

Participation of Distributed Generation in Balance Management

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Abstract—Distributed generation is not yet considered to participate in balance management in power systems. Low marginal costs and poor predictability make them less attractive for this application. However, further integration of distributed generation will make participation in balance management a necessity both for down regulation as well as up regulation. The potential of different distributed generators to participate in balance management is analysed. Economic and regulatory boundaries are discussed, as well as improvements to create incentives for distributed generators to participate.

Index Terms—Distributed generation, Energy storage, Frequency control, Power control, Power generation economics.

I. NOMENCLATURE

$E(\Pi)$	Expectation of profit
Π_s	Profit resulting from production
Π_{r+}	Profit resulting from production of positive reserve power
Π_{r-}	Profit resulting from production of negative reserve power
C	Production costs
r^-	Probability for providing negative reserve capacity (surplus)
r^+	Probability for providing positive reserve capacity (shortage)
λ	Electricity price
λ_{r-}	Price for negative reserve capacity
λ_{r+}	Price for positive reserve capacity
P_t	Total production capacity
P_s	Production capacity for normal production
a, b, c	Constants for the 2 nd order cost function

II. INTRODUCTION

The introduction of poorly predictable distributed generators makes it more difficult to maintain the balance between supply and demand in power systems. In the past, distributed generators were considered as negative loads. However, as their share in total production becomes significant, this approach can not be retained.

Distributed generation (DG) differs from conventional generation since the production is, in most cases, not driven

by the demand for electricity, but by meteorological conditions (wind power and photovoltaic power), or by demand for heat as in combined heat and power (CHP) units. This increases complexity to match consumption and production. To continuously balance supply and demand, ancillary services for balance management are defined. This ancillary service exists next to the other ancillary services, such as for reactive power support and black start capability.

Whenever there is imbalance in a power system, the frequency will start deviating from its nominal value. This activates both primary and secondary control. These control mechanisms stabilise frequency variations and restore the frequency to its nominal value. Currently, distributed generators do not participate in primary control, nor in secondary control. Balance is restored only by conventional generators. However, as the share of DG in production increases, their participation in balance management will become necessary [1].

This paper discusses the need of DG to participate in ancillary services for balance management. Section 3 elucidates on balance management and the different control strategies that exist for this. Section 4 is about the development of DG. Section 5 discusses the technical potential of different distributed generators to participate in balance management. Per type of DG it will be explained how to participate in balance management. The economic incentives for DG to participate in balance management and the effect of subsidies are explained in section 6. Improvements in the regulatory framework to improve or increase these incentives are mentioned in section 7. The conclusions of this article are given in section 8.

III. BALANCE MANAGEMENT

Currently, most of the electricity is generated by large (> 60 MW) synchronous generators. The frequency of the grid is set by these rotating machines. As long as the supply and demand of electricity are in balance, the frequency of the grid will remain nominal. However, any imbalance between the supply and demand will be compensated by changing the stored kinetic energy of the rotating machines and therefore leads to a frequency deviation. Frequency deviations should remain within certain limits to avoid blackouts or damaged equipment. To ensure this, ancillary services for balance management have been introduced. In the UCTE interconnection, these ancillary services consist of primary, secondary, tertiary, time control and scheduling and accounting. More details about this are given in [2] and [3].

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– Primary Control

Primary control is performed decentralised. Each participating generator has a proportional controller which increases the power output of a generator if the frequency is below the nominal value. Vice versa, the power output will be decreased if frequency is above the nominal value. Primary control acts fast (within 30 seconds), stops the frequency deviation and holds the frequency at a commonly called quasi-steady-state frequency deviation. Participation in primary control can be either obliged or stimulated with economic incentives [4].

– Secondary Control

After primary control stabilises the frequency, secondary control restores the frequency from its quasi-steady-state frequency deviation to its nominal value. Therefore secondary control is based on a proportional integral controller activated per control zone. Secondary control is slower (within 900 seconds) than primary control and in liberalised markets based on a market for control power [4].

– Tertiary Control

Tertiary control can be regarded as economic optimisation of dispatch for secondary control [4]. This paper will not elaborate on tertiary control.

– Time Control and Scheduling and Accounting

Time control is the mechanism that makes the average frequency equal to the nominal frequency of 50Hz. If the average frequency deviation exceeds a defined threshold the frequency set point in the complete synchronous zone is set to either 49.99 or to 50.01Hz for full periods of one day [4]. Participation in secondary control causes the actual cross-border exchange to deviate from the scheduled cross-border energy exchange. This is restored by scheduling and accounting. This paper will not further address time control nor scheduling and accounting [5].

Primary, secondary and tertiary control are activated subsequently. This sequence is displayed in Fig. 1.

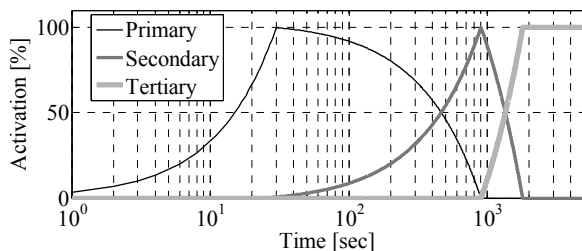


Fig. 1. Subsequent deployment of primary, secondary and tertiary reserve as a function of time.

It can be concluded that each type of control power has a specific deployment time, capacity and increase rate. The specifications for primary and secondary control are stated in Table I. Next to these technical specifications, each type of control power has a price for being available and a price for the actual deployment. This will be discussed further in section VI.

TABLE I
CHARACTERISTICS OF PRIMARY AND SECONDARY RESERVE CAPACITY

	Primary	Secondary
Deployment time	30 seconds	15 minutes
UCTE capacity	3000 MW	5700 MW ¹
Ramping rate	200 %/min	7 %/min
Activation duration	< 15 min	Not specified

IV. DISTRIBUTED GENERATION

DG is defined by the European Commission in [6] as generation which is connected to the distribution grid. This generation is usually small (< 60 MW) and can be based on renewable sources. The types of DG which will be discussed in this paper are wind energy, photovoltaic energy, combined heat and power (CHP) and micro CHP (μ CHP). The European Commission has stated that by the year 2020, 20% of the energy consumption in the European Union has to be based on renewable energies [7]. This leads to an increase of DG in the electricity grid [8].

DG is often characterised by low marginal costs. Therefore they tend to participate in base load production. The incentive to keep reserves to participate as control capacity does usually not exist and often DG is regarded as negative load. However, as their share in the total production of electricity increases, this strategy needs to be changed. Due to the dependency of some DG on weather conditions, the electricity production of DG can fluctuate and, moreover, variations can be rather unpredictable and consequently lead to more imbalance in the grid [9].

V. DISTRIBUTED GENERATION IN BALANCE MANAGEMENT

As concluded in the previous section, the increase of DG leads to an increase in the need for reserve capacity, while the share of conventional generation is reduced. Therefore, DG may be required to participate also in balance management. In section III it was stated that to contribute in either primary or secondary control for balance management, a producer or generator must be capable of increasing or decreasing its production within a specific timeframe. Conventional generators which are contracted to participate in balance management should therefore maintain a specific amount of reserve capacity. For primary control all large units should reserve part of their capacity. Units with higher marginal costs are selected for secondary control. Renewable generation is often characterised by low marginal costs compared to conventional generation. Therefore it is not presumable that they will participate in balance management, otherwise than as obligation when necessary.

DG is often considered to be marginally controllable since the power output depends on weather conditions. Also with CHP, weather conditions play a role since power production is determined by demand for heat. Down regulation is mostly not a problem; up regulation however is difficult without jeopardizing economics. The properties of different generators determine their capability to participate in either or both

¹ 5700 MW is the sum of all control zones' individual available secondary control capacity. The individual capacities are based on maximum load values of the UCTE members in the year 2007 [5].

primary and secondary control. For the different types of generation the options to act as reserve capacity are shown in Table II. A '+' means that a type of generation can participate in a certain type of balance management whereas a '-' means that it can not.

TABLE II
TECHNICAL CAPABILITY OF DIFFERENT GENERATORS TO PARTICIPATE AS CONTROL CAPACITY

	PV	CHP	μ CHP	Wind
Primary up	-	+	+	+
Primary down	+	+	+	+
Secondary up	-	+	+	-
Secondary down	+	+	+	+

– Photovoltaic

In photovoltaic power generation the power is converted by power electronics. These are controlled such that the photovoltaic panels are operated in the maximum power point. If solar power is available it would be possible to decrease the production by controlling the inverter. This enables photovoltaic generation to participate in primary and secondary reserves. Up regulating is not possible since the inverters are already designed to operate in the maximum power point. In theory this could be adapted but this is not realistic.

– CHP

CHP power production is often driven by heat demand. Usually CHP provides heat for an industrial process. The production of electricity is therefore related to the demand for heat (Fig. 2).

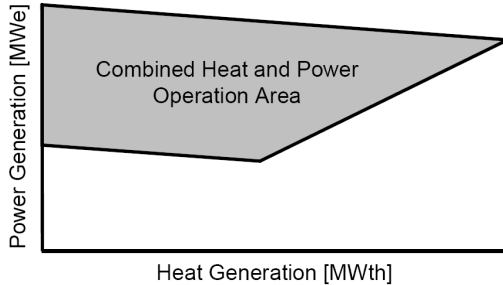


Fig. 2. Operation area of CHP [13]

However, the CHPs might also be controlled by demand for electricity. This would require heat storage not to jeopardise the primary process. By controlling power production, CHP can participate in both primary and secondary control for both up regulating and down regulating.

– μ CHP

μ CHPs are expected to be located in households to produce heat and electricity. The power production is controlled by the demand for heat. However it might also be controlled by demand for electricity if heat storage is available. μ CHP could then participate in both primary and secondary control.

– Wind

In [10] it is suggested to use the kinetic energy in the rotor of a wind turbine to briefly increase the power output of the wind generator for several seconds. In this way, a wind turbine can contribute to primary control. This concept is

illustrated in Fig. 3 where two different schedules for wind generation with primary control are shown.

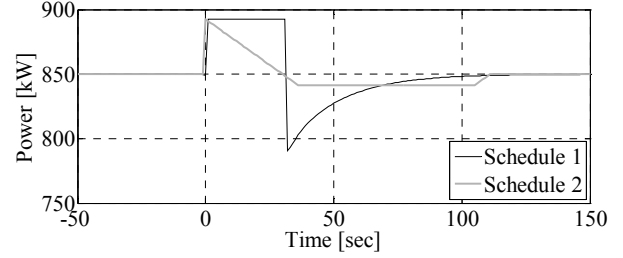


Fig. 3. Schedules for wind power participating in primary reserves

Important to notice from the Fig. 3 is that the increase in power output from the wind turbine is coming from its kinetic energy. This means that, while the ancillary service is provided, the rotor of the turbine decelerates. This causes a decrease in the wind power converted into electrical power. After the participation in balance management has stopped, the turbine needs some time to increase the speed of its rotor back to the nominal value. During this, the generator provides less power than it produced prior to the imbalance and therefore this situation may cause a further imbalance.

To investigate whether the participation of wind generators actually improves balance management, this concept was integrated in a model of a power system. The model consists of two production units (conventional and wind generation respectively) and a load. The conventional generator participates in primary and secondary control. The load is modelled as a stepwise function with an increase in value at $t = 0$ sec. Imbalance is calculated as the sum of both production units minus the load. Frequency is deduced from the imbalance with an integrating function. More information about the set up of the model is given in [11]. Three simulations have been executed. In the first simulation the wind generator does not participate in balance management. In the second simulation the wind generator contributes to balance management according to the schedule 1 in Fig. 4. The third simulation shows the response for implementation of schedule 2. For both schedules the wind turbine increases its output simultaneous with the increase of the load. The frequency responses of the system for the simulations are given in Fig 4.

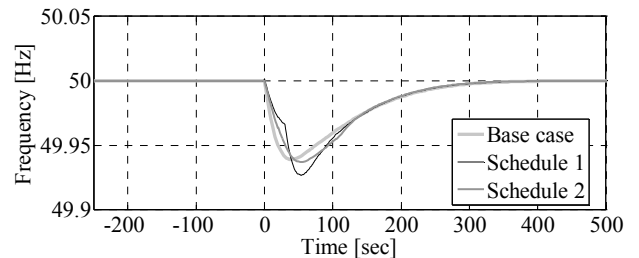


Fig. 4. Frequency response with immediate activation of reserves

From Fig. 4 can be concluded that participation of DG appears to improve the initial frequency response. However, when the contribution of the wind generation to balance management is stopped, the system is confronted with an even higher imbalance than initially. Therefore participation only causes a delay in the minimum value of the frequency. This

can be improved by delaying the participation of DG with several seconds. This strategy is tested with simulations and the results are shown in Fig. 5, in which a delay of 30 seconds was implemented.

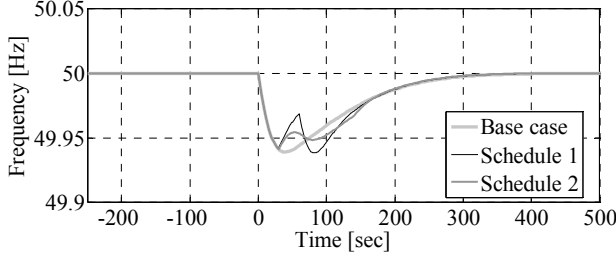


Fig. 5. Frequency response with activation delay of 30 seconds.

Fig. 5 shows that schedule 2 in combination with a delay improves best the frequency response of the grid. Therefore it can be concluded that wind generation can help in balance management. Coordination however will be vital to achieve improvements in the frequency response.

VI. ECONOMIC ANALYSIS

In the previous section it was discussed that some of the distributed generators have the potential to participate as reserve capacity. However, as the marginal costs of production by DG are usually low, there is little incentive to participate. This effect is often aggravated by subsidies which are being given per unit of produced energy to generators of renewable energy. This section discusses the economic dispatch of DG and the impact of subsidies, paid per unit of produced energy.

– Unit Commitment and Unit Dispatch

Unit commitment is defined in [12] as the process of deciding whether to turn on or off a generator in a power grid at a given hour. After the unit commitment decisions have been taken unit dispatch decisions are made to determine the share in production of each generator in a portfolio [13]. During this latter step it is also determined whether or not generators will withhold part of their capacity as reserve capacity. Within a series of constraints the owner of a power plant portfolio will use unit commitment and unit dispatch decisions to maximise its profit.

For reserve capacity, two main payment strategies are in use [12]. These are:

- *Payment for Power Delivered*

In this case, reserve capacity is only rewarded if it is actually used. The payment consists of a price per unit of energy sold as reserve capacity. Generators choose to keep reserve capacity when the price per unit of energy for reserve capacity λ_r is larger than the price for normal production λ .

- *Payment for Reserve Allocated*

In the second case, withholding reserve capacity is always rewarded. The generator will receive a payment per unit of energy of lost production. Since most of this electricity will never be produced, little production costs are made and the price for allocation

λ_r of the reserve capacity can be lower than the price for normal production λ .

According to [14] a number of European countries use both strategies (e.g.: United Kingdom & Wales, France and Denmark) and a number of countries use a payment for power delivered (e.g.: Netherlands, Germany, Poland, Italy, Spain, Sweden and Finland). In this paper a payment for power delivered is assumed since this is applicable in most cases.

Next to the decision whether to have a payment for power delivered or a payment for reserve allocated, also a decision needs to be taken how to determine the price for the product. For this again two strategies exist. In the marginal pricing system, all selected bidders receive the same price whereas in the pay-as-bid system, all selected bidders receive their own individual bidding price.

After a generator is selected to be switched on in the unit commitment process, the owner of the generator has to determine whether to use this generator completely for power production or to withhold part of the capacity as reserve capacity [12]. In case the portfolio of the producer exists only of a single generator the expectation of the profit for the power producer can be described with (1) to (5):

$$E(\Pi) = E(\Pi_s + \Pi_{r^+} + \Pi_{r^-} - C) \quad (1)$$

In which:

$$\Pi_s = (1 - r^-) \lambda P_s \quad (2)$$

$$\Pi_{r^+} = r^+ \lambda_{r^+} (P_t - P_s) \quad (3)$$

$$\Pi_{r^-} = r^- \lambda_{r^-} P_s \quad (4)$$

$$C = -a \left((1 - r^-) P_s + r^+ (P_t - P_s) \right)^2 - \dots \quad (5)$$

$$\dots - b \left((1 - r^-) P_s + r^+ (P_t - P_s) \right) - c$$

where:

- $E(\Pi)$ is the expectation of the profit of a producer.
- Π_s corresponds to the income resulting from production of normal energy and selling it to the normal price.
- Π_{r^+} corresponds with the income originating from the production and selling of positive reserve capacity during a shortage of energy. The maximum reserve capacity is determined as the difference between P_t and P_s .
- Π_{r^-} corresponds with the income proceeding from deployment of negative reserve capacity. This means that part of the production P_s is decreased in order to receive the price for negative reserve capacity.
- r^- and r^+ are the probabilities of providing negative and positive reserve capacities.
- λ is the electricity price of that moment. λ_{r^-} and λ_{r^+} the prices of negative and positive reserve capacities.
- C corresponds with the costs for production of the required amount of electricity. A 2nd order polynomial cost function is selected.

For the power producer (1) should be treated as an optimisation problem (6) to optimise the expected profit given certain values for r^+ , r^- , λ_{r^+} , λ_{r^-} , λ , a , b and c .

$$\max_{P_s} E(\Pi) \quad (6)$$

The differences between prices λ , λ^+ and λ^- as a function of the amount of imbalance in a control zone have been investigated in [15] (Fig. 6) and it was concluded that usually the prices λ^+ and λ^- are higher than λ .

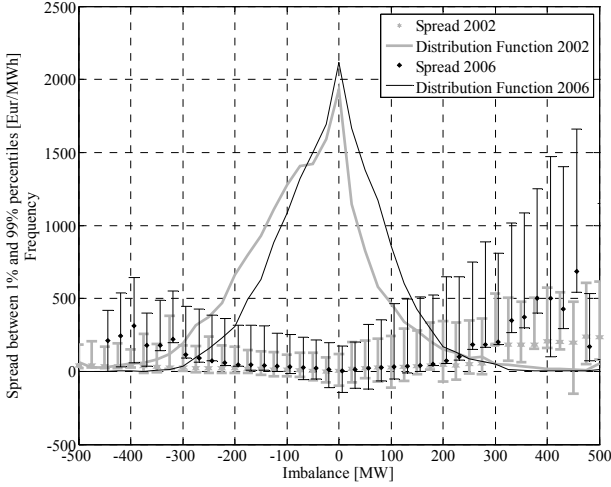


Fig. 6. Distribution functions of the imbalances and the spread of price differences between the Amsterdam Power Exchange, and the imbalance system market clearing prices. Data from the years 2002 and 2006 was selected. For negative imbalances, the price differences between λ^- and λ are given whereas the positive imbalances determine the difference between λ^+ and λ [15].

In many countries, subsidies are given to producers as an incentive to invest in distributed or renewable generation. Often these subsidies are paid per unit of energy, delivered by the generator of renewable energy. This changes the equations for the profit of a generator (1) to (5) in equations (7) to (11) by adding the subsidy price λ_{sub} .

$$E(\Pi) = E(\Pi_s + \Pi_{r^+} + \Pi_{r^-} - C) \quad (7)$$

In which:

$$\Pi_s = (1 - r^-)(\lambda + \lambda_{sub})P_s \quad (8)$$

$$\Pi_{r^+} = r^+(\lambda_{r^+} + \lambda_{sub})(P_t - P_s) \quad (9)$$

$$\Pi_{r^-} = r^-\lambda_{r^-}P_s \quad (10)$$

$$C = -a\left(\left(1 - r^-\right)P_s + r^+(P_t - P_s)\right)^2 - \dots \quad (11)$$

$$\dots - b\left(\left(1 - r^-\right)P_s + r^+(P_t - P_s)\right) - c$$

As a result the conditions to withhold capacity for the use of either positive or negative reserve capacity changes into (12) and (13) respectively.

$$\lambda_{r^+} > \lambda + \lambda_{sub} \quad (12)$$

$$\lambda_{r^-} > \lambda + \lambda_{sub} \quad (13)$$

In case of perfect competition and liquid markets for both power and reserve capacity, the prices λ_{r^+} and λ_{r^-} will evolve such that $r^+\lambda_{r^+} = \lambda$ and $r^-\lambda_{r^-} = \lambda$ [16]. Since λ_{sub} in (8), (9), (12) and (13) is assumed to be positive, the variable P_s^* for the optimisation of (6) will change to P_t . This means that both

conditions (12) and (13) will never be fulfilled and that it is not beneficial for subsidised generators to provide either positive or negative reserve capacity.

VII. REGULATORY FRAMEWORK

If DG is supposed to participate in balance management, the correct regulatory framework must be created for this. This section elucidates on several possible improvements of the current framework to aggravate the incentives for DG to participate in the secondary reserves market.

– Gate Closure Time

To be able to be selected by the transmission system operator to provide reserve capacity for balance management, a producer must declare its ability to withhold capacity. This statement (or bid) must be sent in before gate closure. Usually the gate closure time is at noon on the day before the day of execution. As producers with DG are often relying on predictions, which tend to be more reliable as the prediction time decreases, an early gate closure forms an obstacle for effective bidding in the imbalance system. Delaying the gate closure time would therefore be an improved incentive to participate in balance management.

– Flexible Bidding

Often electricity storage is mentioned as the enabling factor for further implementation of DG in the electricity grid. By using storage, surpluses and shortages of electricity can be balanced. However throughout Europe, no good incentives exist yet to invest in storage for this purpose. One of the obstacles is that storage devices have to, like any other generator, state exactly in what programme time units they will absorb or release their energy. Since the balance situation in a control zone is unpredictable on the long term, it is not feasible to make biddings in the imbalance market for storage devices. Introducing new tradable products in the imbalance market that state the production or consumption of a certain amount of energy within a certain time frame, but not related to a certain programme time unit, would enable effective bidding by electricity storage in the imbalance system. These bidding products would also create more flexibility for DG to, either independent or together with storage devices, participate as reserve capacity.

– Cross Border Balancing

Currently cross border balancing is regarded as an emergency service and is not competing with intra-control-zone balancing [17]. However, implementing weather dependent renewable generation could increase the need for further implementation of cross-border balancing. Exploiting the simultaneous occurrence of both positive and negative imbalances in different control zones could be an incentive for renewable generation to participate in balance management although cross-border transmission capacity would need to be reserved for this [17].

VIII. CONCLUSIONS

In this paper, ancillary services for balance management in a power grid are discussed. First the technical potential of

distributed generators to participate as primary and secondary reserve capacity is discussed. It was shown that many of the distributed generators have the ability to participate in either or both primary and secondary control. Both positive and negative reserve capacities have been analysed.

The economic analysis shows that due to low marginal costs, it is often not profitable for DG to participate in balance management. By elucidating on the unit dispatch optimisation problem it was shown that subsidies for generators of renewable energy, which are paid per unit of delivered energy, are an incentive not to participate in balance management. If participation of DG in balance management is required for enabling further implementation of DG new economic incentives have to be created for this.

Finally possible changes to the existing regulatory framework for balance management have been discussed.

IX. ACKNOWLEDGMENT

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XI. BIOGRAPHIES

Jasper Frunt was born in 's-Hertogenbosch in 1981. He received his B. degree in electrical engineering in 2003 from the University of Professional Education in 's-Hertogenbosch. In 2006 he received his M.Sc. degree in sustainable energy technology at Eindhoven University of Technology. For his graduation projects he worked with Kema N.V. and Tennet TSO bv (Dutch Transmission System Operator) respectively. Currently he is working towards a PhD in the EOS (Energy Research Subsidy) project 'Regelduurzaam' at Eindhoven University of Technology. His research focusses on current and future deployment, legislation and organisation of control power for balance management.

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Wil L. Kling received his M.Sc. degree in electrical engineering from the Technical University of Eindhoven in 1978. From 1978 to 1983 he worked with Kema, from 1983 to 1998 with Sep and since then up till the end of 2008 he was with TenneT, the Dutch Transmission System Operator, as senior engineer for network planning and network strategy. Since 1993 he is a part-time Professor at the Delft University of Technology and since 2000 also at the Eindhoven University of Technology, the Netherlands. From December 2008 he is appointed as a full professor and chair of Electrical Power Systems group at the Eindhoven University of Technology. He is leading research programs on distributed generation, integration of wind power, network concepts and reliability issues. Prof. Kling is involved in scientific organisations such as CIGRE and the IEEE. As Netherlands' representative, he is a member of CIGRE Study Committee C6 Distribution Systems and Dispersed Generation, and the Administrative Council of CIGRE.

Johanna M. A. Myrzik was born in Darmstadt, Germany in 1966. She received her MSc. in Electrical Engineering from the Darmstadt University of Technology, Germany in 1992. From 1993 to 1995 she worked as a researcher at the Institute for Solar Energy Supply Technology (ISET e.V.) in Kassel, Germany. In 1995 Johanna joined to the Kassel University, where she finished her PhD thesis in the field of solar inverter topologies in 2000. Since 2000, Johanna is with the Eindhoven University of Technology. In 2002 she became an assistant professor and since 2008 she is an associate professor in the field of residential electrical infrastructure and distributed generation. Her fields of interests are: power electronics, renewable energy, distributed generation, electrical power supply.