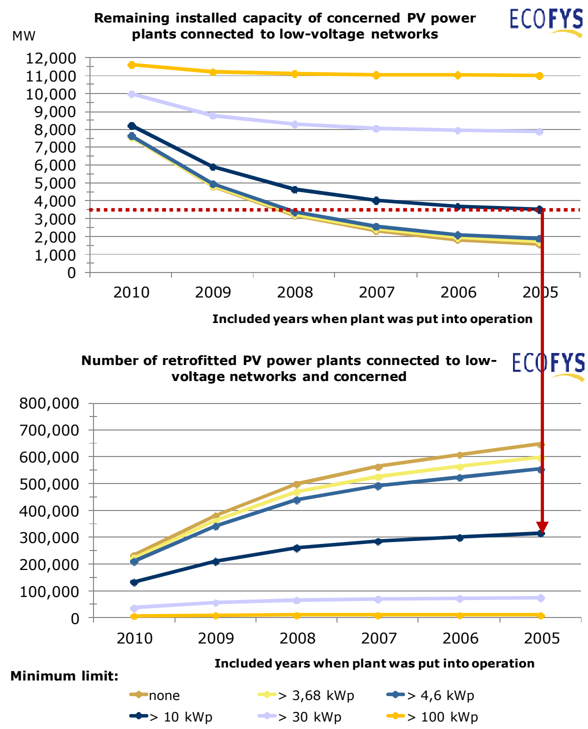

Fig. 7. Sensitivity analysis of remaining installed capacity and number of retrofitted concerned PV power plants connected to low-voltage networks. Source: [2], [3] and own investigations & assumptions.

C. *Technical analysis*

The technical analysis has shown three viable solutions for retrofitting of the concerned DG (Fig. 8):

- **Option I:** Update to VDE|FNN application guide VDE-AR-N 4105; power-frequency characteristic without hysteresis, reconnection when frequency stays below 50.05 Hz for more than 60 seconds;
- **Option II:** Update to BDEW technical guideline generating plants connected to the medium-voltage network; power-frequency characteristic with hysteresis, reconnection when frequency stays below 50.05 Hz;
- **Option III:** Parameter change according to VDE|FNN technical instruction on a temporary arrangement for PV systems; disconnection and reconnection at the same frequency value, stochastically distributed, reconnection when frequency stays below such value for more than 30 seconds.

Depending on the PV inverter type, at least one of these options can be used without the need to replace the inverter. Options I and II can be implemented by updating the inverter's firmware or replacing its EPROM. Options III requires the change of a software parameter.

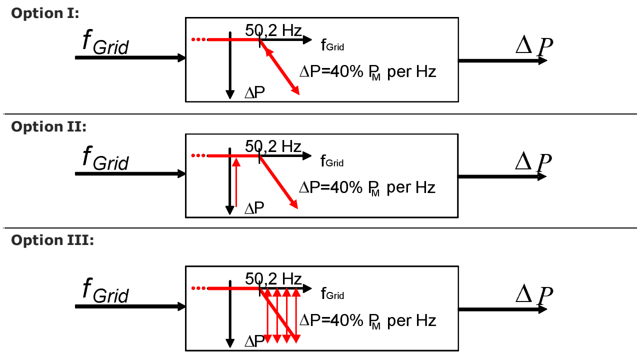

Fig. 8. Viable solutions for retrofitting based on [4], [10] and [12].

While the differences between Option I and II are small, implementation of Option III in large-scale would have significant impact on the operation of so-called emergency standby power systems. These systems are used during maintenance of distribution feeders and substations, which occur about every two years.

The secure operation of these systems requires a disconnection of DG. This is traditionally achieved by increasing the electrical frequency of the supplied feeder to a value above the over-frequency protection setting of those DG (i.e. 50.2 Hz) and keeping it at about 50.5 Hz.

Due to the nature of Option III, according to which the DG would reconnect when the frequency stays below the disconnection frequency value for more than 30 s, the previously described operational approach becomes obsolete.

D. *Economical analysis*

The economical analysis has been based on industry consultations with manufacturers of PV inverters. A sensitivity analysis was performed for two different minimum limits of the installed PV power plant capacity (Fig. 9).

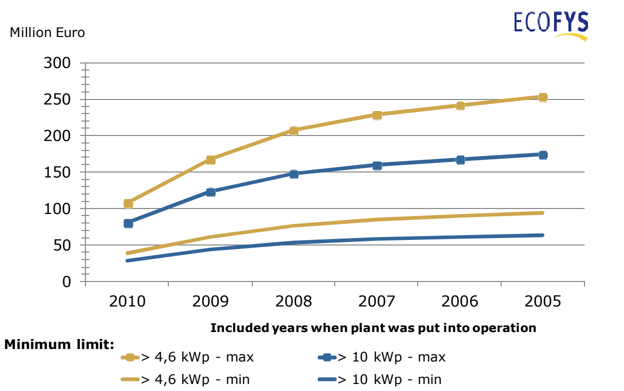

Fig. 9. Sensitivity analysis of costs related to the retrofitting of concerned PV power plants connected to low-voltage networks. Source: [2], [3] and own investigations & assumptions.

IV. Summary of Recommendations

It is recommended that all PV systems be retrofitted:

- which began operating after 01.09.2005 and
- which are larger than 10 kWp.

It is recommended that, in view of the different retrofitting solutions,

- the concerned PV power plant operators should have the liberty to choose among the following options (Fig. 8)
  - Option I: Update to VDE|FNN application guide VDE-AR-N 4105 [10],
  - Option II: Update to BDEW technical guideline generating plants connected to the medium-voltage network [12] or
  - Option III: Parameter change according to VDE|FNN technical instruction on a temporary arrangement for PV systems [4];
- the following order of priority is recommended: Option I comes before Option II, and this precedes Option III; a replacement of the inverter should be avoided in all cases.

It is recommended that, in compliance with the order of priority for the inverter retrofit,

- the inverter manufacturer should be required to create recommendations for their products, and
- the electrical installers should be required to comply with these recommendations when retrofitting PV systems.

In order to guarantee a swift upgrade, it is recommended to aim for a high level of acceptance of the retrofit measures. To provide such high acceptance levels, appropriate legal provisions should be developed.

Based on discussions with distribution network operators, manufacturers of inverters for PV systems and the electrical trades, a procedure for retrofitting existing PV installations was proposed. This procedure should be streamlined in cooperation with the federal network agency (BNetzA).

V. Summary of Impact

A full implementation of the above recommendations would lead to the following effects:

- Approximately 315 000 PV systems (> 10 kWp) must be retrofitted.
- The effort required for electrical technicians to implement this would limit the number of retrofits to about 8,500 ... 11 000 per month.
- The total cost for the retrofitting of the PV systems is estimated between € 65 million ... 175 million, plus associated administrative costs from inverter manufacturers and distribution network operators.
- The total cost of adapting the operation of emergency standby power systems is expected to be approximately € 500 thousand … 2 million.

VI. Overview of Further Necessary Coordination in the Course of the Retrofits

BNetzA - Distribution Network Operators

- Establishing federal BNetzA standard letters and forms;
- (Fixed) levies for the administrative costs incurred at the Distribution Network Operators;
- Timed requirements for adapting the emergency standby power system operations.

PV Inverter Manufacturers - Distribution Network Operators - TSOs

- Values of over-frequency protection;
- Upper and lower limit of the frequency range for over-frequency protection;
- Defined increment for over-frequency protection values;
- Stochastic distribution of the respective cut-off frequencies;
- Values of *under*-frequency protection (!).
- Time for reconnection delay, preferably longer than the 30 seconds (options II and III) or 60 seconds (option I).

PV Inverter Manufacturers - Electrical Installers

- Information;
- Retrofitting Instructions.

VII. Overview of Further Actions Required

In addition to the necessary retrofit of PV installations in Germany, the following actions are also required:

- for the German Wind Energy Association (BWE) and Verband Deutscher Maschinen- und Anlagenbau - German Engineering Federation (VDMA): The under-frequency protection values of wind-turbines should be adapted by the power plant operator from a value of 49.5 Hz to 47.5 Hz at best or, alternatively, 48.0 Hz at the next regularly scheduled maintenance;
- for European Network of Transmission System Operators for Electricity (ENTSO-E): The over- and under-frequency protection of distributed generation plants should also be adapted in Denmark and Italy, and maybe also in other countries of the Continental Europe network region, e.g. Belgium and France;
- for ENTSO-E: The values of under- and over-frequency protection of generating facilities should be made to harmonize throughout all continental European countries.

VIII. Further Reading

For further reading refer to the executive summary of the study “Impact of Large-scale Distributed Generation on Network Stability During Over-Frequency Events and Development of Technical Mitigation Measures” by Ecofys and the Institute of Combustion and Power Plant Technology (IFK) at University of Stuttgart, available online [in German] at http://www.ecofys.com/documents/2011-09_Ecofys_IFK_50-2-Hz_Kurzfassung.pdf.

IX. References

[1] German Parliament (2008): Act Revising the Legislation on Renewable Energy Sources in the Electricity Sector and Amending Related Provisions – Renewable Energy Sources Act – EEG 2009. In *Federal Law Gazette* I (49), pp. 2074-2100.

[2] Deutsche Gesellschaft für Sonnenenergie (DGS) e.V. (2011): EnergyMap.info. Database for renewable energy power plants in Germany. Available online at http://energymap.info/, updated on February 2011.

[3] Federal Network Agency (2011): EEG feed-in tariffs for PV systems. Plant registry. Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway. Available online at http://www.bundesnetzagentur.de/cln_1912/DE/Sachgebiete/ElektrizitaetGas/ErneuerbareEnergienGesetz/VerguetungssaetzePhotovoltaik_Basepage.html?nn=135464, checked on 20/05/2011.

[4] FNN (2011): Technical instruction on a on a temporary arrangement for PV systems for frequency-dependent active power reduction by PV systems connected to low-voltage networks. Forum network technology / network operation (FNN) in the VDE e.V. Berlin. Available online at http://www.vde.com/de/fnn/dokumente/documents/fnn_hinweis_uebergangsloesung-50-2hz_2011-03.pdf, checked on 27/04/2011.

[5] Prestandard DIN V VDE V 0126-1-1/A1, Juni 2011: Automatic disconnection device between a generator and the public low-voltage grid, checked on 27/04/2011.

[6] Prestandard DIN V VDE V 0126-1-1, February 2006: Automatic disconnection device between a generator and the public low-voltage grid, checked on 17/05/2011.

[7] Weißbach, T.; Welfonder, E. (2011): Große Frequenzabweichungen im europäischen Verbundnetz (large frequency deviations in the European interconnected power system). Teil 1: Leistungsungleichgewicht im Strommarkt (part 1: power imbalance in the power market). In *Ew* 110 (5), pp. 36–40.

[8] UCTE (2007): System Disturbance on 4 November 2006. Final Report. union for the co-ordination of transmission of electricity. Brussels. Available online at https://www.entsoe.eu/fileadmin/user_upload/_library/publications/ce/otherreports/Final-Report-20070130.pdf, updated on 29/01/2007, checked on 3/07/2011.

[9] UCTE (2003): Final Report of the Investigation Committee on the 28 September 2003 Blackout in Italy. union for the co-ordination of transmission of electricity. Brussels. Available online at https://www.entsoe.eu/fileadmin/user_upload/_library/publications/ce/otherreports/20040427_UCTE_IC_Final_report.pdf, updated on 28/04/2004, checked on 3/07/2011.

[10] VDE Application Guide VDE-AR-N 4105, 1/08/2010: Generators in the low voltage distribution network. Application guide for generating plants’ connection to and parallel operation with the low-voltage network. Available for purchase at http://www.vde.com/de/fnn/arbeitsgebiete/seiten/n4105.aspx.

[11] entso-e (2011): Open letter to Commissioner Oettinger: Automatic frequency disconnection settings of installed photovoltaic (PV) panels in some European countries. European Network of Transmission System Operators for Electricity (ENTSO-E). Brussels. Available online at https://www.entsoe.eu/fileadmin/user_upload/_library/publications/ce/110718_DD_to_COett_pv_final.pdf, checked on 12/09/2011.

[12] Bartels et al. (2008): Technical Guideline Generating Plants Connected to the Medium-Voltage Network. Guideline for generating plants’ connection to and parallel operation with the medium-voltage network. BDEW Bundesverband der Energie- und Wasserwirtschaft e. V. (German association of energy and water industries).

X. Biographies

Jens Bömer received his Dipl.-Ing. in Electrical Engineering from Technical University of Dortmund, Germany in 2005. He specialised on power systems and renewable energies. He supported the German Environment Ministry in the drafting of the Ancillary Services Ordinance for wind power plants (SDLWindV) and developed an operational strategy for the Irish transmission system operator EirGrid/SONI with regard to very high instantaneous shares of wind power in the All Island Power System. Since September 2007 he works as a Consultant in the Power Systems and Markets Group at the Ecofys office in Berlin. He is also Ph.D.-candidate with the Electrical Power Systems group, Electrical Sustainable Energy Department at Delft University of Technology.

Karsten Burges combines a PhD in electrical engineering from the Technical University of Magdeburg (Germany) with a Masters degree in Environmental Management from the University of Amsterdam (The Netherlands). Since joining the renewable energy consultant Ecofys in 1992, Dr. Burges has been focusing on integration of renewable energy sources and technologies in electrical power systems.

Pavel Zolotarev received his Dipl.-Ing. in Technical Cybernetics from University of Stuttgart, Germany in 2007. Since 2008 he works as a research scientist at the Institute of Combustion and Power Plant Technology (IFK) at the University of Stuttgart. The main focus of his research is the optimisation of procurement and activation of ancillary services with respect to technical and regulatory constraints.

Joachim Lehner received his diploma in mechanical engineering from the University of Stuttgart in 2005. Since graduation he is a researcher at the Institute of Combustion and Power Plant Technology (IFK) at the University of Stuttgart. Since 2010 he is head of the department "Power Generation and Automatic Control". His main research is focused on power system stability issues and the integration of renewable and decentralised power generation into the grid.

Patrick Wajant is operation planning engineer with EnBW Transportnetze AG. He is responsible for the assessment and optimization of the daily operation planning processes, e.g. Day Ahead Congestion Forecast (DACF). His special interest is in the network operation with increasing volatile generation from renewable energies. Mr Wajant holds a diploma in electrical and informational technology from University of Stuttgart.

Rainer Brohm is director for governmental affairs at the German Solar Industry Association in Berlin. He is heading several projects to develop the regulatory framework for the promotion and integration of solar energy in Germany. In this context Mr. Brohm is furthermore engaged in the development of guidelines and policy measures for the grid integration of photovoltaic power systems. Before joining the German Solar Industry Association he worked for several years as political advisor in different German and European institutions. Mr. Brohm studied political science and international relations in Berlin and Amsterdam and received his Masters degree in 2002.

Thomas Kumm has studied electrical engineering at Technical University of Berlin (Germany) focusing electrical power transmission and distribution. He received a PhD on High Voltage cable diagnostics. Dr. Kumm joined the Association of German Network Operators (VDN) in 2006, since June of 2008 he works as technical manager at the Network Technology and Operation Forum of VDE (FNN). He deals with technical codes aimed to a secure and reliable grid operation.