Panel Session: Impact of Dispersed and Renewable Generation on System Structure Including Impact of Enlarged Community on Energy Development, Power Generation, International Interconnections, Transmission and Distribution

(Tom Hammons and Zbigniew Styczynski)

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Topic: Integrating New Sources of Energy in Power Systems

INTRODUCTION

In Europe the dependency on imported primary energy increases from year to year. As a countermeasure against this growing dependency national programs inside the European Community are directed to increase the share of renewable energy sources and the efficiency of power generation by cogeneration of heat and power (CHP). Targets are set by the European Commission for each country to gain a sustainable electricity supply in the future.
Generally, the share of renewable energy sources has to be increased until 2010 from 14% to 22% and the share of CHP has to be doubled from 9% to 18%.

Assuming that the wind power will grow preliminary by way of large wind farms feeding into the transmission grids with additional 35 GW installed power by 2010 (today approximately 36 GW are operated in Europe and about 50 % of these are located in Germany), the dispersed generation based on CHP and small renewable sources shall achieve an additional growth of 300 TWh/a to meet the mentioned goals.

The output of most of the renewable energy sources depends on meteorological conditions and the CHP output is driven by the demand for heat. The rated installed wind power, for example, is used in Germany for approximately 1600 h per year only. Thus, if the contribution of renewables and CHP in electric energy generation shall achieve 40 %, their share of the peak load coverage must exceed 60 % in periods with a maximum wind power and CHP output.

The question arises, how can the power system be operated with such a large share of mostly

[#] Document prepared and edited by T J Hammons not dispatched power sources? How can the reserve power be limited, which is required for compensation of power fluctuations and ensuring a safe network operation?

Thus, it becomes clear that advanced planning and energy management approaches have to be introduced to ensure that the existing high level of power quality will exist in the future as well.

In this context, a vision sees the power system of the future consisting of a number of self-balancing distribution network areas. In each of these areas a significant share of the power demand will be covered by renewable and CHP generation. However, the power balance of these areas shall be planable and dispatchable in such a way that the import or export of power from or into the higher-level network has to follow a schedule, which can be predicted with high level of accuracy in advance.

As the result of this vision the distribution networks will become active and have to provide contributions to such system services like active power balancing, reactive power control, islanded operation and black-start capability. These services have to be coordinated with the transmission system operators where the responsibility for system stability will be allocated in the future as well.

On the other hand, large-scale integration of wind power at the transmission level and international area trade of energy will lead to higher utilization of the transmission grids. Consequently, the transmission capability has to strengthen and short-term congestions have to be managed in an efficient and innovative way.

All these trends create new challenges for power system operation at all of its levels and require the introduction of advanced and economic solutions concerning:

- Supervisory control for congestion management
- Real-time security assessment
- Coordinated central and decentralized energy management including the unit commitment based on predictions of fluctuating power sources, demand side and storage management
- Coordinated trade of energy and transmission capacity.

The new tasks require a significant growth of information exchange. Communication networks using the existing infrastructure with different communication technologies like radio channels, power line carrier, fiber optics or traditional telecommunication cables will be the base. International communication standards shall be applied to simplify the engineering and operation of these new types of communication networks.

Under these mentioned circumstances the interplay of transmission and distribution will reach a new quality.

This Panel Session panel fits very well with the scope of the advisory council of the European Commission "Platform of the Electricity Network of the Future".

Some of the key persons of the advisory council will participate with technical presentations.

The Panelists and Titles of their Presentations are:

1. Johan Driesen and Ronnie Belmans, KU Leuven, Leuven, Belgium. Distributed Generation: Challenges: and Possible Solutions (paper 06GM0404)
2. Pier Nabuurs, Chief Executive Officer, KEMA, Arnhem, The Netherlands. Dispersed Generation and System Structure - The Crucial Exchange Layer between Transmission and Distribution (06GM1038)

3. Bernd Michael Buchholz, Director, PTD Services, Power Technologies, Siemens AG, Erlangen, Germany and Zbigniew Antoni Styczynski, Dean of Faculty of Electrical Engineering and Information Technology, Otto-von-Guericke University, Magdeburg, Germany. New Tasks Create New Solutions for Communication in Distribution Systems (paper 06GM0435)
4. Peter Børre Eriksen, Antje Orths and Vladislav Akhmatov, Energinet.Dk**,** Analysis and Methods, Fredericia, Denmark. Integrating Dispersed Generation into the Danish Power System - Present Situation and Future Prospects (paper 06GM0520)
5. Christian Sasse, General Manager, AREVA T&D, Stafford, UK. Electricity Networks of the Future (paper 06GM0339)
6. Bruno Meyer, Director ‘Power Systems Technology & Economics", EDF R&D, Clamart, France, Yves Bamberger, Executive Vice President, Head of Corporate EDF R&D, EDF R&D, Clamart, France and I. Bel, Research Engineer, EDF R&D, Clamart, France. Electricité de France and Integration of Distributed Energy Sources (paper 06GM0475)
7. J. Kabouris, Hellenic Transmission Operator, Greece and Nikos D. Hatziargyriou, National Technical University Athens, Athens, Greece. Wind Power in Greece–Current Situation, Future Developments and Prospects (paper 06GM1335)
8. Kurt Rohrig, ISET Kassel, Germany. Application of Wind Power Prediction Tools for Power System Operations (paper 06GM0523)
9. Livio Gallo, Eugenio Di Marino, Christian D’Adamo and Simone Bottom, ENEL Distribuzione, Italy. Integration of New Sources of Energy in the Italian Distribution Network (paper 06GM0373)
10. Invited Discussers..

Each Panelist will speak for approximately 20 minutes. Each presentation will be discussed immediately following the respective presentation. There will be a further opportunity for discussion of the presentations following the final presentation.

The Panel Session has been organized by Tom Hammons (Chair of International Practices for Energy Development and Power Generation IEEE, University of Glasgow, UK) in consultation with Bernd Michael Buchholz (Director, PTD Services, Power Technologies, Siemens AG, Erlangen, Germany).

Tom Hammons and Zbigniew Styczynski (University of Magdeburg, Germany) will moderate the Panel Session.

PANEL SESSION PAPERS

1. DISTRIBUTED GENERATION: CHALLENGES AND POSSIBLE SOLUTIONS

J. Driesen, Member, IEEE, and R. Belmans, Fellow, IEEE

Abstract--This contribution starts from the observation that there is a renewed interest in small-scale electricity generation. The authors start with a discussion of the drivers behind this evolution indicating the major benefits and issues of small-scale electricity generation. Attention is paid to the impact of a massive penetration of distributed generation in the grid on the system safety and protection. An overview of the impact on voltage quality and stability is given, both static and dynamic. A practical example is discussed in order to show the problems and indicate solutions. Different types of generators and grid interfaces are treated. In a final chapter, an attempt is made to correctly define small-scale generation also commonly called distributed generation, embedded generation or decentralized generation.

Index Terms-- Distributed generation, voltage stability, dispersed generation, grid safety

IV. I. INTRODUCTION

DISTRIBUTED generation (DG), for the moment loosely defined as small-scale electricity generation, is a fairly new concept in electric energy markets, but the idea behind it is not new at all. In the early days of electricity generation, distributed generation was the rule, not the exception. The first power plants only supplied electric energy to customers connected to the 'microgrid' in their vicinity. The first grids were DC based, and therefore, the supply voltage was limited, as was the distance covered between generator and consumer. Balancing demand and supply was partially done using local storage, i.e. batteries, directly coupled to the DC grid. Along with small-scale generation, local storage is also returning to the scene.

Later, technological evolutions, such as transformers, lead to the emergence of AC grids, allowing for electric energy to be transported over longer distances, and economies of scale in electricity generation lead to an increase in the power output of the generation units. All this resulted in increased convenience and lower per-unit costs. Large-scale interconnected electricity systems were constructed, consisting of meshed transmission and radially operated distribution grids, supplied by large central generation plants. Balancing demand and supply was done by the averaging effect of the combination of large amounts of instantaneously varying loads. The security of supply was guaranteed by the build-in redundancy. In fact this interconnected high-voltage system made the economy of scale in generation possible, with the present 1.5 GW nuclear power plants as a final stage in the development. Storage is still present, with the best known technology being pumped hydro plants.

In the last decade, technological innovations and a changing economic and regulatory environment resulted in a renewed interest for DG. This is confirmed by the IEA [1]. This paper presents the technical challenges and possible solutions when large amounts of distributed generation are introduced.

V. II. DRIVERS FOR DG

The IEA identifies five major factors that contribute to the renewed interest in DG. These five factors can be grouped under two major driving forces, i.e. electricity market liberalization and environmental concerns. The developments in small-scale generation technologies have been around for a long time, but were as such not capable of pushing the ‘‘economy of scale’’ out of the system. Although it is sometimes indicated, it may be doubted that DG is capable of postponing, and certainly not of avoiding, the development of new transmission lines, as, at the minimum, the grid has to be available as backup supply.

A. Liberalization of Electricity Markets

There is the increased interest by electricity suppliers in DG, because they see it as a tool that can help them fill in niches in the market, in which customers look for the best suited electricity service. DG allows players in the electricity sector to respond in a flexible way to changing market conditions. In liberalized markets, it is important to adapt to the changing economic environment in the most flexible way. DG technologies in many cases provide flexibility because of their small sizes and assumed short construction lead times compared to most types of larger central power plants. However, the lead time reduction is not always that evident. For instance, public resistance to wind energy and use of landfill gasses may be very high.

1). Standby Capacity or Peak Use Capacity (Peak Shaving)

Many DG technologies are flexible in several respects: operation, size and expandability. Making use of DG allows a flexible reaction to electricity price evolutions. DG then serves as a hedge against these price fluctuations. Apparently, this is the major driver for the US demand for DG, i.e. using DG for continuous or peaking use (peak shaving). The energy efficiency sometimes is very debatable. In Europe, market demand for DG is, for the moment, driven by heating applications (through CHP), the introduction of renewable energies and potential efficiency improvements.

1. 2). Reliability and Power Quality

2.

The second major driver of US demand for DG is quality of supply or reliability considerations. Reliability problems refer to sustained interruptions, being voltage drops to near zero (usually called outages). The liberalization of energy markets makes customers more aware of the value of reliable electricity supply. In many European countries, the reliability level has been very high, although black-outs were seen over the last years.

Customers do not really care about supply interruptions as they do not feel it as a great risk. However, this may change in liberalized markets. A high reliability level implies high investment and maintenance costs for the network and generation infrastructure. Because of the incentives for cost-effectiveness that come from the introduction of competition in generation and actions from regulators aiming at short-term tariff reductions for network companies, it might be that reliability levels decrease. However, having a reliable power supply is very important for society as a whole, and industry in specific (chemicals, petroleum, refining, paper, metal, telecommunications, …). Companies may find the grid reliability of a too low level and decide to invest in DG units in order to increase overall reliability of supply to the desired level.

Apart from voltage drops to near zero (reliability problems), one can also have smaller voltage deviations. The latter deviations are aspects of power quality. Power quality refers to the degree to which power characteristics align with the ideal sinusoidal voltage and current waveform, with current and voltage in balance [2]. Thus, strictly speaking, power quality encompasses reliability.

Insufficient power quality can be caused by failures and switching operations in the grid, mainly resulting in voltage dips, interruptions, and transients and by network disturbances from loads yielding flicker (fast voltage variations), harmonics, and phase imbalance. The nature of these disturbances is related to the 'short-circuit capacity', being a measure for the internal impedance in the grid, depending on its internal configuration (e.g. length of the lines, short-circuit capacity of generators and transformers) [3].

3. 3). Alternative to Expansion or Use of the Local Network

4.

DG could partially serve as a substitute for investments in transmission and distribution capacity (demand for DG from T&D companies) or as a bypass for transmission and distribution costs (demand for DG from electricity customers). This is only possible to the extent that alternative primary fuels are locally available in sufficient quantities. For example, increased use of DG could result in new congestion problems in other networks, such as the natural gas distribution network.

5. 4). Grid support

Finally, DG can also contribute in the provision of ancillary services, including those necessary to maintain a sustained and stable grid operation of the, but not directly supplying customers. This may be the capability to generate active power on demand of the grid operator, for instance to stabilize a dropping frequency due to a sudden under capacity in generation or excess demand, or reactive power to support the voltage.

B. Environmental Concerns

At present, environmental policies are probably the major driving force for the demand for DG in Europe. Environmental regulations force players in the electricity market to look for cleaner energy solutions. Here, DG can also play a role, as it allows optimizing energy consumption of firms that have a large and constant demand for heat. Furthermore, most government policies aiming to promote the use of renewables also results in an increased impact of DG technologies, as renewables, except for large hydro and wind parks (certainly off-shore), have a decentralized nature.

Especially on sites where there is a considerable and relatively constant demand for heat, it makes sense to consider the combined generation of heat and electricity instead of generating the heat in a separate boiler and buying electricity from the grid. These so-called cogeneration units form a large segment of the DG market. Compared to separate fossil-fired generation of heat and electricity, CHP (Combined Heat and Power) generation may result in a primary energy conservation, varying from 10% to 30%, depending on the size (and efficiency) of the cogeneration units. The avoided emissions are in a first approximation similar to the amount of energy saving, although the interaction with the global electricity generation system also plays a role [4], [5].

Installing DG allows the exploitation of cheap fuel opportunities. For example, in the proximity of landfills, DG units could burn landfill gasses. Other locally available biomass resources may also be envisaged.

VI. III. GRID PROTECTION AND DG

Power can flow in a bidirectional way within a certain voltage level, but it usually flows uni-directionally from higher to lower voltage levels, i.e. from transmission to distribution grid. An increased share of DG units may induce power flows from low into medium-voltage grid. Thus, different protection schemes at both voltage levels may be required [6].

Safe operation and protection are to be guaranteed at all times. In addition, the protection system has to be sufficiently selective, in order to optimize reliability and availability of supplied power. This is less simple than it seems, since the fault current not only comes from the main power system grid in a unidirectional way, but also form the DG units, making detection far more complicated and the conventional hierarchy (selective) protection methods might fall. Therefore, a more 'active' protection system with some form of communication is required to keep up the required level of safety in future.

The protection problems are illustrated by using a distribution system with five feeders in Fig. 1. If a short circuit occurs at F2 or F3, the short-circuit current is supplied by the generators connected to this feeder (G1 and G2), other DG units in adjacent feeders, and the main grid. If the contribution to the short-circuit current of G1 and G2 is large compared to that of the grid and the other feeders, the current through the circuit breaker and fuse CB1 might be too low to operate in order to eliminate the short circuit in the feeder. On the other hand, if the contribution to the short-circuit current from generators in adjacent feeders is significant, healthy feeders (feeder 4) might be disconnected before the faulty feeder is disconnected.

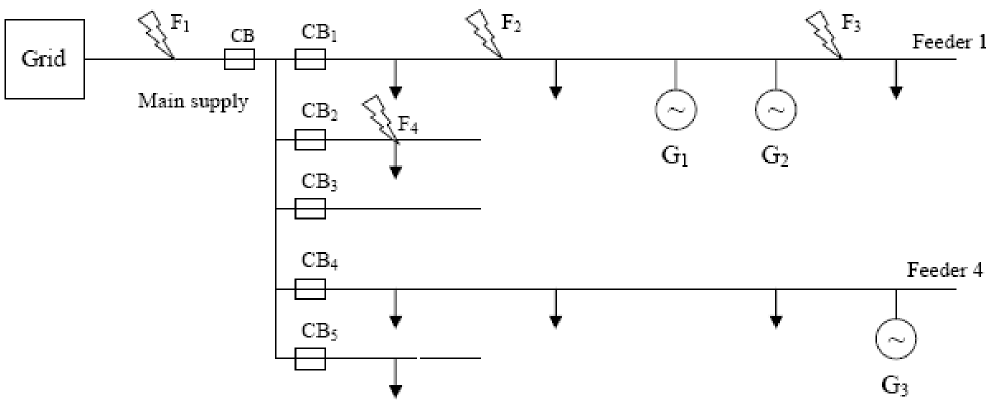

Fig. 1. Grid with safety problems due to high DG penetration.

As long as islanding is not intended to backup a loss of mains, it should be avoided [7]. According to technical standards (e.g. IEEE 1547), DG must be automatically disconnected, when faults or abnormal conditions occur, with the assumption that interconnection systems detect such conditions. In this way, conventional protection selectivity can be restored, guaranteeing person and equipment safety. In future, when more DG will be used, this requirement would reduce expected benefits of DG. To make optimal use of DG, unnecessary disconnection of DG should be avoided. Generators should be able to ride through minor disturbances [8].

DG flows can reduce the effectiveness of protection equipment. Customers wanting to operate in 'islanding' mode during an outage must take into account important technical (e.g. the capability to provide their own ancillary services) and safety considerations, such that no power is supplied to the grid during the time of the outage. Once the distribution grid is back into operation, the DG unit must be resynchronized with the grid voltage.

VII. VOLTAGE QUALITY AND DG

A. System Frequency

Imbalances between demand and supply of electricity cause the system frequency to deviate from its rated 50/60 Hz value. These deviations should be kept within very narrow margins, as the well functioning of many industrial and household applications depends on it. In economic terms, system frequency can be considered as a public good. As a consequence, the transmission grid operator is appointed to take care of the system frequency as well as of other services with a public good character that need to be provided.

The installation and connection of DG units are also likely to affect the system frequency. These units will free ride on the efforts of the transmission grid operator or the regulatory body to maintain system frequency. They will probably have to increase their efforts and having an impact on plants efficiency and emissions. Therefore, the connection of an increasing number of DG units should be carefully evaluated and planned upfront.

B. Voltage Level

The relation between DG and power quality is an ambiguous one. On the one hand, many authors stress the healing effects of DG for power quality problems [1], including the potential positive effects of DG for voltage support and power factor corrections [6].

On the other hand, large-scale introduction of decentralized power generating units may lead to instability of the voltage profile: due to the bi-directional power flows and the complicated reactive power equilibrium arising when insufficient control is introduced, the voltage throughout the grid may fluctuate. Eventually an 'islanding' situation may occur in which a local generator keeps a part of a disconnected grid energized leading to dangerous situations for the repair personnel coming in.

Others also stress the potential negative externalities on power quality, caused by the installation of DG capacity. According to [9], the impact on the local voltage level of DG connected to the distribution grid can be significant. A same reaction was noted through the CIRED questionnaire [10], where, next to the general impact on power quality, a rise in the voltage level in radial distribution systems is mentioned as one of the main technical connection issues of DG. The IEA [1] also mentions voltage control as an issue when DG is connected to the distribution grid. This does not need to be a problem when the grid operator faces difficulties with low voltages, as in that case the DG unit can contribute to the voltage support. But in other situations it can result in additional problems.

C. Reactive Power

Small and medium-sized DG units often use asynchronous generators that are not capable of providing reactive power. Several options are available to solve this problem. On the other hand, DG-units with a power electronic interface are sometimes capable to deliver reactive power.

D. Power Conditioning

Some DG technologies (PV, fuel cells) produce direct current. Thus, these units must be connected to the grid via a DC–AC interface, which may contribute to higher harmonics. Special technologies are also required for systems producing a variable frequency AC voltage. Such power electronic interfaces have the disadvantage that they have virtually no ‘inertia’, which can be regarded as a small energy buffer capable to match fast changes in the power balance. Similar problems arise with variable wind speed machines [9].

VIII. PRACTICAL DISTRIBUTION NETWORK

A. Distribution Grid Lay-Out

An existing Belgian medium voltage distribution system segment is used to study the power quality and voltage stability with different DG units (Fig. 2). The system includes one transformer of 14 MVA, 70/10 kV and four cable feeders. The primary winding of the transformer is connected to the transmission grid and can be considered as an infinite node. Normal operation of the distribution system is in radial mode and the connections at node 111 with feeders 2, 3 and 4 are normally open.

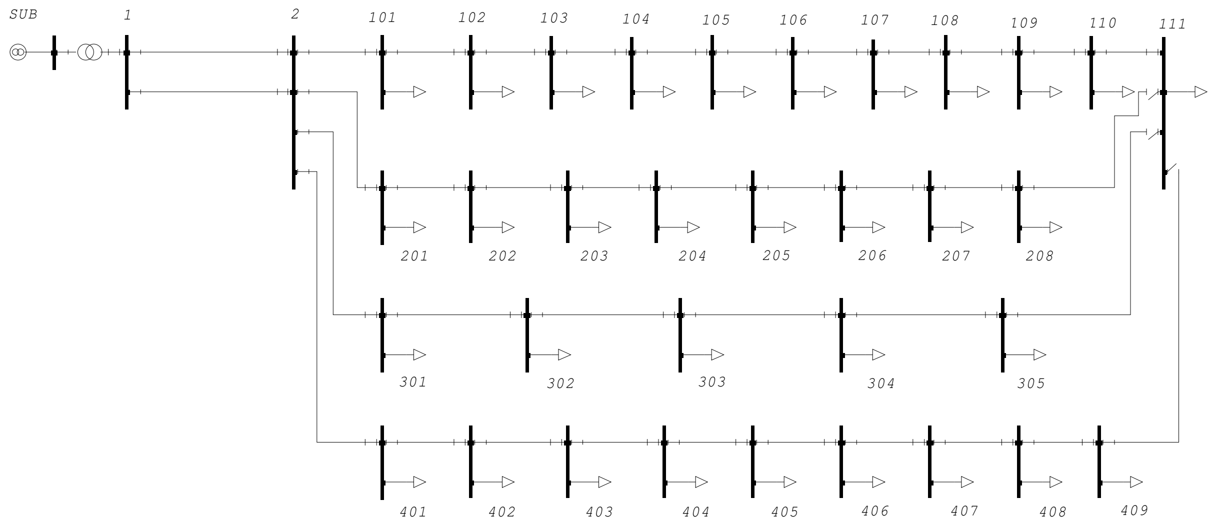

Fig. 2. Practical distribution system.

B. *Steady-State Voltage Rise*

A DG unit is connected at node 406 of feeder 4. The total load in the system is 9.92 MW, 4.9 Mvar. A synchronous and an induction generator are simulated with different power output. The synchronous generator is simulated at power factor 0.98 leading at 3 and 6 MW. The induction generator is simulated at power factor 0.95 lagging also at 3 and 6 MW. The power of the DG for both synchronous and induction generators raises the voltages of feeder 4, compared to the base case without DG (Fig. 3). For higher active and reactive power generation (synchronous 6 MW), an overvoltage occurs at node 406 and its neighbors.

Fig. 4 illustrates the voltage at node 406 with different power generation levels and power factors. Compared to the case that DG only injects active power or operates at unity power factor, synchronous generators raise the voltage of the system faster due to reactive support. For induction generators, the voltages rise is slower and at a certain level of power generation, the voltage starts to decrease. This is due to the fact that induction generators need reactive power, yielding in a reduction of the voltage rise.

Through this study, it can be seen that the impact of induction generators is less than that of synchronous ones in terms of voltage rise (Fig. 5). If there is an overvoltage with a synchronous generator, it has to operate under-excited and to absorb reactive power instead of injecting it.

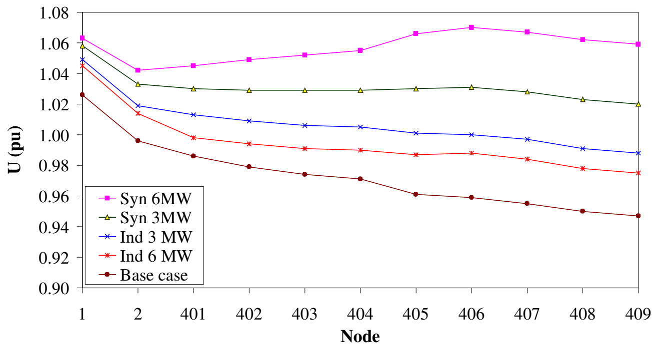

Fig. 3. Voltage profile of feeder 4 with DG connected at node 406

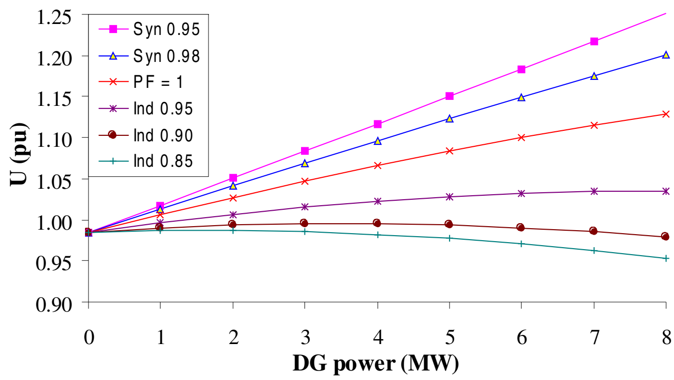

Fig. 4. Voltage at node 406 with different power factors

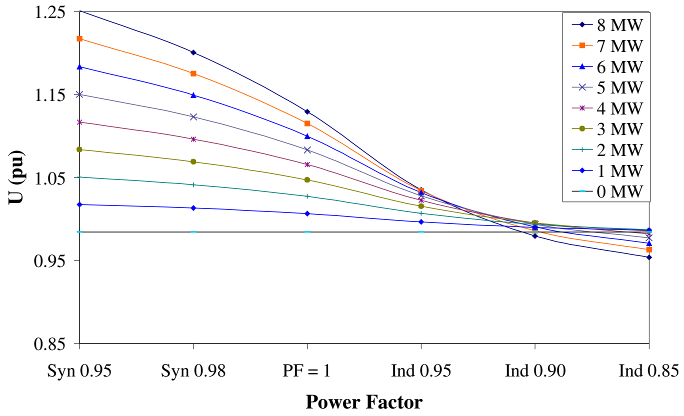

Fig. 5 Voltage at node 406 with different power generation levels

C. Voltage Fluctuations

In order to see the voltage fluctuation problem with DG, a photovoltaic (PV) system is used. The reactive power is produced by a capacitor of the inverter's grid filter and is almost constant. The PV system is treated as a PQ node with negative active power. The PV power is calculated from 5-s average irradiance data measured during one year in Leuven – Belgium. In this study, a PV array with 50 kW rated peak power is connected at node 304. Fig. 6 shows the one-hour power output of the PV system at noon of a slightly clouded summer day. In order to isolate the voltage fluctuation impact of PV from short-time load variation at individual nodes, the loads are assumed constant during the calculation. The total load in the system is 4.4 MW, 1.9 Mvar. In Fig. 6, the voltage fluctuations correspond to the variations of injected active power of the PV system. At times when clouds cover the sun, the power generated can quickly drop by 60%, causing sudden variations in node voltages in the range of 0.1%. The installed capacity of PV in this study is rather low compared to the capacity of the distribution system and the loads, so the value of voltage fluctuation is limited. However, with a high connection density or the connection of a large PV system, the voltage fluctuation problem might become more severe.

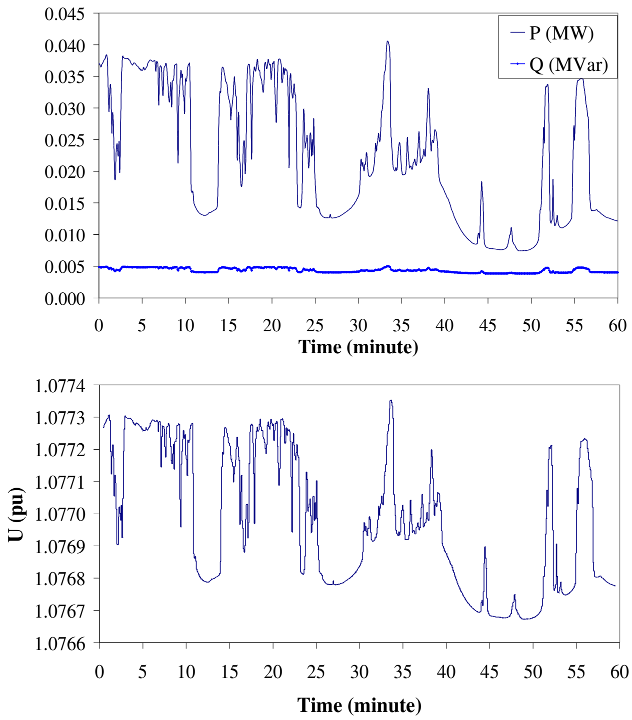

Fig. 6. Injected power and voltage at node 304

D. Voltage Dip

i. Opening of One Branch

A total DG capacity of 30% of the total system load is distributed equally over nodes 108, 204, and 406. The simulations have been carried out for induction and for synchronous generators. All operate at power factor 0.98 lagging. One of the 1-2 lines is opened during dynamic simulations at time t = 100 s. The distributed generators are connected at node 108, 204 and 406 with rated power 1 MW for both synchronous and induction generators.

The voltage dips are highest with constant power load characteristic and lowest with impedance load characteristic for both synchronous and induction generators (Fig. 7 and Fig. 8). With synchronous generators, after a short voltage dip, the voltage recovers close to the voltage before the disturbance. For induction generators, the voltage does not recover due to the lack of reactive power support. There is not so much difference between a voltage dip in the base case and with DG connection, being around 1%. So the connection of DG in the distribution system does not affect dynamic voltage stability significantly. In most cases it reduces the voltage dip value.

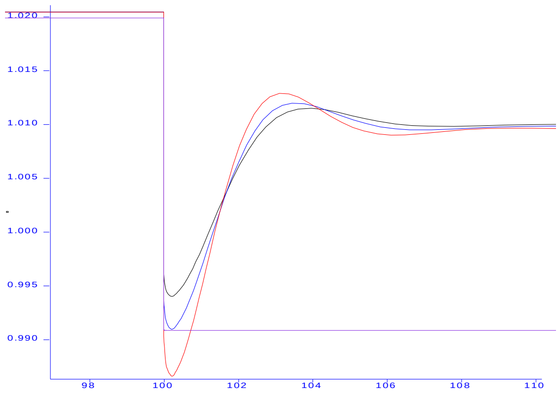

Fig. 7. Voltage dip at bus 2 with synchronous generator

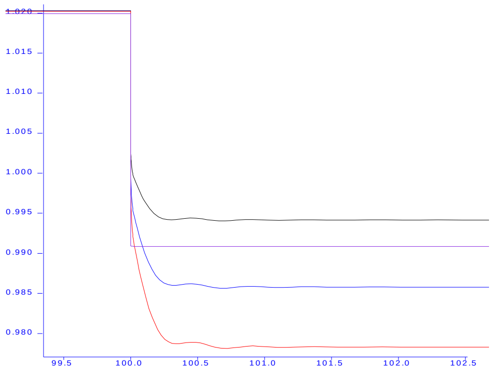

Fig. 8. Voltage dip at bus 2 with induction generator

ii. Generator Start-Up

In order to see the voltage dip problem when a DG starts up, an induction generator connected at node 108 with rated power of 3 MW is tested at lagging power factor of 0.9. When the induction generator starts up, it causes a transient and a voltage dip up to 40% in the system and lasts for several seconds (9). It is due to an initial magnetizing inrush transient and power transfer to bring the generator to its operating speed [11]. This results in a major problem for sensitive loads connected near the DG. If the distribution system is equipped with an under-voltage relay and DG unit has islanding protection, the voltage dip may lead to an action of the protection relay resulting in an outage of the system. A soft-start circuit is required for large connected induction DG.

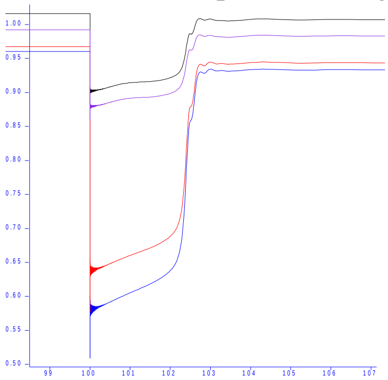

Fig. 9. Voltage dip when starting-up of an induction generator

E. Static Voltage Stability

The voltage stability is studied for synchronous and induction generators with three cases of DG connection: a) one DG unit connected at node 108, b) one at node 2, c) DG units distributed in the system at nodes 108, 204, 406. The total load of the system is 9.92 MW, 4.9 Mvar, all impedances. The total installed capacity of DG units in all cases is 3 MW. The voltage stability at node 111, at the end of feeder 1, is studied. DG units generally increase the voltage and support stability in the system (Fig. 10 and Fig. 11). The connection point of DG influences the voltage stability in the system. DG strongly supports the voltage at nearby nodes and has less impact on distant ones. This is also true for the other load characteristics. Compared to induction DG, the synchronous generator has a larger impact on the voltage stability because of its capability of reactive power injection. On the other hand, the influence of induction DG on voltage stability is not so different frothe base case (without DG).

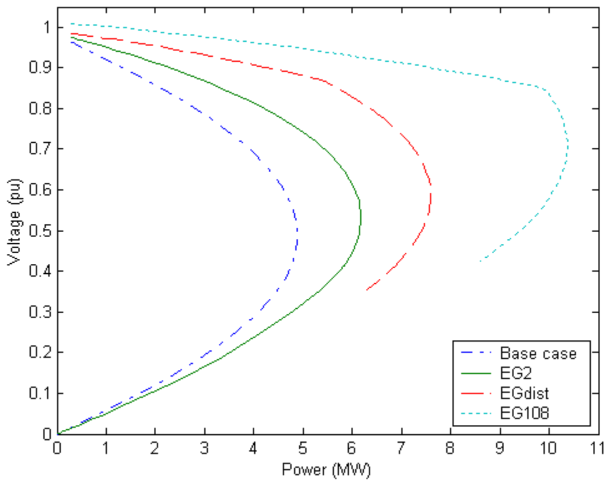

Fig. 10. Static voltage stability at node 111 with a synchronous generator

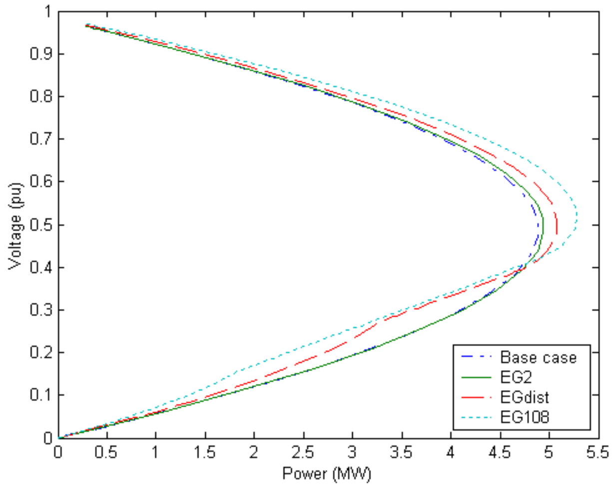

Fig. 11. Static voltage stability at node 111 with an induction generator

IX. ENERGY SECURITY

In some discussions, energy security is linked to the diversification of primary energy supplies, while in others, it is interpreted as the reliability of the electricity system. Under the first interpretation, energy security improves as the diversification of primary energy supplies increases. In this case, the advantages of DG are limited, as most technologies - with the exception of systems based on renewables - directly or indirectly depend on natural gas.

Under the second interpretation, it is felt by many authors [1], that DG can contribute to reduce the risks and costs of blackouts. Here, DG is seen as an instrument that helps to reduce the private costs and risks for electricity customers of system failures. Others, like [10], claim that DG does not contribute to system security. On the contrary, it would have a negative effect. Such a negative impact on the system security occurs when the share of non-dispatchable generation capacity increases. Examples of such units are wind turbines, photovoltaic systems and cogeneration units closely tied to heat demand. The latter units cannot be centrally controlled because of the natural variability of their power supply. As a consequence, there is an increased need for regulating (backup) power.

X. DEFINITION OF DISTRIBUTED GENERATION

A. General Considerations

In the previous sections, DG was loosely defined as small-scale electricity generation, but what exactly is small-scale electricity generation? Different technologies can be used for DG [12], but is it possible to give an overall, concrete definition? A short survey of the literature shows that there is no consensus. This is confirmed in [10], on the basis of a questionnaire submitted to the member countries. Some countries define DG on the basis of the voltage level, whereas others start from the principle that DG is connected to circuits from which consumer loads are supplied directly others as having some basic characteristic (e.g., using renewables, cogeneration, being non-dispatched).

CIRED has a working group that devotes efforts to DG. It defines DG as all generation units with a maximum capacity of 50 to 100 MW, usually connected to the distribution network and neither centrally planned nor dispatched [10]. Clearly, this latter part of their definition implies that DG units are beyond the control of the transmission grid operator. Thus, generation units built by the transmission grid operator as a substitute for grid expansion and that have measures implemented for dispatching, are not considered to be DG according to this philosophy.

The IEEE defines DG as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system.

On the basis of the definitions surveyed [6] DG is defined as a small source of electric power generation or storage (typically ranging from less than a kW to tens of MW) not part of a large central power system and located close to the load. Storage facilities are also included in the definition of DG, which is not conventional. Furthermore, this definition emphasizes the relatively small scale of the generation units as opposed to CIRED and CIGRE.

DG is also defined DG as relatively small generation units of 30 MW or less [13]. These units are sited at or near consumers to meet specific needs, to support economic operation of the distribution grid, or both. With the exception of the CIGRE definition, all definitions assume that DG units are connected to the distribution network. This is also the case for the definition used in [1], which sees DG as units producing power on a customer's site or within local distribution utilities, and supplying power directly to the local distribution network. IEA, however, makes no reference to the generation capacity level as opposed to all other definitions.

It should be clear by now, that many definitions of DG exist, allowing for a wide range of possible generation schemes. Some definitions allow for the inclusion of larger-scale cogeneration units or large wind farms connected to the transmission grid, others put the focus on small-scale generation units connected to the distribution grid. All these definitions suggest that at least the small-scale generation units connected to the distribution grid are to be considered as DG. Moreover, generation units installed close to the load or at the customer side of the meter are also commonly identified as DG. This latter criterion partially overlaps with the first, as most of the generation units on customer sites are also connected to the distribution grid.

However, it also includes somewhat larger generation units, installed on customer sites, but connected to the transmission grid.

This leads to the definition proposed in [9], defining DG in terms of connection and location rather than of generation capacity. It is defined as a DG source of an electric power generation connected directly to the distribution network or on the customer side of the meter. We favor this definition, even though it is rather broad. Indeed, it puts no limit on technology or capacity of potential DG application. Therefore, some additional criteria can be helpful and necessary to further narrow the definition in function of the research question tackled. The following paragraphs list a (non-exhaustive) number of these criteria along with a short discussion.

B. Voltage level at grid connection (transmission/ distribution)

Although some authors allow DG to be connected to the transmission grid, most authors see DG as being connected to the distribution network, either on the distribution or on the consumers' side of the meter. In all cases, the idea is accepted that DG should be located closely to the load. The problem is that a distinction between distribution and transmission grid, based on voltage levels, is not always useful, because of the existing overlap of these voltage levels for lines in the transmission and distribution grid. Moreover, the 'legal' voltage level that distinguishes distribution from transmission can differ. Therefore, it is best not to use the voltage level as an element of the definition of DG. It would be more appropriate to use the concepts 'distribution network' (usually radial) and 'transmission network' (usually meshed).

C. Generation Capacity (MW)

One of the most obvious criteria would be the generation capacity of the units installed. However, the short survey of definitions illustrated that there is no agreement on maximum generation capacity levels and the conclusion is that generation capacity is not a relevant criterion. The major argument is that the maximum DG capacity that can be connected to the distribution grid is a function of the capacity of the distribution grid itself. Because this latter capacity can differ widely, it is impossible to include it as an element of the definition of DG.

However, this does not imply that the capacity of the connected generation units is not important. On the contrary, many of the policy issues and benefits are related to capacity of generation units. Thus, a narrowed definition of DG could, among other things, be based on the capacity criterion.

D. Services Supplied

Generation units should by definition at least supply active power in order to be considered as DG.

The supply of reactive power and/or other ancillary services is possible and may represent an added value, but is not necessary.

E. Generation Technology

In some cases, it can be helpful to clarify the general definition of DG by summing up the generation technologies taken into account. It would however be difficult to use this approach to come to a definition because the availability of (scalable) technologies and of capacities, especially in the field of renewables, differs between countries. Also conventional systems such as gas turbines are available over wide ranges (a few kW to 500 MW and more).

Sometimes, it is claimed that DG technologies should be renewable. However, it should be clear that many small-scale generation technologies exist that do not use renewables as a primary source. On the other hand, not all plants using ‘green’ technologies are supplying DG. This would, for example, depend on the plant size or on the grid to which the installation is connected (transmission or distribution). Should a large off-shore wind farm of 100 MW or more be considered as DG? And what about a large hydro power plant located in the mountains?

F. Operation Mode

The operation mode (being scheduled, subject to pool pricing, dispatchable) is not considered as a key element in the general definition of DG [9]. This is a correct view, but at the same time it must be recognized that many problems related to DG, essentially have to do with the fact that these generation units being beyond control of grid operators. So, it can be meaningful to use (elements of) the operation mode as a criterion to narrow the definition.

G. Power Delivery Area

In some cases, DG is described as power generated and consumed within the same distribution network. As correctly stated in [9], it would be difficult to use this as a criterion, even for a narrowed definition, because it requires complex power flow analyses.

H. Ownership

Also ownership is not considered as a relevant element for the definition of DG [9]. Thus, customers, independent power producers (IPPs) and traditional generators can own DG units.

XI. SUMMARY AND CONCLUSIONS

This paper started from the observed renewed interest in small-scale electricity generation. General elements of the drivers for this development are discussed both from the economic and environmental point of view. Small-scale generation is commonly called DG and we try to derive a consensus definition for this latter concept. It appears that there is no agreement on a precise definition as the concept encompasses many technologies and many applications in different environments. In our view, the best definition of DG that generally applies seems to be ‘an electric power generation source that is connected directly to the distribution network or on the customer side of the meter'. Depending on the interest or background of the one confronted with this technology, additional limiting aspects might be considered. A further narrowing of this 'common divider' definition might be necessary depending on the research questions that are looked at. However, the general and broadly understandable description as proposed here, is required to allow communicating on this concept.

From a technical viewpoint, the paper discusses the impact on the protection and the safety of the grid. A lot of attention is paid to the interaction of the DG units with the quality of the grid voltage. Both static and dynamic voltage analysis are used to demonstrate the interactions. The choice of generator type has a major influence: two types are distinguished, synchronous and induction; the impact of the power electronic converter that may be used, is treated. An actual grid is used for supporting the results by simulations.

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Johan Driesen (S'93–M'97) was born in 1973 in Belgium. He received the M.Sc. degree in 1996 as Electrotechnical Engineer from the K.U. Leuven, Belgium. He received the Ph.D. degree in Electrical Engineering at K.U.Leuven in 2000 on the finite element solution of coupled thermal-electromagnetic problems and related applications in electrical machines and drives, microsystems and power quality issues. Currently he is an associate professor at the K.U.Leuven and teaches power electronics and drives. In 2000-2001 he was a visiting researcher in the Imperial College of Science, Technology and Medicine, London, UK. In 2002 he was working at the University of California, Berkeley, USA. Currently he conducts research on distributed generation, including renewable energy systems, power electronics and its applications, for instance in drives and power quality.

Ronnie Belmans (S'77-M'84-SM'89-Fellow '04) received the M.S. degree in electrical engineering in 1979, the Ph.D. in 1984, and the Special Doctorate in 1989 from the K.U.Leuven, Belgium and the Habilitierung from the RWTH, Aachen, Germany, in 1993.

Currently, he is full professor with K.U.Leuven, teaching electrical machines and variable speed drives. He is appointed visiting professor at Imperial College in London. He is also President of UIE.

He was with the Laboratory for Electrical Machines of the RWTH, Aachen, Germany (Von Humboldt Fellow, Oct.'88-Sept.'89). Oct.'89-Sept.'90, he was visiting associate professor at Mc Master University, Hamilton, Ont., Canada. During the academic year 1995-1996 he occupied the Chair at the London University, offered by the Anglo-Belgian Society. Dr.Belmans is a fellow of the IEE (United Kingdom). He is the chairman of the board of Elia, the Belgian transmission grid operator.

2. DISPERSED GENERATION AND SYSTEM STRUCTURE – THE CRUCIAL EXCHANGE LAYER BETWEEN TRANSMISSION AND DISTRIBUTION

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Abstract—The transition from the present power system with a high share of large-scale generation towards a network that is able to accommodate a large amount of dispersed and intermittent generation has started. This paper investigates the effects of dispersed generation on the system structure. The power exchange layer between the future transmission and distribution system is essential, as is the developing shared public – private responsibility for Power Quality

and reliability. The Need for new experiments with distributed systems, test- and certification procedures and analyzing tools, spanning the technical, economic and regulatory levels in the power systems, becomes clear.

Index Terms—Dispersed Generation; Transition; Intelligent Control; Power Quality; Reliability; Testing; Integrated Tools;

I. INTRODUCTION

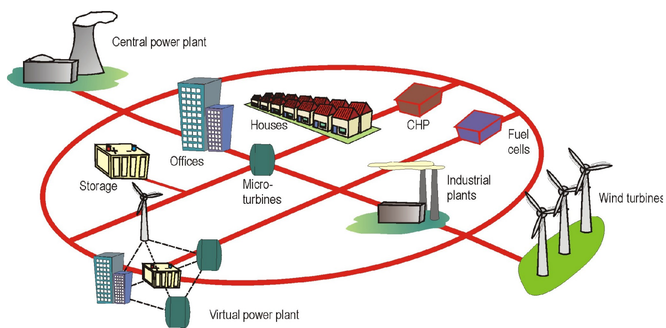
The electrical power system of today is a large sophisticated technological entity with a history of more than 100 years. That history stretches from a time when electricity was a minor energy source to the present day, when electric power provides many of our everyday energy needs and is crucial for everyday life. This migration towards a larger share of electricity of our energy consumption will continue, as will increase our dependency on electricity [1], [2].

Nearly all forecasters foresee society making increasingly use of this least tangible yet most convenient energy carrier in the future. The existing power system has grown organically. Each new development in society was accompanied by its own incremental modification to the network, with the most obvious features of change being the continuous increase in scale and interconnection for increased reliability. Until the end of the 20th century, the majority of all the power, supplying the transmission and distribution network, came from central generating capacity. The power system is, in organizational terms, like a pyramid with its control centers at the top.

Things have changed now and are still changing. The new regulatory frameworks connected to the deregulation of the electricity markets have emerged. National policies to increase the amount of renewables, with drivers like the global climate change have been put in place. New technologies that make use of economy of numbers instead of economy of scales are introduced. Real time price information systems and advanced control of power flow are being developed. Power markets are in a transition phase finding a new equilibrium between costs, performance and risk as depicted in Fig. 1.

Fig. 1. New equilibrium between costs, performance and risk.

Energy generation and transmission & distribution networks will be operated different in the future. Dispersed Generation (DG) and Renewable Energy Resources (RES), including e.g. wind, solar, biomass and gas-based micro-technologies are expected to supply at least 15% of all electricity requirements in 2010 in the European Union [3]. Small to medium sized (<100 kW – 50



MW) conversion technologies, including high speed micro and mini power turbines, reciprocal machines, fuel cells, power electronics, and energy storage, will be installed on the electrical network over the next years [4]. Their share will continue to increase in the decades after 2010. As a consequence visions of a future power system that look like an energy web emerge, like the one depicted in Fig. 2. It accommodates different technologies, large quantities and a wide range of power ratings of DG and RES.

Fig. 2. Vision of a Future Power System.

Dispersed generation and renewable energy sources are already part of today's power system. They have been connected to the network, but do not take part in power system management. This 'fit and forget' policy is possible as long as the share of these sources is low. However, if this 'fit and forget' policy is maintained in the future the power system will become increasingly more difficult to manage, with high associated costs and inefficiencies. In [5], [6] these associated costs are calculated for the UK case.

II. THE EMERGING FUTURE POWER SYSTEM

With the general belief that there is a shift towards small scale dispersed generation [7], local distribution grids, including mini and micro grids, get a lot of attention in the scientific community and much research funding. However the large-scale part of the power system must not be forgotten, it not realistic to think of a future power system that consists solely of local distribution grids and its only generation comes from the many small scale generators. Large generators in the future can be or renewable nature such a large (off-shore) wind farms and photovoltaic systems. As a result the vision is that in the electricity network of the future a global or regional transmission system with large-scale generation is connected to local distributions systems containing numerous small-scale generators. Both systems in their interaction form the sustainable, reliable and affordable power system of the future.

The future transmission system is very familiar with the present day situation, except for more power flows across the transmission network, due to trading and the additional presence of large-scale intermittent sources such as (off shore) wind power plants and photovoltaic systems. The local power distribution system(s) on the other hand can be quite different from todays. Nearly self-supporting rural, urban or industrial areas are possible, compared to areas with a more classical (consumption only) behavior. Many generators of different technology based on renewable energy or CHP are present here. Furthermore the future electricity customer becomes more directly involved in the power system because he "owns" part of the assets on the local distribution level. The customer is environmental concerned and becomes "more in control" and asks for service differentiation (Power Quality and reliability) based on his specific needs.

Based on this vision a number of consequences follow, such as: increased need for power flow steering at the transmission level (bulk power), power flows in both directions at the local distribution level, more balancing needs (due to fluctuating nature of generation) and availability of real time price information and options for differentiating Power Quality (PQ) and reliability.

This gives rise to questions like:

- How will the power exchange layer between transmission (global) and distribution (local) look like?
- What markets (mechanisms) are needed e.g. for balancing?

- How is dealt with the emerging shared public-private responsibility for Power Quality and reliability investments?
- How is the transition from the present state of the power system to the desired future accomplished? Which stakeholders must be involved and what is needed to speed up the process?

III. THE POWER EXCHANGE LAYER

A key question to consider is how the power exchange layer will develop between the still existing large-scale generation, including e.g. large-scale offshore wind power, and the numerous distributed resources. Two models are examined, the Camel and the Dromedary model, which are illustrated in Fig. 3. The Camel model envisages large power plants connected to one another via a high-voltage transmission network, while a low-voltage distribution network interconnects the micro and mini grids that are (nearly) self-supported. Power is exchanged between the high (HV) and low voltage (LV) layer over a relatively lightweight medium-voltage (MV) network. Alternatively, the Dromedary model assumes that both the large-scale plants and the mini and micro grids are connected to each other via a well-developed and strong medium-voltage network.

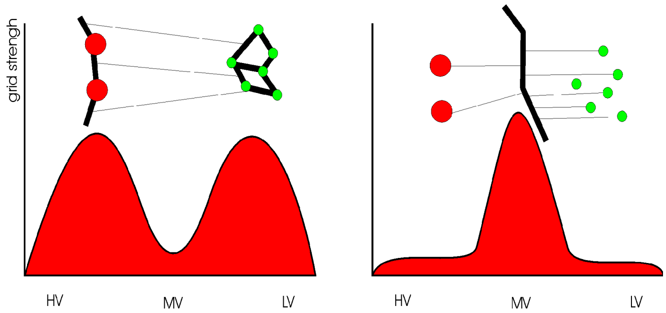


Fig. 3. Camel and Dromedary model for the exchange of power between the HV and LV layer.

If the Camel model becomes reality investments are done mainly in the HV and LV network. MV network investments are avoided when possible. When looking at the LV network, substantial investments are done locally (probably at the customers site) to balance between local demand and supply as much as possible, maintain voltage levels within tolerances and control the Power Quality and reliability at the connection points. Because maintaining the voltage levels and control of the PQ is a difficult task in the LV network with a relative weak MV coupling there will probably be a large emphasis on information technology and control systems. The involvement of the customer to a large extent in this model gives rise to public – private investment questions like: who is responsible for what part and which costs and who receives what benefits [8]?

When the Dromedary model becomes reality, the MV network will be reinforced and serves as a strong primary means for keeping the voltage levels of the LV feeders within limits and maintain a certain PQ and reliability. This resembles most closely the present (ideal) network situation. As a consequence limited special measures need to be taken at the local LV network. The network company installs advanced measuring and control tools at the feeders and the MV substations. Even in this strong MV network maintaining the voltages within the tolerance band and assure PQ and reliability with a lot of small scale embedded generators will become increasingly difficult with only direct control functionality at the entrance point of the feeders. It is therefore likely that there will again be a demand for intelligence being introduced at the individual connected generators. And as a consequence the question arises: who controls the dispersed generators, to what extent?

IV. SHARED PUBLIC - PRIVATE RESPONSIBILITY

Both the network company and the customer determine the Power Quality and reliability at the connection point. This is shown in Fig. 4. together with the necessary controls, which will become interrelated.

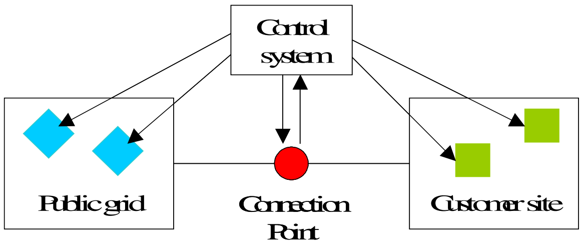


Fig. 4. Power Quality at the connection point determined by both public grid and customer site.

The performance is determined by the nature of the public grid, e.g. “strong” (Dromedary model) versus “weak” (Camel model). Also the installed network components affect the PQ and reliability of all customers connected to that particular part of the network. On the other hand individual customers may “pollute” their own site with installed equipment like inverters and also their neighbors through the public grid. It is evident that PQ and reliability is a shared responsibility between the public grid and the private customer. To determine each contribution and share of the investment a complex decision problem arises: what should be done publicly (by the network company) – to the benefit of all – and what privately (by the individual customer)? Also a complex control problem emerges: how to safeguard the PQ and reliability at the customer site and with this the testability of the integrity of the system? These problems arise because the hardware is distributed between the public grid and the customer site. The control system (Fig. 4.) must have information access and control capabilities in both the public grid and customer site.

V. NEEDED MARKET MECHANISMS

The value of DG and RES for society within a deregulated framework is determined in markets. Currently the power market is mainly an energy market (in terms of kWh). Already a lot can be done to improve the integration of DG and RES. Examples are:

- Develop better generation forecasting tools.
- Cluster a large number of intermittent sources.
- Combine (clusters of) intermittent and controllable production (e.g. wind and CHP).
- Make use of storage facilities.

Information and communication technology that operates on the power market is essential for this. Tariffs based on real-time prices are step forward. This presumes of course that intelligent and distant metering is introduced.

Markets for energy (kWh's) alone will however not solve the problems with regard to grid investment costs. It might be possible to postpone or defer grid investments if distributed generation can be used to shave local peak demands and provide capacity. The creation of a real-time capacity market (kW) on several grid levels (high, medium an perhaps low voltage) is needed.

A third market that needs to be created is a market for ancillary services e.g. for Power Quality. Uncontrolled distributed generation might make PQ and even reliability worse. However, when it is activated at the right time at the right place, it can even help to improve. Specific incentives to do so are currently lacking in the European Union. In the future such a market is needed.

Last but not least, those DG resources that deliver most valued benefits to society, e.g. in terms of reducing the stress on the environment should be preferred. Providing a reward in the form of carbon-credits and green certificates can fulfill this task if the DG contribution can be determined objectively.

VI. TRANSITION

For a successful transition to a future sustainable energy system all the relevant stakeholders i.e. government, consumers, network companies, generators and traders must be involved. There is a strong need for experiments to create awareness and acceptance, pilot new equipment, develop new test procedures for distributed and integrated systems. But not only technical experiments are needed but also experiments in markets and at the organizational level. For example regulatory regimes should be revised on a regular basis, based on new knowledge and gained experience and based on this improved to provide the right ground for innovations. New business models and organizational structures can be introduced and experimented with e.g. allowing network companies limited commercial activities with respect to long time investments. Traditionally the power sector consists of three levels (technical, economic and regulatory) as show in Fig. 5. Information exchange between these three levels differs in intensity and hinders innovation and thus transition because the system as a whole should change. It is therefore crucial to bridge the gaps and prevent distortion & delay. As markets define the success of the technologies, and markets are pre-conditioned by the governance structure and regulation, a dynamic interaction between the three levels is needed, employing an integral approach.

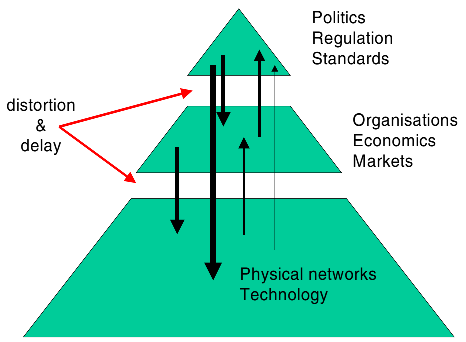


Fig. 5. Technical, economic and regulatory level in the power system

Just as new test procedures and methods have to be developed for the emerging distributed and integrated nature of new technical systems, new modeling and analyzing tools for learning spanning the three levels in the power system have to be developed. These tools combine the realms of network physics, economics and governance and are not simply a sum of individual system, market or socio-economic studies.

VII. SUMMARY AND CONCLUSION

The power system is changing fast. Our dependency of electricity is increasing and requires a high Power Quality and reliability. The amounts of Dispersed Generation and Renewable Energy Sources are increasing in the power system.

The effect of dispersed generation on the system structure becomes visible at the power exchange layer between the transmission and distribution network, and depends on the exchange layers character. Dispersed generation asks, not only for new markets but also solutions for shared public - private Power Quality and reliability problems. The Need for more intelligent control systems, new distributed systems and adequate test- and certification procedures becomes evident to safeguard the integrity of the power system as a whole. The transition towards a sustainable future power system also needs new tool for modeling and analyzing. These integral approach tools have to span the technical, economic and regulatory levels in the power systems to facilitate new learning and thus a swift way forward.

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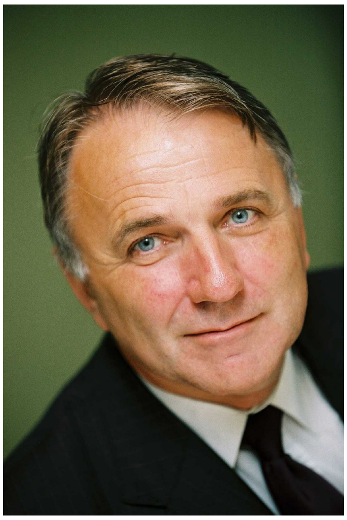

Pier Nabuurs studied electrical engineering and graduated in telecommunications from Eindhoven Technical University. He started his career at Philips Electronics as product developer and project manager optical recording (e.g. compact disc). Afterwards he joined the business unit Strategic Product Planning office copiers and printers of Océ. He was R&D manager electronics & software engineering. He became responsible for globalization of purchasing in the manufacturing & logistics department. As Manager Purchasing he introduced Early Supplier Involvement (ESI) and co-makership. As CEO of Océ-Belgium he was executive director of the strategic business unit Document Printing Systems and responsible for strategy, international marketing and sales and the product development program. In January 2002 he became CEO of KEMA, an international company specialized in high-grade technical consultancy, inspection, testing and certification.

Peter Vaessen studied electrical power engineering and graduated from Eindhoven Technical University in 1985, the same year that he joined KEMA. He held several research positions in the field of large power transformers and measurements in high-voltage networks. From 1991 to 1996, he managed several realization projects, among them construction of the Dutch 400 kV substations at Meeden and Eemshaven. As a consultant he has experience in the conceptual design of integrated electrical systems and innovative techniques and tools for transforming existing large-scale hierarchical systems into flexible dynamic structures, allowing economic utilization, competition and integration of RES and DG. He is actively involved in the technology strategy of KEMA and works for the Dutch Ministry of Economic Affairs on setting up scientific research programs in the areas of power electronics and the future long-term reliability of the Dutch electricity network.

Peter Vaessen has successfully chaired and participated in (inter)national panel sessions and conferences, delivered numerous presentations and published some 30 papers. He is co-author of the Dutch book "Rapid current, the next revolution in electricity." He has coached some 60 students (University and Polytechnic) during their practical work at KEMA.

3. NEW TASKS CREATE NEW SOLUTIONS FOR COMMUNICATION IN DISTRIBUTION SYSTEMS

Bernd Michael Buchholz[1], Zbigniew A. Styczynski[2]

Abstract— In Europe Dispersed and Renewable Energy Sources (D&RES) are mostly operated without remote control mechanisms, feeding in a maximum possible generation. The further increase of the contribution of D&RES in the peak power balance up to 60 % in accordance with the goals of the European Communities for the year 2010 requires innovative approaches to keep the reliability of the power supply on the actual high level. First of all this requires an extended contribution of D&RES to the system services. New communication facilities are required to provide a decentralized energy management and to ensure the provision of system services by D&RES. In a case study, it is analyzed how the existing infrastructure can be used to build a communication network with different physical communication channels. Further more, the application of communication standards is investigated and in the result the use of the data models and the services of the communication standard IEC 61850 (for substation communication) is recommended. It is shown that the advantageous application of this standard and its subsequent standards IEC 61400-25 for wind power plants and IEC 62350 for dispersed generation requires consistency of all described models. Finally, it becomes clear that the implementation of more communication in the distribution level helps to improve the distribution system management. The example of a faster network restoration after faults is demonstrated.

Index Terms - renewable generation, energy management, network operation, communication, performance criteria

I. INTRODUCTION

In the environment of a growing share of dispersed and renewable generation the distribution networks will change from passive into active systems. In the power systems of the future also distribution networks have to contribute to the system services in coordination with the transmission system. The idea of virtual power plants (VPP) will become reality where a number of dispersed and renewable generation units (partially with intermittent power output), storage units and controllable loads will be clustered and managed in such a way that the power exchange with the outer world can be scheduled and dispatched with a high level of accuracy. The decentralized energy management inside VPPs requires communication facilities which are mostly not applied in the today's practice of the distribution system operation.

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[2]

II. BASIC PRINCIPLES AND TASKS

The efficiency of future communication networks in the distribution level requires some basic principles:

1. In contrary to the existing practice, where power generation is located on a rather concentrated area and therefore information and data is transferred on local networks or field busses, the supervisory control and dispatching of dispersed generation will be spread over a wide area. For economical reasons already existing infrastructure has to be used; that also means the utilization of different communication channels like radio, fiber optics, power line carrier and telecommunication cables will be applied within one network as long as they are available in the environment.
2. The communication over the different physical layers has to be compliant to a common standard regarding data modeling and communication services. The main requirements for such a standard are:

- plug and play ability,
- possibilities for mapping to different physical layers,
- expandability of the data models and introduction of new models in accordance with the new and enhanced communication tasks.

3. Thus, if the communication network for dispatching the VPP covers a whole distribution network additional system services can be provided by the same network.

Therefore, communication tasks for distribution networks of the future include

- the contribution to the active power balancing through dispatch of power generation, storage and controllable loads in the framework of a VPP,
- the transfer of metered values as a support for the decentralized energy management and for billing,
- the provision of further system services like congestion management, reactive power and voltage control, fault location, network recovery after faults, islanded operation, black start capability etc.

The application of these ideas is investigated in the framework of the German "Network for Energy and communication", a project sponsored by the German Ministry for Education and Research.

III. CASE STUDY

The design of the communication network was investigated for a typical distribution network shown in Figure 1.

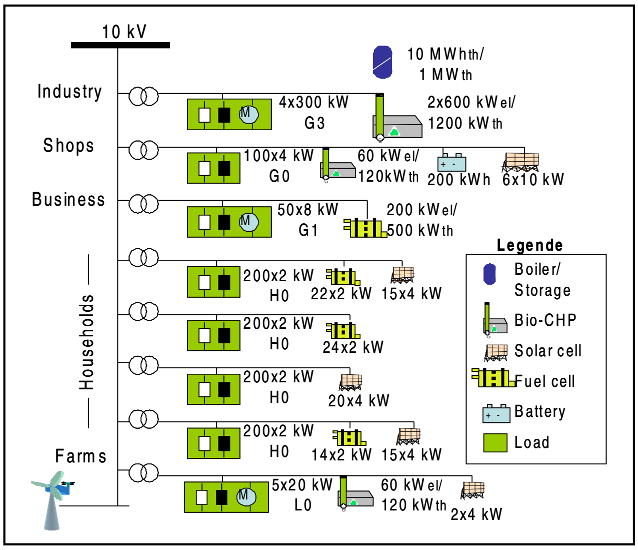

Fig. 1. Considered distribution network

Along a 10 kV feeder 8 ring main units supplying different types of low voltage consumers are connected. At the end of the feeder there is a further wind power plant.

The low voltage lines supply consumers with different load profiles in accordance with the German standard load profile types defined by the German Network Society (VDN): G3 - industry, G0 - shopping center, G1 - business center, H0 - households, L0 - rural farm. Various D&RES and storage units are located in the low voltage networks as shown in figure 1. They provide their specific generation profile partially depending of weather conditions. Demand side management is planned with 12 x 20 kW in the industrial network, 10 x 2 kW in the shopping area and 40 x 2 kW in the business center.

For the distribution network described the optimum communication network has to be designed in accordance with the following criteria:

1. A maximum latency time is assigned to each class of information, e.g.

- Control with return information	2 s
- Alarm	1 s
- Event message	5 s
- Metered or measured value	2 s
- Power schedule (96 target values)	20 s

2. The content and the classes of information exchange have to be defined for each active component of the network - loads, generators, storage units, substation equipment. The amount of data for communication is quite different, for example only the metered value will be communicated every 15 minutes for non-controllable loads or photovoltaic units. On the other hand the larger CHP plants provide 6 alarms, 24 event messages, 12 measured and 2 metered values, 6 controls, 2 target values as well as target profiles for active and reactive power.

3. The volume of data transfer has to be defined in accordance with operational needs for worst case and normal scenarios. In the normal case the metered values of all components will be transferred in a 15 minutes interval. One time per day the target profiles of the

generation units above 100 kW will be communicated. Further more, 40 target values, 20 event messages, 10 controls will be communicated. In the worst case (e.g. voltage dip) each component will send a report with alarms and measured values and this has to be performed within 5 s.

4. The selection of the communication protocol defines the data volume for each data class. Chapter IV discusses special features of available IEC standards, in particular the application of IEC 61850.

5. The selection of communication channels is based on their availability, a cost comparison of different alternatives and the baud rates providing the performance in worst case and normal scenarios.

The experience gained in first pilot projects with VPPs [1, 2] underlined the need to apply communication protocols based on common standards for all channels used. Otherwise the engineering expenses will grow and the operation of the communication network will become inconvenient.

IV. COMMUNICATION STANDARDS

The first international standards for digital communication in power systems were developed in the nineties. These standards were limited regarding their 'plug and play' ability. Figure 2 gives an overview over IEC standards for supervisory control in electric networks.

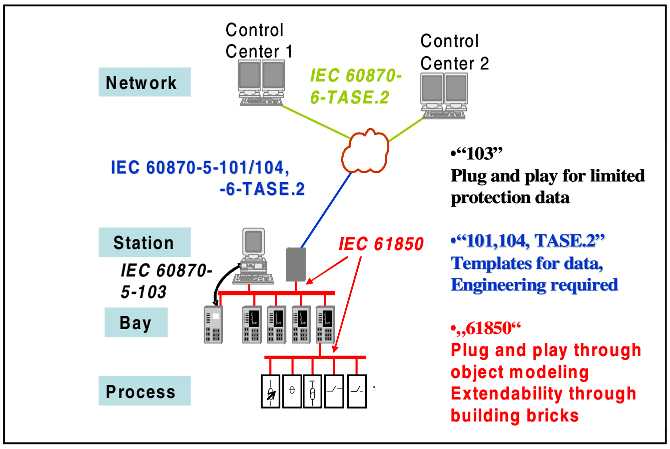

Fig. 2. IEC standards for communication in electric networks

Only the latest standard IEC 61850 for communication in substations (published as standard in 2004) responds to the requirements of chapter II, topic 2.

The 'plug and play' - ability is reached by the detailed object modeling based on logical nodes (objects like circuit breaker or transformer etc.) and data (information like "status ON" or "Buchholz alarm" etc.) with the supplement of different attributes (like time stamps, validity information etc.) [3].

The mapping to different application layers was foreseen in the reference model of the standard in accordance with figure 3.

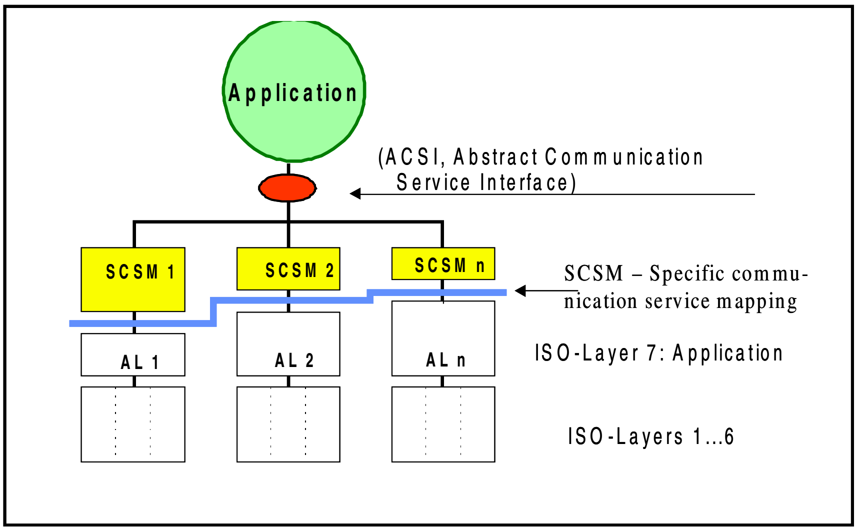

Fig. 3. Reference model of IEC 61850

The abstract communication service model describes the data models and the services in an abstract form. The protocol requires the definition of all layers of the ISO/OSI model. IEC 61850 defines in Part 8.1 the 'Manufacturing Message System' (MMS) as the base for the first standard conform application layer (AL1) and Ethernet for the lower layers. The specific communication system mapping SCSM ensures the adaptation of the services and models to the layers selected. This way, IEC 61850 allows the adaptation of future communication methods to the core elements of the standard - the ACSI (described in the parts 7.1-7.4). Consequently, through the SCSM different link and physical layers can be applied.
Last but not least, the object models can be extended on demand. IEC 61850 defines the building rules for such extensions.

In the result of these features the standard IEC 61850 is suitable to serve as a general standard for all communication tasks in power systems. Therefore, the basic rules and models of IEC 61850 are inherited in the following subsequent standards:

- IEC 61400-25 for communication of wind power plants [4],
- IEC 62350 for communication of dispersed generation [5].

As a goal of the new standards it was declared that all existing services and models of IEC 61850 will be taken over as defined and only the needed extensions will be added.
Unfortunately this goal is not reached with the drafts existing [5, 6]. The new standards

- use a different wording for the same contents and arise confusion,
- define data models for the same objects in different ways instead using the existing models,
- don't use the building bricks for supplement models.

Table 1 demonstrates the different terms for the data classes.

Table 1 Comparison of terms for data classes

IEC 61850	IEC 62350	IEC 614000-25
Common LN information	Configuration settings	General information
Controls	Controls	Control information
Status information	Status information	State information
Measured values	Measured values	Analogue information
Setting	Control settings	Setpoint information

Table 2 demonstrates the different names of the logical node "converter" and of a part of its measured values. A proposal to harmonize the names with IEC 61850 (where the definitions are allocated in other logical nodes "LN" for measured values - MMXU for three phase measurements and MMXN for general measurements) is added in the first row.

Table 2 Comparison of names for data models

Attribute	Harmonized	61850	62350	614000-2!
LN Name	ZCON	ZCON	DINV	WCNV
Measured Values				
Actual frequency	Hz	(LN MMXU: Hz)	OutFr	Hz
AC Voltage	PPV, PhV	(LN MMXU: PPV,PhV)	OutV	GriPPV,GriPh\
AC Current	A	(LN MMXU: A)	OutAmp	GriA
DCVoltage	Vol	(LN MMXN: Vol)	InpV	DcV
DC Current	Amp	(LN MMXN: Amp)	InpA	DC/A

In accordance with figure 1 there will be a need to communicate information from wind power plants, other D&RES and substation equipment over a common communication network. Consequently, the consistency of the data models used is mandatory.
The relevant IEC working groups of TC 57 (62350) and TC 88 (61400-25) are requested to ensure the consistency of all subsequent standards with IEC 61850. Otherwise there will be no acceptance of the new standards from both, power automation industry and utilities.

V. DESIGN OF THE COMMUNICATION NETWORK

IEC 61850 was analyzed regarding the size of telegrams for each data class. The results in table 3 present the worst case, what means the maximum possible number of bytes. In practice the services of IEC 61850 create reports within a given time interval in which all changed information will be embedded. Therefore, the net bytes will be much lower as stated. However, these figures build a good base for the communication network design. The design task consists of the distribution of the communication clients over the possible communication channels with minimum expenses and under the condition that the baud rates of the selected channels ensure the required performance in worst case and normal scenarios. A possible design of the communication network which meets the performance requirements and combines different physical channels is shown in figure 4. The large CHP- plants of the industrial network play a significant role in the power balance of the distribution network and impact the energy tariff of the industrial plant. They are connected by a dedicated ISDN line which was available. The other generation and storage units in the shopping and business area as well as the access to weather forecast data (for load and renewable generation prediction) need only a dial up line. The wind power plant is connected via a radio channel with the target to combine this kind of communication with the others.

The main load of communication is assigned to the 'Distribution Line Carrier' (DLC), which can reach baud rates higher than 300 kBd [6]. Over this channel the dispersed generation units in the household and rural networks communicate, the metered values of all loads are reported, the control commands for demand side management are send out and the equipment in the substations is incorporated to provide a new class of distribution system management. For this network the installation of new communication lines was avoided.

Table 3 Telegram size for different data classes (Byte)

Data class	Raw data array	Overhead Layer 7 (MMS)	OverheadOther layers	Overall
Status inform.	11	161	64	236
Control	14	1245	384	1643
Measured value	15	161	64	240
Metered value	15	161	64	240
rray (96 metered values)	1440	1320	128	2888
Target value	15	693	192	900
Schedule (96 target values)	480	388	128	996

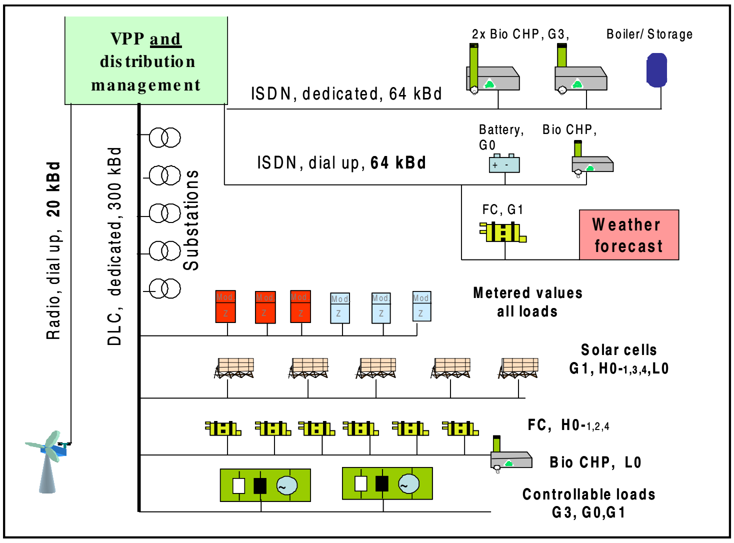

Fig. 4. Scheme of the communication network

VI. BENEFITS FOR OTHER SYSTEM SERVICES

The availability of communication channels in the distribution level allows the improvement of various system services. The example of a supply restoration after faults is demonstrated in figure 5.

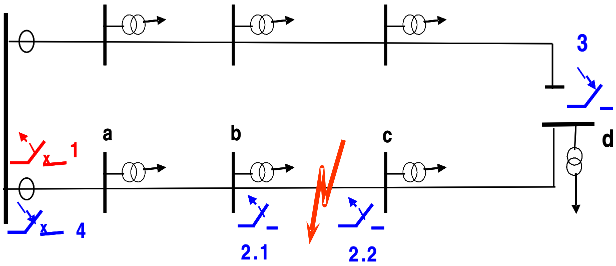

Fig. 5. Supply restoration after faults in an open loop

Preferably, distribution networks are operated with open loops. The loop in Figure 5 is disconnected in the ring main unit “d”. In case of a fault the protection of the feeding substation trips and the faulted feeder will be switched off. All ring main units (a-d) loose their supply (operation 1). Now, the maintenance staff allocates the faulted feeder part through driving along the feeder and reading the fault indicators in the ring main units. After localization the faulted part is disconnected by the switching operations 2. The restoration of supply is provided after that by the switching operations 3 and 4. The whole restoration procedure takes more than one hour in average. But, if communication channels are available in the ring main units the restoration procedure can be performed remotely. The restoration time will shorten up to minutes only. Similar benefits can be demonstrated for other system services as well. Therefore, communication is a key to improve power quality.

VII. CONCLUSIONS

The expected large scale penetration of D&RES requires a new sharing of system services between transmission and distribution levels The distribution networks will become more active and communication networks have to be established for that purpose.

Setting up a cost efficient communication requires the use of existing communication channels and of standardized protocols. On behalf of an example of a distribution system with different characteristics for load and generation the design of the communication network was investigated. It is shown that IEC 61850 provides the required features to serve as communication standard. However, the consistency of the subsequent standards IEC 61400-25 and IEC 62355 should be reached as a prerequisite for a broad acceptance in practice. Examples of actual deviations and inconsistencies are given. Further more, it is shown that the communication tasks of the example system can be performed by a combined communication network with dedicated and dial up communication channels on different physical media like ISDN, Distribution Line Carrier and radio transmission. The availability of communication channels in the distribution level benefits the management of system services and helps to improve the power quality.

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IX. BIOGRAPHIES

Bernd Michael Buchholz (1948) received his MS and PhD at the Power Engineering Institute in Moscow in 1973 and 1976 respectively. After that he was assigned project manager and later director of R&D at the Institute of Energy Supply in Dresden. In 1990 he joined the Siemens AG and took over the head oft the R&D department of the division “Protection and Substation Control Systems” in Berlin and Nuremberg. Since February 2000 he is director of the business unit “Power Technologies” in the “Service” division of the Power Transmission and Distribution group in Erlangen. Between 1995 and 2000 he worked as editor for the parts 4 and 7 of IEC 61850. He is the German member of the SC C6 of CIGRE “Dispersed generation in distribution systems”.

Zbigniew Antoni Styczynski (1949) received his MS and PhD at the University of Wroclaw. He finished his professorial dissertation in 1985 at that University for which he received a special award from the Polish Ministry of Higher Education. From 1991 until 1999 he worked at the Technical University of Stuttgart, Germany. In 1999 he became the Head of the Chair of Electric Power Networks and Renewable Energy Sources of the Faculty of Electrical Engineering and Information Technology at the Otto-von-Guericke University, Magdeburg, Germany. Since 2002 he is also the dean of the Faculty. His special field of interest includes electric power networks and systems, expert systems and optimization problems. He is senior member of IEEE PES, member of CIGRE SC C6, VDE ETG und IBN and fellow of the Conrad Adenauer Foundation.

4. INTEGRATING DISPERSED GENERATION INTO THE DANISH POWER SYSTEM - PRESENT SITUATION AND FUTURE PROSPECTS - (Paper 06GM0520)

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***Abstract*—**Since the early 80s a huge amount of dispersed generation (DG) has been implemented into the Danish power systems. Today the Danish system has a share of 18,5% electricity consumption produced by wind turbines and 26,5% produced by combined heat and power units (CHP), of which the biggest part is installed in the western part of Denmark. The paper shows the technical measures as well as utilization of market mechanisms applied by the Danish system operator, Energinet.dk, to handle the challenging situation of safe and reliable system operation. Future prospects with respect to the internationally growing wind power capacity and respective need for a market for ancillary services are presented**.**

***Index Terms*—**dispersed generation, energy market, CHP units, wind power, regulating power, forecasting systems.

I. INTRODUCTION

DENMARK is electrically divided into two parts - western Denmark forms the northern part of the UCTE- and eastern Denmark constitutes the southern part of the Nordel synchronous area (Fig.1). The eastern and western Danish networks are planned to be connected by a High Voltage Direct Current (HVDC) link by the year 2009. Being a link between the two synchronous areas Denmark faces high energy transits.

Since the early 80s a huge amount of dispersed generation has been implemented into the grid - mainly in the UCTE part of Denmark, where e.g. today 23 % of the energy consumption is produced by wind turbines and about 32 % by CHP units. More than 50% of the total production capacity is implemented within local distribution grids, making control and forecasting of system operation very challenging.

Thus the transmission system operation requires a careful planning as well as the intelligent utilization of possibilities offered by the liberalized electricity market.

Energinet.dk is responsible for secure and reliable operation of the power system (and natural gas), a well functioning energy market and for owning, operating and expanding the transmission infrastructure for electricity (and natural gas).

Daily operation of a system with massive infeed from uncontrolled generation units is a challenging task and depends strongly on interconnections to neighbouring countries and a well functioning international electricity market.

The further - also international - growth of wind power capacity may lead to increasing demand for national security of supply as well as the implementation of an international market for ancillary services for the efficient utilization of the available resources.

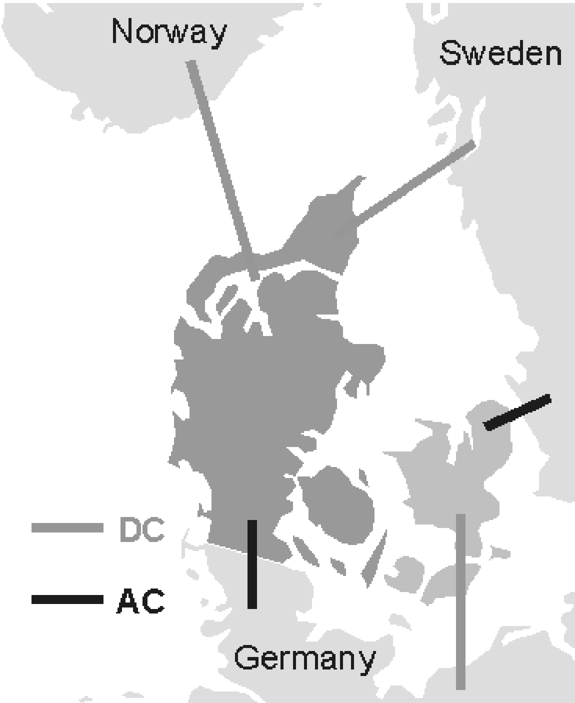

Fig. 1. Denmark between two synchronous areas

II. SYSTEM OVERVIEW

A. Structure of the Electric Power Network

The transmission system in Western Denmark is operated at 400 kV and 150 kV. To the south, it is connected to the UCTE synchronous area via 400 kV, 220 kV and 150 kV AC-lines to Germany. To the north, it is connected the Nordel synchronous area via HVDC links to Norway (1,000 MW) and Sweden (600 MW). The Eastern Danish system is operated at 400 kV and 132 kV respectively as a meshed transmission systems with AC connection to Sweden and HVDC connection to Germany.

Table 1 and Fig.2 give the key figures of the Danish power system. The primary power plants are thermal units, fired by coal or gas. A significant part of today`s installed capacity in the Danish system are decentralized units, such as wind turbines and combined heat and power (CHP) units, mostly connected to the distribution grid. This combination results in a change of the classical hierarchical loadflow structure - former passive networks have become active networks due to the changed loadflow direction, especially on windy days.

In the Western system the offshore wind farm Horns Rev A (HRA) with a rated power of 160 MW is connected to the 150 kV transmission system. The construction of the second offshore wind farm, Horns Rev B (HRB), with a rated power of 215 MW is announced by the year 2009 XIII.

In the Eastern system another new big offshore wind plant with a rated power of 215 MW is planned to be operating in 2009 -2010.

TABLE I

KEY FIGURES OF THE WESTERN DANISH POWER SYSTEM

	West DK Power [MW]	East DK Power [MW]	West DK Energy [GWh]	East DK Energy [GWh]
Production, Total:	7,648	5,222		
Primary power Plants	3,516	3,837	12,951	9,441
Local CHP units	1,593	642	6,839	2,559
Local Wind Turbines	2,379	578	4,875	1,709
Offshore Wind Farm	160	165		
Consumption, Total			21,246	14,262
Minimum Load	1,281	750		
Maximum Load	3,639	2,665		
Exchange Capacity				
Export UCTE	1,200	550		
Import UCTE	800	550		
Export Nordel	1,440	1,700		
Import Nordel	1,460	1,300		

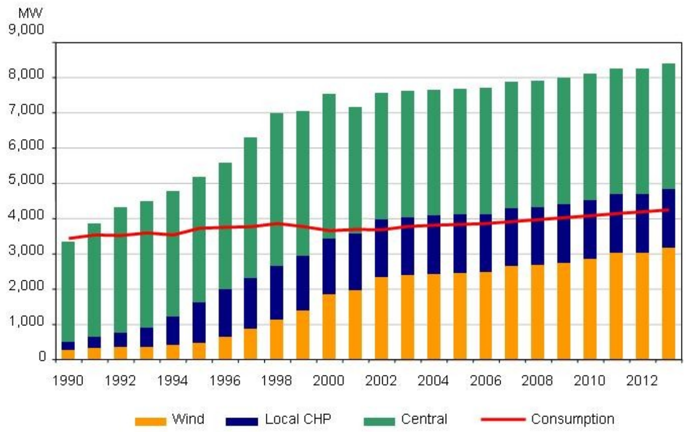

Fig. 2. Development of the Power Balance in Western Denmark

B. Planning and Operation of the system

Significant share of wind power and CHP units introduces several technical tasks to the system operator regarding the stable, safe and reliable operation of the transmission system, such as:

- Development of technical specifications for the grid connection of wind turbines which is based on prior experience; e.g. requirements like fault-ride-through capability of large offshore wind farms XIII.
- Constant improvement of wind power forecasts.
- Long- and short-term balance for the Danish power system.
- Responsibility for voltage stability and power quality.
- Wind turbine modeling as part of the Danish power system model.
- Preparation of the system for the implementation of more wind power.

Wind Energy

III. WIND ENERGY

A. Operation of a System with Wind Energy

The power generation of wind turbines depends on the wind velocity and follows natural wind fluctuations.

Large offshore turbines usually are located close to each other and show significant correlation between their output power. Experience from the operation of Horns Rev A (HRA) shows that power fluctuations within 10-min intervals can be remarkable high due to the concentration of wind power in a small area of about 20 km^2 XIII. The power gradients may reach values of 15 MW/min for this 160 MW wind farm resulting in changes of generated power between none to the rated power within 10 to 15 minutes. Without control such power fluctuations may be introduced into the transmission system and even distributed to the neighboring transmission systems.

A control system has been developed which reduces this effect XIII. This is achieved by applying power gradient limits of the wind farm and by using secondary control of primary power plants and additionally fast power control of HVCD.

B. Power Balance and Regulating Power (Western Denmark)

The main target of keeping the power balance is to adjust power generation including power import and power consumption including power export as well as keeping the power exchange between Western Denmark and the UCTE synchronous area at the planned level.

The high share of wind power within the system results sometimes in extreme requirements for system operation due to power fluctuations mentioned above.

An impressing example is the hurricane of the 8th of January 2005 which crossed the whole area of Denmark resulting in a disconnection of nearly the total wind production (Fig.3). In this case the system operator had to handle a record high imbalance between schedule and production of more than 1,700 MW.

C. New Offshore Wind Farms

Up to now a sufficient amount of regulating power is available in the Western Danish power system to compensate intense power fluctuations from HRA by applying the load-frequency controller (LFC) accessing the secondary control on the central power plants.

The second offshore wind farm HRB will be located very close to the existing wind farm HRA. An analysis showed that it might be critical to compensate the additional power fluctuations using only the domestic regulating power XIII. A part of the power fluctuations will be reduced by the offshore wind farms` control themselves. In the analysis HRB was obliged to comply with the power gradient limit of +5 MW/min. Additionally, the use of the fast power control of the HVDC-connections will be necessary to keep the power balance in the Western Danish power system. This requires application of some HVDC- links' capacity for the regulating power to compensate the wind farms` fast power fluctuations.

However, the LFC control is not capable to handle the power regulation being required for the case shown in Fig. 3.

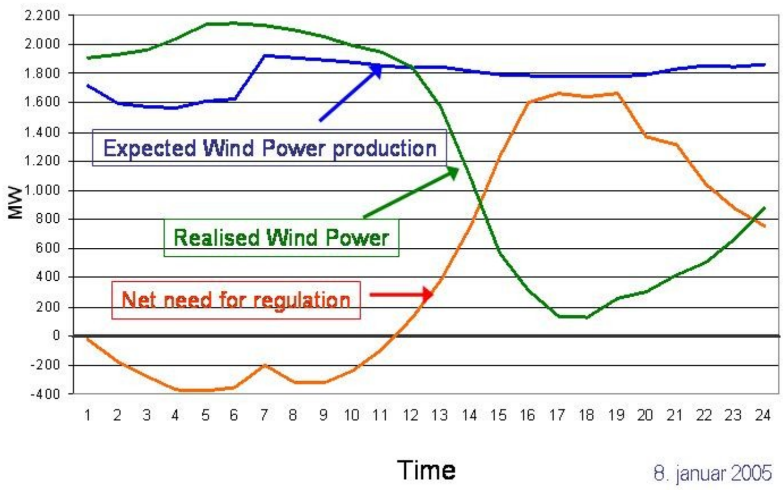

Fig. 3. Need for Regulation in Western Danish System during Passing of a Wind Front

D. Wind Forecasting System (Western Denmark)

Improving forecasting systems is one of the possibilities to improve the power balance. Reliable wind forecasts are essential for power system operation in Denmark.

The planned active power from a wind farm is based on wind forecasts which are transferred to active power forecasts. The first active power forecast is made a day ahead, but can be updated during the day.

The active power produced by wind farms is part of the power supplied from a group of power plants available to the Power Balance Responsible Player (PBRP). The PBRP controls the active power from this group of the power plants according to the latest power forecast in a way to comply with the planned total power production.

Deviations between power forecast and the delivered total active power are injected into the transmission system and should therefore be minimized.

The aggregated Western Danish wind power curve (Fig.4) has a very high power slope, resulting in a deviation of ±320 MW for a ±1 m/s wind velocity prediction fault appearing between wind speeds of 5 and 15 m/s. A relieving factor is the regional distribution of the wind turbines over the whole Western Danish area.

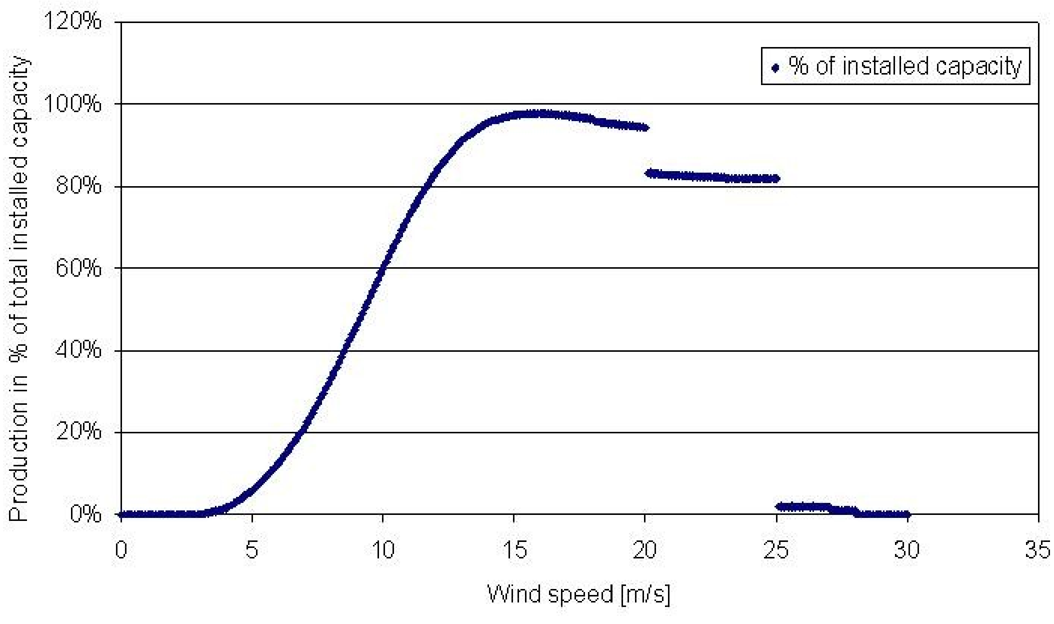

Fig. 4 Aggregated Wind Power Production Curve for Western Denmark

The wind forecast models have to be improved in several ways:

– Improvement of day-to-day forecasts because the amount of grid incorporated wind power is significant and still increasing (work in progress).
– Improvement of hour-by-hour forecasts: they have to comply with the power balances and planned operation of the power plants, planned power transits and consumption (work in progress).

In 2002, Energinet.dk funded a research project on ensemble forecasting at University College Cork (UCC), Ireland. In this context a real-time forecasting system called MELTRA was designed to meet specifically set requirements in Energinet.dk. It consists of 75 ensemble members and a graphics package for visualization of the forecasts (Fig.5).

MELTRA has undergone many changes since its first implementation. The upgraded 2005 system generates 3-day forecasts every hour and consists of around 6000 forecasts per day. Half of the forecasts are carried out as nested forecasts in higher resolution. The forecasts are converted into probabilities and, in combination with observations, provide the best possible forecasts of wind power. The MELTRA ensemble system is run on a 92 processor Linux cluster, which is believed to be a very cost-effective hardware solution. The resolution in the meteorological model is 45 km with a finer 5 km nested grid covering Denmark.

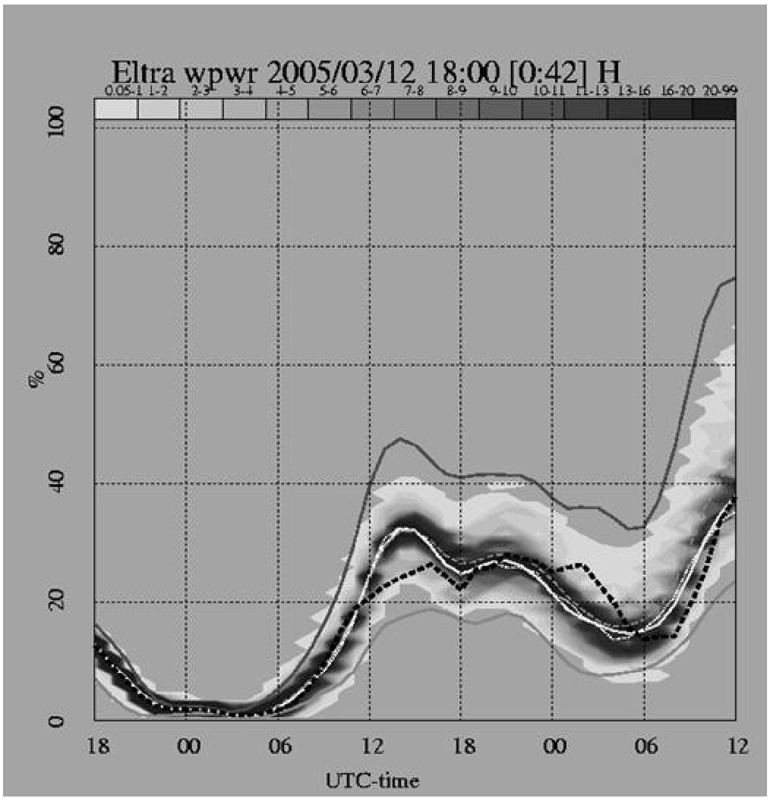

Fig. 5. 48-hour Power Prediction for the Western Danish Area; Grey colours: Probability Distribution; White Curve: Average Prediction; Black dotted curve: Measured Production

The major benefits of the first year's real-time experience with the MELTRA system can be summarized to:

- Averaged over one year, the implemented ensemble technique has a potential of at least 20 % better forecasts of wind power compared to a single forecast.
- The ensemble technique is also better in predicting wind power for single sites or smaller areas than a single forecast XIII.

E. Future Requirements for further expansion of Wind Power

An increase of the share of wind energy up to 35 per cent of the Danish electricity demand by 2015 has been suggested and will probably be given serious consideration XIII. This requires focusing on regulation power which is available within the present frames. Several issues are directed to:

Utilization of domestic regulation power could be applying the further development of price response mechanisms and better utilization of local scale CHP units introducing them to market terms.

The establishment of the planned Great-Belt connection between both Danish systems will allow for utilizing the regulating power control of both systems.

Further, the establishment an offshore transmission system connecting the large offshore wind farms with the grids of Norway, Denmark, Germany and Holland may reduce the impact onto the Danish transmission system.

IV. CHP UNITS

A. Technical Features with Respect to Control Power

Since the energy crisis of the 1970s small scale CHP power plants have been established to supply local heating systems of small cities. Simultaneously industrial CHP units have been installed. This concept is followed until today resulting in a high share of dispersed installed capacity, which is not as a matter of course available for power regulation and thus not contributing to system balance.

The distributed CHP-units' range in size is from a few kW up to 100 MW. Most of these units are gas turbines or gas engines. Traditionally the power production from these units depend to the heat demand, thus heat and electricity are strongly coupled. To eliminate this dependence, these units are equipped with heat storage tanks.

Most of the large thermal units are coal-fired CHP units which can extract steam for heat production. These units have an operating domain between 20 % and full power load without heat production. However, the operating domain for the power depends on the heat production - with higher heat production the minimum power load increases and the maximum power load decreases. According to the power station specifications XIII, these thermal units have a regulating capability of 4 % of full load/minute in the operating domain from 50-90% and 2 % of full load/minute below 50 % and above 90 % load. Besides the normal regulating capabilities these units can disconnect the heat production and, for a short period, utilize the extracted steam for electricity generation.

B. Closer Cooperation between TSOs and DSOs

Increasing security problems have provoked the tradition for a high degree of independence between TSOs and DSOs (distribution system operators) to be reconsidered.

A new control strategy shall include all local grids with DG into new responsibilities, such as control of reactive power, provision of data for security analyses, supervision of protection schemes at local CHP plants, updating under-frequency load shedding schemes and new restoration plans, including controlling dead start of local plants in emergency cases.

The implementation of such new responsibilities will require development of new control, communication and information systems. During normal operation all functions should be automatic. For emergency situations restoration plans have to be carefully prepared and trained. The targets concerning the systems redesign are:

- balance between demand and supply shall be ensured by sufficient available domestic resources,
- operators have to get access to an improved knowledge of the actual system conditions, both locally and centrally,
- efficient system control shall be available, especially during emergencies
- Black start capabilities using local generators shall be provided.

C. Cell Controller Pilote Project

Actually Energinet.dk executes a cell controller pilote project (CCPP) defining a demonstration area of a real distribution network ("cell"), where a new concept implementing new communication systems and new controller shall be implemented and tested according to the following ambitions XIII:

- in case of a regional emergency situation reaching the point of no return the cell shall disconnect itself from the high voltage grid and transfer to island operation
- after a total system collapse the cell has black-start ability to a state of island operation.

The CCPP aims to

- gather information about feasibility and approaches to utility-scale microgrids
- develop requirements specifications and preliminary solutions for a pilot implementation of the cell concept
- implement measurement and monitoring systems to gather and analyze data from the pilot area
- perform detailed design, development, implementation and testing of a selected pilot cell.

V. ASPECTS CONCERNING THE ENERGY MARKET

A. Structure of the Nordic Energy Market

The Nordic electricity market consists of several markets: the physical day-ahead market (Elspot), the hour-ahead (Elbas) trade and the real-time market for balance power (Fig.6).

The power plants find a Production Balance Responsible (PBR) to sell their energy production. The PBR sells the production either directly to the Nord Pool spot market or announces the capacity to Energinet.dk`s regulation power market. Energinet.dk transfers the regulation power bids to the Nordic TSOs Nordic Operational Information System (NOIS). In the NOIS a merit order list, visible to all TSOs is composed of the bids. Actual regulation measures are based on this list. Regulating power prices can differ in case of network congestions, when several price areas have to be defined.

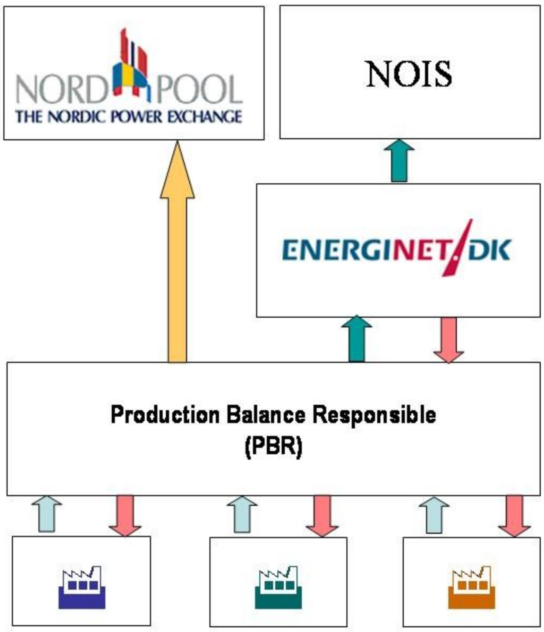

Fig. 6. Electricity Market Overview

B. Residual Market

The residual market is a market for the production of energy which is not supplied by prioritized renewable generation. The commercial suppliers face a decreasing power demand leading to a decrease in the commercial production capacity`s utilization and thereby a reduction in profit making opportunities.

The approach of defining the volume of the residual market is based on a fictitious West Danish 100 % thermal system with base-load and peak-load units XIII. The system is modeled in the simulation tool SIVAEL (simulation of heat and electricity), and the consequences of increased installation of wind power are analyzed by means of model simulations. The share of wind power is gradually increased from 0 % to 100 % coverage of the annual energy consumption. Two types of units are used: coal-fired base-load units and natural gas-fired gas turbines as peak-load units.

On the given assumptions, base-load units are preferable when utilization times exceed 2,000 hours, whereas peak-load units are more profitable when utilization times are less than 2,000 hours. As for the calculations, the number of units and their distribution on base load or peak load are adjusted exogenously in the model in such a way that this criterion is observed.

A 100 % thermal West Danish system in 2025 with an annual consumption of about 26 TWh has been chosen as a basis in order to be able to relate the calculation results to something well-known. Combined heat and power and inter-national connections have been disregarded to maintain simplicity and generality – this means that the system must be able to make adjustments for variations in consumption and wind-power production.

The expansion of wind power is assumed to be increased onshore and offshore in parallel. A maximum production of some 6 TWh onshore is assumed. Offshore, wind power production is some 20 TWh in the case of 100% share of wind power. Wind power production is included in the model as time series based on wind-speed measurements offshore near Horns Rev and the island of Læsø and on wind-power production measurements from onshore wind turbines in Jutland and on Funen as well as from the offshore wind farm at Horns Rev.

SIVAEL solves the week-plan problem on an hourly basis and finds the optimum load dispatch with regard to start-stop, overhauls and outages. Optimum occurs when the total variable costs are at a minimum.

Fig. 7 shows the wind energy production, the share that can be sold immediately and the surplus electricity. It shows that the system can absorb about 30% wind power with no surplus electricity. On the other hand, the surplus grows substantially when the share of wind power is more than about 50%.

Following this idea, there will be two different residual markets: one for demand and one for overflow. The SIVAEL-Model calculated for a share of 100 % wind power a residual energy consumption of 8 TWh / year and a surplus energy of 8 TWh / year, thus the resulting residual market has an energy volume of 16 TWh and a capacity differential of about 9,000 MW. (Comparison: For a pure thermal system the volume of the electric energy market equals 26 TWh and the demand for capacity about 4,500 MW.)

This business area can in future be cultivated by market players, e.g. by means of developing new products.

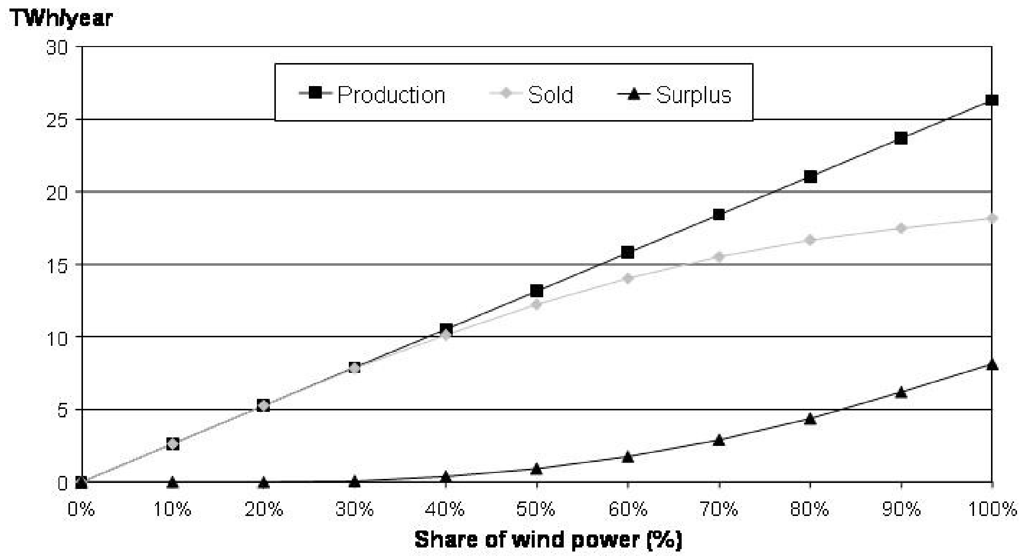

Fig. 7. Wind Power Production on an Annual Basis (TWh/year), the share of Wind Power that can be Sold for the Assumed Consumption (TWh/year) and the Remaining Surplus.

C. Demand Response

The increasing share of wind energy results in an increasing need for balance tools, which also may be located on the demand side. Demand response is defined as a short-term change in electricity consumption as a reaction to a market price signal XIII. The Nordel study XIII identifies demand response as both an alternative and a prerequisite for investments into new production capacity and recommends that all Nordic TSOs prepare action plans for developing demand response.

The TSO is responsible to maintain the instantaneous balance between supply and demand for each control area. He agrees with the supplier on the amount of power which has to be available at a certain time. If the reserve is activated it is financially compensated according to the suppliers bid.

Sometimes energy is very cheap - even for free (Fig.8). It would be valuable to use this cheap energy rather than activating reserve energy which has to be paid for and simultaneously exporting the wind energy.

A further expansion of wind power capacity makes only sense if consumption is increased accordingly or thermal production can be reduced. Using demand response manual reserves can be activated by suppliers or consumers, whereas up regulation means interrupted consumption and down regulation means extra consumption. If there is an unbalance in the system, either the production can be increased or the consumption decreased or vice versa - depending on the kind of unbalance. The smallest bid is 10 MW, and the price for being available as reserve power for the system operator can be between 27,000 EUR/MW/year and 67,000 EUR/MW/year for up regulation power and up to 20,000 EUR/MW/year for down regulation power. Thus not only supply, but also electricity consumption should follow price signals. The former philosophy of influencing the consumers` behavior by means of time-tariffs or campaigns is substituted by new market products, which illustrate the market value of consumers` reaction and capitalize market gains. The system operator acts as a catalyst promoting the consumers` price flexibility. By this means utilization of cheap wind energy instead of valuable coal or oil shall be achieved. During Energinet.dk`s demonstration projects it has turned out for some big customers like e.g. an iron foundry to be economically efficient to install a parallel electricity based consumption system which is used during times of extremely low prices for wind energy.

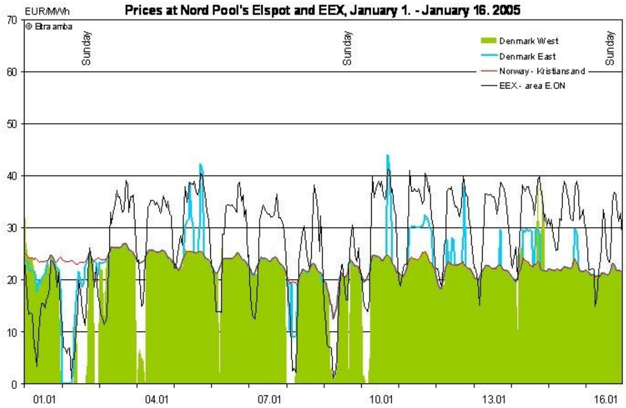

Fig. 8. Energy Prices in Denmark, Norway and at the EEX.

In Denmark there is also a large technical potential for increased electricity consumption in district heating systems in periods with heavy wind production substituting fossil fuel. Consequently the substitution of primary resources is obtained and investments into non-economic peak load units can be avoided. The respective change of consumers` behavior can be: moving the time of consumption to periods with lower prices; reducing or stopping consumption during periods when consumer benefit from using electricity does not exceed the price (possibly by means of substitution to another energy source) or increase the consumption during times when electricity price is lower than the marginal utility and the price of another energy source, e.g. during times of high wind production. This measure results in a smaller slope of the demand curve, where due to limited demand response sometimes no market clearing point can be found (Fig. 9). An action plan has been made including 22 specific initiatives aiming at the development of demand response in the electricity market and all Nordic TSOs cooperate on this topic XIII.

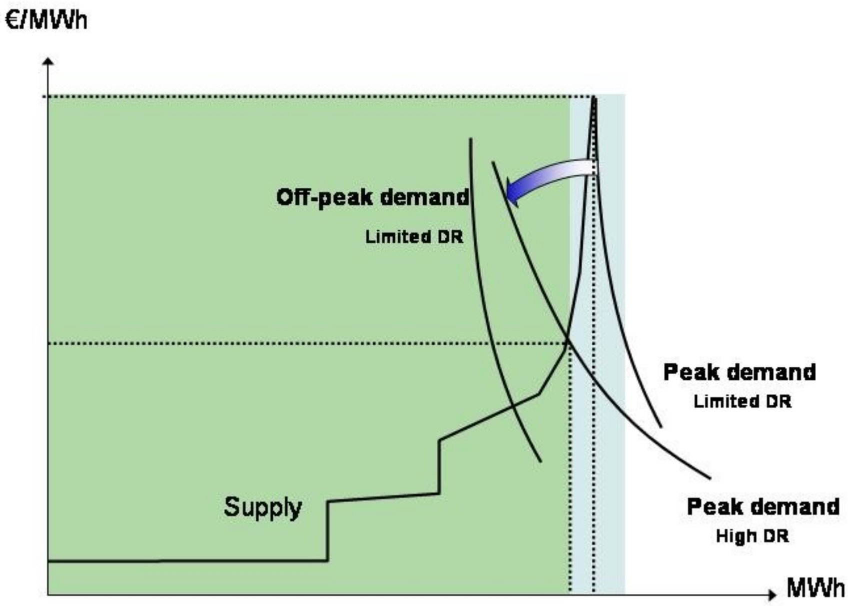

Fig. 9. Demand and Supply Curve for different Elasticity Coefficients due to Grade of Demand Response

VI. SUMMARY

The Danish System is facing several difficulties on several levels: Technically, a high share of dispersed generation challenges the transmission system operator who is responsible for reliability and security of supply and constantly has to balance demand and supply. This is additionally complicated by high transits passing the system. Interconnections to neighboring countries are essential for the functioning of the system and a further expansion of the network as well as the interconnections has to be planned carefully.

Referring to market requirements the Danish transmission system operator, being situated in two synchronous areas operating with different schedules has to adapt to both systems and to use the opportunities of the market to improve the national power balance situation by means of the real time market.

In Denmark a further wind energy expansion is expected, but it has been found out, that there will be a limit up to which the energy can be sold for positive prices. Consequently the future role of small scale CHP units has to be newly defined aiming at better utilization through operation on market terms.

Also the use of electricity is newly been discussed. A demand response project illustrated the potential of integrating the consumer into the well functioning of the market. In times of high wind production it can be economically efficient to use electricity for district heating systems by using e.g. heat pumps or heat boilers.

Acknowledgment

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VIII. BIOGRAPHIES

Peter Børre Eriksen holds a MSc (1975) from the Technical University of Denmark. From 1976 until 1990 he was working as consulting engineer with his work focusing on power plants and environmental consequences of power production. Between 1990 and 1998 he was employed in the System Planning Department of the former Danish utility ELSAM. In 1998 he joined Eltra, the independent transmission system operator of Western Denmark. From 2000 until 2005 he was head of Eltra`s Development Department. In 2005 the two regional TSOs on power (Eltra and Elkraft) and the TSO on natural gas (Gastra) were merged forming the new national TSO: Energinet.dk, which bears the overall responsibility for power and natural gas systems in Denmark. Today Peter Børre Eriksen is head of *Analysis and Methods* in Energinet.dk. He is author of numerous technical papers on system modeling.

Antje G. Orths (M'2001) graduated in electrical engineering at the Technical University of Berlin, Germany. In 1999 she joined the Otto-von-Guericke-University Magdeburg, where she received her Ph.D in 2003. One year later she joined the Fraunhofer Institute for Factory Operation and Automation IFF Magdeburg, leading the group Critical Infrastructures. In 2005 she joined the Planning Department (*Analysis and Methods*) of Energinet.dk, the Danish TSO for Gas and Electricity. Her special fields of interests include electric power networks and systems, modeling of dispersed energy resources, distribution network planning and optimization problems. She is member of the IEEE-PES, VDE-ETG and CRIS.

Vladislav Akhmatov graduated at the Technical University of Denmark. In 1998 he joined the Danish electric power company NESA A/S, first as a trainee and after graduation as an electric power engineer. He worked with power system stability investigations for the eastern Danish power system with incorporation of large offshore wind farms and developed wind turbine models in PSS/E. He combined his work for NESA A/S with his industrial Ph.D. at Technical University of Denmark in 2003. Since 2003 he is with the Planning Department (Analysis and Methods) of Energinet.dk, the Danish TSO for Gas and Electricity. His interests are power system analysis, wind power and simulation tools (DigSilent). In 2002 he received the Angelo's Award for "building bridges between the wind power branch and the electric power supply in Denmark".

5. Electricity Networks of the Future

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Chairman of Advisory Council - EU 'Technology Platform for the Electricity Networks of the Future

***Abstract*--**In May 2005 the European Commission Research Directorate-General defined an initial scope for the creation of a 'Technology Platform for the Electricity Networks of the Future'. This was namely to increase the efficiency, safety and reliability of European electricity transmission and distribution systems and to remove obstacles to the large-scale integration of distributed and renewable energy sources, in line with the proposed priority for "Smart Energy Networks" in the Research Directorate-General's Framework Program 7 (FP7). In January 2006, the Platform's Vision Paper was published. This paper presents an overview of the initial issues raised.

***Index Terms*--**Intelligent networks, Interconnected power systems, Research and development planning, Management, Technology planning

I. NOMENCLATURE

Distributed Generation (DG)
Renewable Energy Sources (RES)
Combined Heat and Power (CHP)
Demand Side Management (DSM)

II. INTRODUCTION

The main goal of the Technology Platform for the Electricity Networks of the Future is currently proposed as:

To increase the efficiency, safety and reliability of the European electricity transmission and distribution system by transforming the current electricity grids into an interactive (customers/operators) service network and to remove obstacles to the large-scale deployment and effective integration of distributed and renewable energy sources [1].

The electricity grids that serve European consumers today have evolved over more than a hundred years. They have been built up to perform efficiently and effectively, but significant new challenges ahead in parallel with major technical breakthroughs call for fresh thinking.

The concept of **SmartGrids** is proposed in the Platform's Vision Paper, which has been defined as:

Creating a shared vision that will enable Europe's electricity grids to respond to the challenges and opportunities of the 21st century for the benefit of consumers, companies and society at large, through an integrated and innovative approach to technical, commercial and regulatory dimensions.

The Vision Paper identifies key aims as:

- Understanding the key challenges that the industry and its stakeholders will face in the future;
- Outlining a shared vision of the possibilities and the areas where Research and Technological Development will be necessary.

The key challenges that have been identified include:

- Policies that are developing and that may change further still (e.g. market liberalization, sustainability, renewable energies, innovation and competitiveness);
- Energy prices that may become more volatile due to market growth and the increasing scarcity of primary fuels;
- Environmental constraints that will be more closely intertwined with energy issues (e.g. carbon trading, impacts on local environments);
- Extensive grid renewal that is anticipated
- New technologies that may enable more flexible and lower carbon generation, and in addition provide smarter uses of energy with responsive management of demand.

Both the current and emerging Stakeholders identified in the Vision paper include Governments and parliaments, Regulators, Power utilities, Energy service companies, Technology providers, customers, traders and new businesses.

As in other European Technology Platforms, a group of high level stakeholders were brought together with the primary objective of defining a coherent and unified approach to tackling major economic, technological and societal challenges of vital importance for Europe's future competitiveness and economic growth. More specifically, an Advisory Council has been established to develop and consolidate a joint vision for the European Electricity Networks of the Future and to put forward a Strategic Research Agenda that sets out research and technological development priorities for the medium to long-term. The flexible framework that has been proposed in the Vision Paper is intended to integrate a partnership of public and private research and development so that the barriers to the adoption of the desired outcomes are minimized.

III. DRIVERS TOWARDS SMARTGRIDS

Energy is the primary prerequisite for economic growth and it is a key issue affecting the competitiveness of our economy. Current issues affecting energy which are pushing for changes are:

- Internal market
- Security of supply
- Environment

Modern societies critically depend on a secure supply of energy. Countries without adequate reserves of fossil fuels are facing increasing risks concerning primary energy availability. Furthermore, Europe's current transmission and distribution electrical networks' aging infrastructure is now providing a major challenge to the security, reliability and quality of a system, not redesigned to account for new tasks. The liberalized market and the wider energy portfolio are introducing these new tasks. Vast amounts of investment will be required to develop and renew these aging infrastructures.

TABLE I. Change Drivers influencing European Electrical Networks

Drivers for change	Evidence
Diversification of energy sources	
Energy Sufficiency	EU Green Paper of November 2000 'Towards a European strategy for the security of energy supply' [2]
Better efficient use of energy	
Cleaner and more Ecosystem efficient technologies	EU Directive 2001/77/EC issued September 2001 'on the promotion of electricity produced from renewable energy sources in the internal electricity market' [3]

Besides issues of security of supply, the major disadvantage of fossil fuels is that they emit CO_2, SO_2, NO_X and other pollutants when burnt to generate electricity. The greenhouse gases contribute to climate change, recognized as being one of the greatest environmental and economic challenges currently facing humanity. Research is needed to help identify the most environmentally and cost-effective technologies and measures that would enable the EU to meet its targets under the Kyoto Protocol and beyond.

Examples of newer forms of generation are large wind farms and the proliferation of DG. They have to be accommodated into existing transmission and distribution networks that were not designed for this role. These forms of generation have different characteristics to traditional plant. They tend to be small or medium in size and are intermittent in supply. It is difficult to predict the impact of distributed generation on the future energy mix. However, if the EU energy policy continues to promote the increased use of distributed systems, there will be an urgent need to transform our networks to allow for the larger scale deployment of these new technologies.

Meeting this challenge requires intensified and prolonged research efforts. The Lisbon Strategy, a major priority of the European Union, outlined the intention to boost competitiveness, job creation, social cohesion and environmental sustainability throughout the continent. Both research and energy are key elements to this Strategy. The 2002 Barcelona European Council goal of increased Research and Technological Development expenditures from the present 1.8% of EU GDP to 3% of EU GDP by 2010, increasing the private funding proportion from 55% to two-thirds, was put in place to close the competitiveness gap between the EU and its major competitors.

The difficulty facing future networks is **uncertainty**. This takes the form of:

- uncertainty in the primary energy mix,

- uncertainty in the electricity flows created by the liberalized market,
- uncertainty of the instantaneous power output of many renewable power sources.

The strategy to deal with uncertainty is to build **flexibility and robustness** into the networks, through the research and development of **SmartGrids**.

Coordination between the Member States, at regional and European levels is needed to reform and strengthen the public research and innovation systems. This will facilitate public-private partnerships, ensure a favorable regulatory environment, and help to develop supportive financial markets and should create attractive educational, training and career conditions to achieve this goal.

This should boost research and innovation performance and in turn effectively create more growth, jobs and competitiveness for the EU. In addition research and innovation are needed to make the EU economy more sustainable, by finding win-win solutions for economic growth, social development and environmental protection.

IV. GRIDS TODAY

Today's electricity networks are based on large central power stations transmitting power via high voltage transmission systems, which is then distributed in medium / low-voltage local distribution systems. The transmission and distribution systems are commonly run by a monopoly national or regional body. In contrast, the generation sector is increasingly competitive. The overall picture is still one of power flow in one direction from the transmission system, via a distribution system, to the final customer. The power is typically dispatched centrally by the generating companies, and network control is set by predetermined actions from the grid dispatch center(s). There is little or no consumer participation and no end-to-end communication.

Traditional network design was based on ideas of economies of scale in large centralized generation and the geographical distribution of generation resources (locations near coalfields, cooling water, etc). The grids were optimized for regional self-sufficiency. Interconnections were originally developed for mutual support between regions, but are increasingly being used for trading between states. The transmission grid provides an arena that has traditionally enabled centralized economic optimization and enhances the overall security of supply. The existing grid system provides an excellent foundation from which future challenges and opportunities can be met. However, by necessity this requires incremental rather than revolutionary change and so the need for a long-term strategy is overwhelming.

Transmission grids are active and accommodate bi-directional power flows. European electricity systems have moved to a market model in which generation self-dispatches and the grid control undertakes an overall role (active power balancing and voltage stability). Distribution networks, on the other hand, have seen little change and tend to be radial with unidirectional flows and 'passive' operation. Their primary role is energy delivery to end-users.

A further common feature is the legacy of mismatched standards and procedures that still persist today in many forms. This has been identified as a barrier to the efficient development of European SmartGrids.

The most fundamental change that the grid system will have to respond to is the change in the distribution of generation across the system. It is likely that the mix of generation technologies that will be developed over the coming decades will embrace kW to GW solutions requiring the entire supply chain to become active, highly controllable and technically flexible.

V. SMARTGRIDS OF THE FUTURE – KEY CHALLENGES

Future models for the electricity network have to recognize changes in technology and in the values in society, in the environment and in commerce. Thus security, safety, environment, power quality and cost of supply are all being examined in new ways and energy efficiency in the system is taken ever more seriously for a variety of reasons.

New technologies should also demonstrate reliability, sustainability and cost effectiveness in response to changing requirements in a liberalized market environment across Europe.

Liberalization of electricity markets is an important factor to take into account. It affects the business framework of companies in a fundamental way and, when well implemented, it can bring about the benefits of competition, choice and incentives for an efficient development. It may be better described as a revision of the regulation of electricity supply and has often been accompanied by a trend towards a liberalized market in power with a splitting of responsibility for the transmission and distribution functions and a changed commercial, regulatory and environmental context. Regulatory frameworks that take full account of distributed and renewable energy sources are a key element.

However, liberalization is not the only challenge to understand how networks will evolve. As explained before, the organization of the network in the future will be affected by stress on the energy markets. Scarcity of primary energy sources on one hand and climate change on the other are likely to affect greatly, the decisions on new investments. It is not so much the case of playing centralized versus decentralized solutions, but rather much more of taking advantage of a wide energy technology portfolio and the coexistence of all possible solutions.

Large penetration of DG, RES, DSM and energy storage may displace energy produced by large conventional plant. Standby capacity might be required, which could be called upon whenever the intermittent RES ceases to generate electricity, and it may be appropriate to seek a European solution rather than a national one. In addition, efficient integration of DG is unlikely to be made without changes to transmission and distribution network structure, planning and operating procedures. Indeed it is envisaged that there will be less of a distinction between them, as distribution networks become more active and share many of the characteristics of transmission.

Grids will become systems with multidirectional flows and a large number of sources covering a range of sizes, sometimes variable, with flow determined locally and dynamic markets that will include trading of power, power quality and other services.

The key challenges that need to be considered in the composition of future networks are:

a) Distributed generation and the **integration** of renewable energy sources, such as biomass, tidal and hydro, but particularly wind and solar, are recognized as growing in importance as more of these power generating schemes are connected to the networks.

Under certain circumstances DG can reduce network losses by generating power closer to the consumption. Network losses in present systems are estimated to be up to 7% of generation in OECD countries. DG can also help in reducing congestion problems and its heat output is easier to utilize than that from centralized generation. In addition, DG offers potentially a more nimble type of system from the point of view of operation and investment, where it can be brought on and taken off line more quickly, as sites can be found and permissions can be obtained more readily.

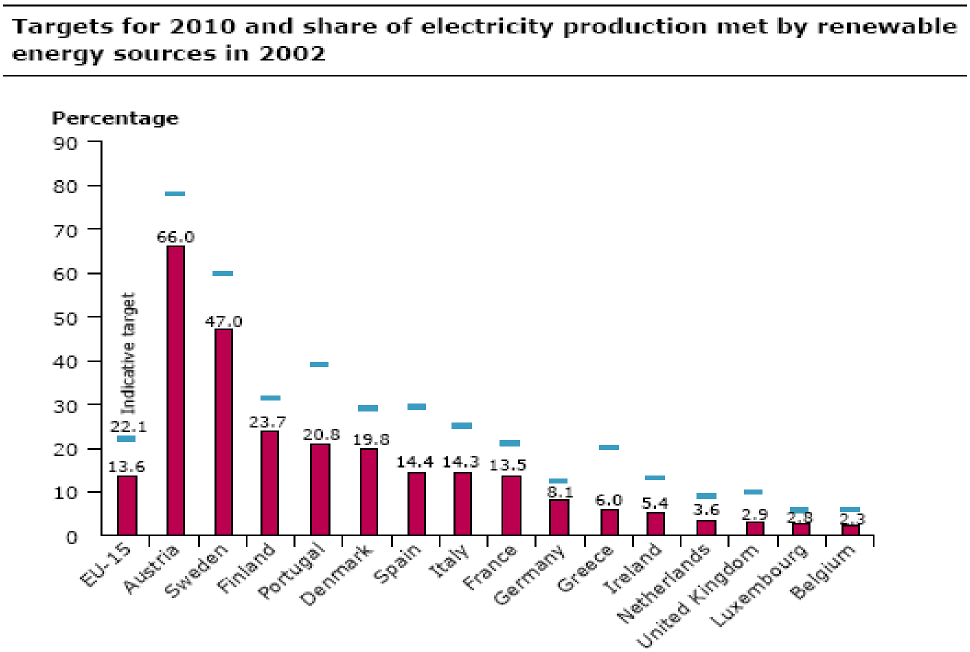

Fig. 1. EU National indicative targets of Electricity produced from Renewable Energy Sources [4]

The threshold of capital employed and risked is lower because of shorter lead times. The penetration of DG will differ according to regions and availability and type of energy sources. Finally, given the modularity feature of DG and the important role that it can play in meeting electricity needs in developing countries, having this technology well developed will give the European Union a competitive advantage to explore a huge market that exists beyond EU borders.

TABLE 2; Share of Renewable Electricity in European Electrical Networks

	Share of renewable electricity in gross electricity consumption (%) 1990-2002 and 2010 indicative targets									
	1990	1995	1996	1997	1998	1999	2000	2001	2002	2010 targets
EEA	17.1	17.5	16.6	17.2	17.7	17.5	18.2	17.8	17.0	-
EU-25	12.2	12.7	12.4	12.8	13.1	13.1	13.7	14.2	12.7	21.0
EU-15 pre-2004	13.4	13.7	13.4	13.8	14.1	14.0	14.7	15.2	13.5	22.1
EU-10 new members	4.2	5.4	4.8	5.0	5.7	5.5	5.4	5.6	5.6	-
Austria	65.4	70.6	63.9	67.2	67.9	71.9	72.0	67.3	66.0	78.1
Belgium	1.1	1.2	1.1	1.0	1.1	1.4	1.5	1.6	2.3	6.0
Bulgaria	4.1	4.2	6.4	7.0	8.1	7.7	7.4	4.7	6.0	-
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
Czech Republic	2.3	3.9	3.5	3.5	3.2	3.8	3.6	4.0	4.6	8.0
Denmark	2.4	5.8	6.3	8.8	11.7	13.3	16.4	17.4	19.9	29.0
Estonia	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.5	5.1
Finland	24.4	27.6	25.5	25.3	27.4	26.3	28.5	25.7	23.7	31.5
France	14.6	17.7	15.2	14.8	14.3	16.4	15.0	16.4	13.4	21.0
Germany	4.3	4.7	4.7	4.3	4.9	5.5	6.8	6.2	8.1	12.5
Greece	5.0	8.4	10.0	8.6	7.9	10.0	7.7	5.1	6.0	20.1
Hungary	0.5	0.7	0.8	0.8	0.7	1.1	0.7	0.8	0.7	3.6
Iceland	99.9	99.8	99.9	99.9	99.9	99.9	99.9	100.0	99.9	-
Ireland	4.8	4.1	4.0	3.8	5.5	5.0	4.9	4.2	5.4	13.2
Italy	13.9	14.9	16.5	16.0	15.6	16.9	16.0	16.8	14.3	25.0
Latvia	43.9	47.1	29.3	46.7	68.2	45.5	47.7	46.1	39.3	49.3
Lithuania	2.5	3.3	2.8	2.6	3.6	3.8	3.4	3.0	3.2	7.0
Luxembourg	2.1	2.2	1.7	2.0	2.5	2.5	2.9	1.5	2.8	5.7
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Norway	114.6	104.6	91.4	95.3	96.2	100.7	112.2	96.2	107.2	-
Poland	1.4	1.6	1.7	1.8	2.1	1.9	1.7	2.0	2.0	7.5
Portugal	34.5	27.5	44.3	38.3	36.1	20.5	29.4	34.2	20.8	39.0
Romania	23.0	28.0	25.3	30.5	35.0	36.7	28.8	28.4	30.8	-
Slovakia	6.4	17.9	14.9	14.5	15.5	16.3	16.9	17.4	18.6	31.0
Slovenia	25.8	29.5	33.0	26.9	29.2	31.6	31.4	30.4	25.9	33.6
Spain	17.2	14.3	23.5	19.7	19.0	12.8	15.7	21.2	13.8	29.4
Sweden	51.4	48.2	36.8	49.1	52.4	50.6	55.4	54.1	46.9	60.0
The Netherlands	1.4	2.1	2.8	3.5	3.8	3.4	3.9	4.0	3.6	9.0
Turkey	40.9	41.9	43.0	38.1	37.3	29.5	24.3	19.1	25.6	-
United Kingdom	1.7	2.0	1.6	1.9	2.4	2.7	2.7	2.5	2.9	10.0

Directive 2001/77/EC issued by the European Parliament and the Council of the European Union on the 27 September 2001 [3] provides member states with significant impetus to increase the market penetration of electricity produced from renewable energy sources. This directive sets national indicative targets for the consumption of electricity produced from renewable sources. The Technology Platform's main goal is aligned with the intentions of this Directive. The National Indicative targets for Year 2010 provided by the Directive are provided for further information and to indicate the extent of the challenges being posed.

b) Another key challenge is to assure the success of the **internal market** and manage cross-border congestion. New technological solutions should be investigated to match bulk power transmission lines with increased transmission demand. In order to limit the number of overhead lines, alternative solutions such as underground cables, superconducting cables or gas-insulated conductors have to be pursued.

c) The problem of **aging infrastructure** cannot be managed as a one-off issue since asset replacement is a rolling activity. Not only does this need to be factored into planning for future networks, but also the need to maintain the service requires that network managers have the guarantee of backwards compatibility. It is also likely that benefits arise in a trans-national approach, through increasing competitive choices and solution options.

d) **Quality and continuity of supply** under the present and future conditions with more and more DG and RES will need to be addressed. Typically, worst-case conditions occur with supply operating at full capacity whilst local demand is at a minimum. Here the network experiences the largest reverse power flows and, consequently, the greatest change which, particularly for rural areas, tends to be the most significant factor constraining generator capacity. Thus network operation and control has to be modified considerably – it has to become active and intelligent.

e) **Co-ordination between actors** is required to ensure the maintenance of a secure supply, an efficient network operation and a transparent market. Common technical rules and tools need to be adopted by the different players as regards data exchange, modeling set up and sharing a vision of electrical system performance. A pan European systems approach is essential. Even if the technology is available and the vision and motivation exist, a smart power grid will fail to be implemented if one cannot set a direction and evolve collectively into the future.

VI. SMARTGRIDS

A. Vision

The single most distinguishing feature of the future electrical network in Europe is the ability for the user to play an active role in the supply chain. Today most users are on-demand receivers of electricity without further participation in the operational management of the network. Each user node is simply a sink for electricity usage.

However, in the past decade electric power utilities in many countries have started the process of liberalization, opening access to transmission and distribution networks. This has been accompanied by a rapidly growing presence of DG of various technologies, some of it in the form of RES, in response to the climate change challenge, the need to improve fuel diversity and provide affordable electricity with quality of supply. There has been a rapid development of renewable energy technologies (particularly wind and solar energy) and co-generation and an increased interest in other distributed energy resources and energy storage technologies.

These developments are changing the trend of 50 years of established grid evolution. They present significant opportunities and challenges for all stakeholders. For example, these developments are creating opportunities for multilateral participation in the minute by minute supply/demand balancing of the grid. Conceptually, a demand reduction is equivalent to a generation increase in the balancing process, i.e. avoidance of usage, or local generation through renewable means such as photovoltaics, enables each user node in the future network to behave as both a sink and a source. Extending the definition of generation to individual households allows demand management to be treated as a form of indirect production of electricity. This landmark change in the concept of grid operational management is now a reality, enabled by modern technological developments including end user communications access.

In summary, grids are being transformed in networks composed of millions of bilateral nodes on all levels of transmission and distribution integrated across Europe. Bulk transmission and distributed generation will coexist on interconnected grids where the distinct difference between traditional transmission and distribution becomes increasingly blurred.

Another important dimension of the liberalized electricity markets is the satisfaction and response to customer requirements. In coming years, customer needs will become even more important, as they need on one hand tailor made energy demand solutions and on the other hand turnkey solutions. Besides high focus on quality of service and cost reduction, total connectivity, energy on demand, service oriented portfolio and flexible contract management will play a leading role to fulfil customer expectations. In addition to ensuring the fundamental provision of a secure supply, savings will need to be made visible, in terms of monetary savings, together with an increase in comfort and a reduction in the maintenance and operation of the system.

In 2020, energy service companies will enable everyone to have access to the provision of genuine energy services such as the demand management capabilities described above. Enabled by smart metering, modern communications and the increased awareness of customers, energy management will play a key part in establishing new services that will create value to the parties involved. In this context, metering services will represent the gateway for access to the active network and will be a critical link to electricity demand evolution. For that reason, electronic meters and automated meter management systems will be enabling technologies. For this goal, service oriented information and communication and business process integration will be valuable components in the real time management of the value chain across suppliers, active networks, meters, customers and corporate systems.

Distribution companies will deal with customers more aware of the possibilities offered by the market i.e. flexible and competitive tariffs, local generation (e.g. CHP), subsidies to renewable energies, energy saving programs, DSM and convergent utilities and communication billing services. Moreover, within a liberalized framework, markets are the mechanisms through which the value of RES and DG for society is determined.

Currently the power market is mainly an energy market (in terms of kWh). However, energy markets alone will not solve the problems with regard to grid investment costs. It may be possible to postpone or defer grid investments if DG and energy efficiency measures can be used to shave local peak demands. Therefore, the creation of a real-time capacity market (kW) on several grid levels will be needed. A third market that needs to be created is a market for power quality ancillary services like voltage control. Uncontrolled DG can make power quality worse. However, when it is activated at the right time at the right place, it can assist in improving it. Specific incentives to do so are currently lacking. In the future such a market will be needed. Last but not least, those DG resources that deliver the most benefits to society, e.g. the most environmentally friendly technologies, should be preferred. Providing a reward in the form of CO_2 credits and green certificates are possible solutions.

Open communication and harmonized rules and cross-border trading procedures will facilitate free trade throughout Europe. Congestion management will be harmonized on a market-based system and customers will benefit by more competitive energy prices because they will have the opportunity to choose the cheapest supplier.

Regulatory bodies will develop harmonized rules to favor competition on an equal basis in the EU context. A harmonized regulatory approach will guarantee open access at all levels, ensuring the removal of unnecessary barriers and ensure access to common benefits and incentives. Harmonized regulation will underpin a common EU energy strategy.

For a successful transition to a future sustainable energy system all the relevant stakeholders i.e. government, consumers, generators, traders, transmission companies, distributions companies, manufacturers and information and communication companies must become involved. There is a strong need for pilot projects, not only in the technical sense but also on the markets and organizational level. For example regulatory regimes should be revised, based on new knowledge about how regulation works to provide the right ground for innovation. New organizational structures can be implemented and monitored for the benefit of all parties, e.g. allowing network companies limited commercial activities with respect to long-term investments.

Traditionally the power sector consists of three levels (technical, commercial and regulatory) as shown in the next figure. Information exchange between those levels differs in intensity and may hinder innovation because the system as a whole cannot respond to release the benefits of new approaches. It is crucial to bridge the gaps, to prevent distortion and delay, and to ensure that benefits are captured for both customers and companies. As commercial structures and markets define the success of the key technologies and markets are pre-conditioned by the governance structure and related regulation, a dynamic interaction between the three levels is needed, that enables an integrated and evolutionary approach. Clear policy goals and open processes are needed. This will ensure that an important balance can be struck so that the benefits of evolutionary change can be obtained whilst providing the stability of business frameworks that are important to commercial parties in a liberalized context.-

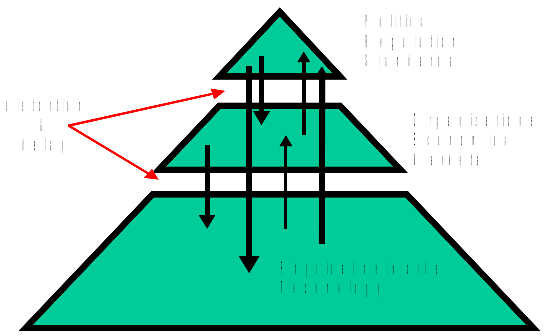

Fig. 2. Technical, commercial and regulatory levels in the power system.

How do we reach the desired situation of a robust, flexible, sustainable and economically efficient network of the future? What is sure is that the changes are not only required in technological solutions within the realm of the physics of the network but also required in regulatory and commercial frameworks recognizing the critical interactions between the different layers. This requires new integrated modeling, learning and analyzing tools with extended functionality and not separated system, market or socio-economic studies.

B. Possible Architectures

Many factors will shape future electricity networks. The actions and decisions taken today will influence longer-term outcomes. It is thus important to recognize that a flexible approach and regular interaction with stakeholders is required to respond to future challenges and opportunities.

Future work should address a techno-economic system approach for a trans-European network, which calls for the development of:

- distribution networks that are accessible to DG and enable demand management interaction with end users,
- distribution networks that benefit transmission dynamic control and overall stability,
- transmission networks with new and more environmentally friendly solutions to overhead and underground networks, and
- transmission networks that can respond to different forms of generation including variable and intermittent sources, with minimum constraints to power flows.

One possible model for the network of the future would be analogous to the internet in the sense that decision-making is completely distributed and that most power flows are bi-directional. Applying this concept to the electricity networks would lead to control being distributed across nodes spread throughout the system. Not only could the source of power for a given consumer vary from instance to instance but also, even for a given consumer and source, the routing could vary as the network self-determines its configuration. Such a system would require hardware and management protocols for connections, whether for suppliers of power or consumers. The market structures and regulatory mechanisms need to be in place to provide the necessary incentives for this.

This type of network eases the participation of DG, RES, DSM and energy storage and would also create opportunities for novel types of equipment and services, all of which would need to respect the protocols and standards adopted. Therefore, new business and trading opportunities can be envisaged based on new sources of power, new regulation in favor of cleaner generation and the development of a complex, multi-connected network establishing links among all players.

It is possible to conceive such a network, but the real hardware, protocols, standards and markets, at all levels, is more difficult to realize. The question of international regulation must be addressed not only at the technical, but also at the political level.

In managing the transition to the internet-like model it may be useful to consider other concepts, either as intermediate states or to be used in combination or part of it. Some of the architectures that have been proposed are:

- Active distribution networks
- Microgrids
- Virtual utilities

These are not fixed, discrete or unique solutions. However, these are concepts under development in a number of projects under the Commission's Framework Programs, such as DISPOWER, CRISP, MICROGRIDS and FENIX.

The European transmission networks already qualify as 'active'. This means there is a high degree of both manual and automatic control that allows the network to be configured according to the requirements of demand and generation in real time. This typically results in bi-direction power flows on circuits, depending on the time of day or season. Existing distribution networks do not share these features but will increasingly be called upon to do so in the future.

The function of the **active distribution network** is to efficiently link the sources of power with consumer demands, allowing both to decide how best to operate in real time. The level of control required to achieve this is much greater than in current distribution systems. Power flow control, voltage control and protection require cost-competitive technologies and new communication systems with several orders of magnitude more sensors and actuators. The increased amount of control required also leads to vastly increased information traffic derived from status and ancillary data. In this way and in the ability to re-route power, the active network represents a step towards the internet-like model.

The evolution of active management is summarized in the next figure and can be described as follows:

- <u>First Stage</u>: Extension of monitoring and control to accommodate generation connections. Some circuits will rely on bilateral contracts with distributed generators for network support services. Rules will have to be defined to outline the physical and geographical boundaries of contracting.

- <u>Second Stage</u>: A management regime capable of accommodating significant amounts of DG. Contracting to use generation to provide network management and supply quality services to the network operator. Management regime has to be defined: local and global services and trading issues, adaptability without information overload, control issues.
- <u>Final Stage</u>: Full Active Power Management. A distribution network management regime using real-time communication and remote control so as to accommodate and use significant quantities of distributed generation to meet the majority of the network services requirement. The transmission and distribution networks are both active, with harmonized control functions and efficient power flows. The active network should be tolerant to errors e.g. communication, fault levels and real-time trading with "delay".

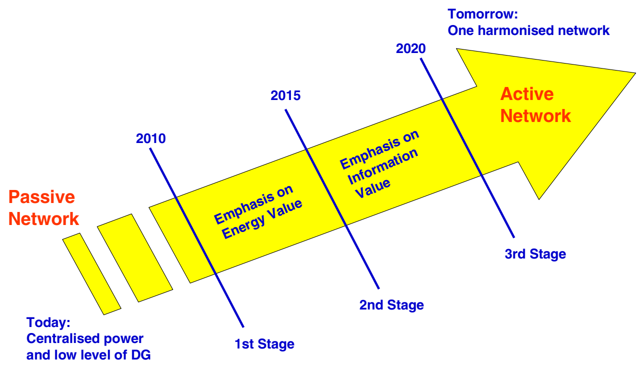

Fig. 3. Conceptual Roadmap for an Active Network

When the final stage is achieved, the users of the network will expect a responsive system. They will anticipate connection according to simple defined standards; an open architecture with no engineering studies. They will also expect accurate billing - to pay for what they use and to be paid for what they supply. Plug and play with real-time trading and accounting will be an inevitable consequence.

Microgrids are generally defined as low voltage networks (below 1kV) with DG sources, together with storage devices and controllable loads (e.g. water heaters and air conditioning) with a total installed capacity in the range of a few hundred kW to couple of MW. The unique feature of microgrids is that although they operate mostly interconnected to the medium voltage distribution network, they can also be automatically transferred to islanded mode, in case of faults in the upstream network.

From the grid's point of view, a microgrid can be regarded as a controlled entity within the power system that can be operated as a single aggregated load and, given attractive remuneration, as a small source of power or ancillary services supporting the network. The installation of DG close to loads will reduce flows in transmission and distribution circuits with two important effects: loss reduction and the ability to potentially substitute for network assets.

In the **virtual utility** (or virtual energy market) the structure of the internet-like model and its information and trading capability is adopted, rather than any hardware. Power is purchased and routed to agreed point(s) but its source, whether conventional generator, RES or from energy storage is determined by the supplier; the system being enabled by information technology. New sources have the potential thereby to gradually substitute for those that are existing.

This vision is only applicable to a market that does not take into account the grid limitations such as congestion or faults that need to be addressed by grid operators in real time operation.

C. *Wider Considerations*

The current change of the electricity supply structure towards more and more decentralized power generation requires changes to current safety, control and communication technologies. Standardization of equipment at multiple levels needs to be maintained in order to enable these concepts for change to be realized and the benefits to be made a reality.

Furthermore, educational issues need to be considered. It is already evident that insufficient numbers of well-trained engineers are being produced in the Power field. To develop, operate and maintain future networks, cross-functional educational strategies (power engineering and information technologies, but also to include economic/market and regulatory/legal issues) must be adopted and recruitment strategies enhanced to meet the skill sets needed.

VII. CONCLUSION

This paper has presented an overview on the issues initially raised in the Vision Paper used to launch the European Commission's 'Technology Platform for the Electricity Networks of the Future' program. The Technology Platform's deliberations is still ongoing and it is hoped that the infrastructure and strategic planning being embarked upon will go some way forward in achieving its ambitious goals.

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IX. BIOGRAPHY

Dr. Christian Sasse was born in London, England, on March 29, 1959. He obtained his MSc in Physics at the University of Karlsruhe in 1986. He completed a Ph.D. in optical light scattering in solar heated fluidized beds in 1992 while working at the German Aerospace Center in Stuttgart, Germany in the area of Solar Thermal Engineering. He moved to Sweden in 1996 where he joined ABB Corporate Research in Västeras. During this innovative period he designed new power and traction transformers. More than 100 patents have been filed in his name related to new transformers and generators. He joined Areva T&D (former ALSTOM T&D) in 2000 where he was appointed as Program Manager for solid oxide fuel cells. Within this program, he formulated a fuel cell strategy and initiated a European partnership with several companies with the objective of designing low cost planar solid oxide fuel cell systems. He is now General Manager for the Areva T&D Technology Center in Stafford, UK. He has also been responsible for the R&D program of distributed power initiated, coordinating and managing research activities in wind energy, fuel cells, biomass, energy storage and solar energy in the UK and in Europe. His recent focus has been on active power networks where he coordinated activities within Areva and initiated new UK DTI and EC FP6 proposals in this area. In May 2005 he was invited to join the EC Technical Platform for Electricity Networks for the Future in preparation for Framework 7.

6. ELECTRICITÉ DE FRANCE AND INTEGRATION OF DISTRIBUTED ENERGY RESOURCES

B. Meyer *Senior Member IEEE*, Y. Bamberger, I. Bel [1]

Abstract **-** DER (Distributed Energy Resources) are in expansion worldwide. This paper underlines technical challenges which arise from this expansion, taking into account the regulatory and technical background in France and Europe.
Index terms - Distributed generation, ancillary services

I. INTRODUCTION

DER (Distributed Energy Resources) are in expansion worldwide. The objective of this paper: to present a brief synthesis of the situation and the regulatory environment concerning the development of DER in France in particular and Europe in general. The paper also presents the drivers for DER development in Europe with a special emphasis on French power system, and its technical and economical barriers. It concludes by presenting technical subjects, partners associated with EDF R&D to carry on research in this field, and actual R&D projects in which EDF is involved to overcome these barriers (e.g. the European project FENIX).

II. DER FIGURES AND EVOLUTION

- DER definition (from CIGRE Working Group 37-23): generation without planning, non dispatchable, connected to distribution power systems, P< 50-100 MW

- The European situation:

Table 1

Country	Power installed (GW)	Distributed energy (GWh)	Distributed energy / Power installed (%)
Germany	116	19	16
UK	69	6.6	10
Denmark	13.6	4.9	36
Spain	54	8.1	15
France	115	2	2
Poland	34,3	5	15

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There are large differences among the European countries, Denmark, Germany and Spain on the top, France is still at the back.

- The French DERs:

The following table shows the evolution of Distributed Generation (DG) in France

Table 2

	2005 (GW)	**2010 (GW)**	**2020 (GW)**
Wind energy	0.5	3 - 6	10 - 20
Micro Cogeneration	≈ 0	0	0 - 6
Photovoltaic	0.03	0.05	0.07 (?)
Waste	<0.4	0.5	0.6 – 0.8
Small hydro	<2	2	2 - 4

Different evolution scenarios confirm that France is facing an increase of wind generation in distribution grids but also an increase of large units connected to transmission grid (on-shore and off-shore projects).

Evolution figures show that wind energy installed capacity reaches 3-6 GW by 2010 and 10-16 GW by 2020. Among this, the share of offshore wind farms is likely to grow.

Micro cogeneration is for the moment at a very low level. Some previsions envisage to reach around 6 GW by 2020. This development is directly linked to a totally liberal scenario for distribution, which is not likely to happen.

As for photovoltaics (PV), France has for the moment a rather low installed capacity but an increase is expected in the next few years. New incentives through higher tariffs will certainly push PV equipment but the possible figure for 2020 is still rather difficult to guess. At the same time, Europe has the ambition to reach a generation capacity of 3 GW by 2010.

III. Drivers for DER development

- from end-users point of view:
  - profitability (governmental incentives, fixed prices, open electricity markets,...)
  - competition at distribution levels
  - environmental considerations
  - grid reliability

- from public entities point of view:
  - environmental considerations
  - new industry development
  - national energy dependability
  - load growth

- Incentives to develop the share of DER in the energy:

- fixed prices of DER energy, and operators obligation to buy at the fixed price energy from any renewable generator. Below, some examples of purchase rates of onshore wind energy in E.U.:

Table 3

Country	Initial purchase rate (c€ / kwh)
France	8.4 decreasing over the years
Germany	9 decreasing over the years
Spain	6.3
Denmark	6.1

Note that purchase rates are quite sensitive to political decisions. Incentive measures are then generally higher at the beginning and tend to reduce over the years.

- public offers as incitation to develop generation capacities based on renewable energy
- obligation of a certain renewable percentage for any distributor (UK)
- tax reductions on renewables
- tax increase on fossils

IV. Regulations and rules for DER connection

Connection requirements are generally based on grid codes. In France, based on decrees and ministerial orders, and also technical requirements that define rules depending on the power of the infrastructure to connect: where to connect and what technical constraints it has to comply with.

Technical points to assess for a grid connection are quite similar in European countries but there are different approaches to cope with the grid reinforcement costs : charged to the DSO, split between TSO and Producer, or entirely charged to the Producer. Connection costs sharing is certainly a major point that explains differences between countries in terms of DG development. In France, the producers have to cover the reinforcement and grid extension costs. The situation is different in Germany and UK that favours DG development.

V. Technical issues for DER integration

The connection of DG to the grid has given rise to new and sometimes challenging problems especially on distribution networks. Indeed, these latter were not initially designed to host DG. In particular they were usually operated with energy flowing in only one direction, namely from the substation to the customers, which is no more true with the advent of DG.

This has often led system operators, electric utilities, governments or regulatory boards to define technical specifications for the grid connection and the operation of DG units.

Besides the constraints generally imposed by DG, the connection of wind farms to the grid (distribution and/or transmission networks) raises specific problems related to this particular type of generation process (wind energy conversion), and to the technologies used. This has led either to the definition of specific technical specifications for the connection of wind power plants or to the adaptation of the existing rules or in some cases to exemptions.

Different issues are at stake with the advent of DG on distribution networks :

- steady-state and short-circuit current constraints
- power quality
- voltage profile, reactive power, voltage control
- contribution to ancillary services
- stability and capability of DG to withstand disturbances
- protection aspects
- islanding and islanded operation
- system safety

Depending on the country, these issues may be more or less important or may be dealt with in rather different ways, since distribution networks throughout the world may be quite different for instance in terms of voltage levels, configuration and architecture, characteristics, operation and protections practices, regulations, types of loads. Other factors such as political or socio-economic factors may also play an important role in this field.

VI. Technical grid evolutions to favour DG

Various evolutions are under study to increase DG connection to distribution grids. Evolutions are envisaged to push technical and organisational constraints.

Power system innovative topologies: meshed, looped

Due to the presence of DG units, distribution systems are no more "passive" but become active networks and therefore more complex to operate, and for high penetration levels of DG, distribution networks might even become as complex to operate as transmission systems. The opportunity to operate distribution grids 'looped' must be studied.

The connection of DG units may change the value and direction of the power flows in the network lines or cables, the values of the short-circuit currents, and the equivalent impedances of the network. These changes may affect the proper operation of the protection system. In particular, the sensitivity and selectivity of the protection system as a whole may be affected.

Some research work are made to determine the method to detect the faults, to determine the faulted section and the probable location of the faults. Additionally, methods for optimal isolation of the faulted portions of the distribution feeder and also restoration procedures for the healthy portions have to be developed.

Grid automated reconfiguration

Nowadays, the operation of distribution power system is based on local automation and manual switches. There are only a few remote control actions. Tomorrow, the operation of distribution power system shall be based on the right combination of local and global control of electrical devices.

The Grid Reconfiguration is equivalent to any function that would lead to any switch status change (where switch can be circuit breaker,…) that addresses feeder, transformer, part of substation, DER unit, capacitor, D-FACTS, load, … except reflex automation initiated by the protection system further to a fault.

Depending on their size, location and black start capabilities, DG units may be requested to contribute to network restoration after a partial or complete shutdown. DG units, for instance, may provide a useful black start service, provided that they have suitable characteristics and equipment.

Observability and state estimation

In order to properly manage and operate the distribution network, the Distribution System Operator needs information on the operation of the DG plants and sometimes on the network status at the connection point. Exchanges of information are therefore required. With a growth of DG on distribution network, exchanges of information and possible remote control of DG units might also become a very important issue.

Voltage control with DER

The connection of a DG unit changes the voltage profile on the grid due to the change in the active and reactive power flows in the network impedances. Generally, the voltage increases at the connection point and along the feeder.

The control of the voltage or the reactive power is therefore an important issue for the DNO, which leads to requirements concerning the contribution of DG plants to the voltage or reactive power regulation on the distribution network. These requirements may take different forms and may vary from very basic ones to more sophisticated contributions, for instance :

- constant reactive power at the connection point by means of capacitor banks,
- constant reactive power or constant power factor ,
- reactive power control / voltage control within the reactive power capabilities of the DG units.

Research activities are under way about an auto-adaptative voltage controller for DG units based on local measurements and that does not need information exchange with the grid or with other units.

The possibility to adapt the transmission system voltage control to distribution grid is also studied:

- a primary voltage regulation which is a fast, local and generally automatic control,
- a secondary voltage regulation which is a remote, "centralized" (for instance at an area level) and somewhat coordinated (for instance between areas) control .

Generation aggregation

Generation aggregation is one of the solution to provide more services to the grid (system or ancillary services). The scope of the European project FENIX is to determine the services that DER can provide to the grid and how generation can be aggregated to provide these services.

One of the objective of FENIX is to boost DER by maximizing their contribution to the electric power system, through aggregation into Large Scale Virtual Power Plants (LSVPP) and decentralized management.

Ancillary services participation

The definition of ancillary services is not unique and varies from country to country. Nevertheless it is generally considered that ancillary services are the services provided by generation, transmission and control equipment which are necessary to support the transmission of electric power from producer to purchaser. These services are required to ensure that the System Operator meets its responsibilities in relation to the safe, secure and reliable operation of the interconnected power system.

More specifically, ancillary services may be expressed in terms of the contribution to:

- active power reserves, load follow capacity and grid frequency control,
- voltage control and reactive power supply,
- stability of the power system as a whole and its capacity to withstand disturbed situations,
- possibly system restoration, black start or islanded operation in emergency situations.

In some countries, other services may sometimes also be considered as ancillary services , for instance :

- compensation for grid losses,
- power factor control,
- contribution to solve network congestions or grid constraints.

Moreover, with the advent of DG and of power electronics converters, power quality improvement might also become a candidate for ancillary services.

Niche opportunities will also emerge for DG to provide ancillary services, usually in circumstances where constraints restrict network development, e.g. environmental, planning and terrain related constraints.

Renewable and fluctuating power integration

Due to the uncertainties of generation produced by wind farms, although wind generation prediction has made recently real improvements, new methods need to develop to assess better integration, increase profitability and limit wind power reduction asked by grid operators. In that field, probabilistic methods seem necessary to improve the accuracy of the studies of wind generation integration to distribution grids.

VII. PARTNERSHIP AND R&D PROJECTS WHERE EDF IS INVOLVED

EDF is involved in numerous international, internal and external research and development projects in order to solve the technical issues. Additionally, EDF has efficient partners with which it carries on researches.

-GIE IDEA Grenoble

From the year 2000, EDF R&D has been involved in a joint venture called IDEA 'Investigating the electric power distribution of the future"based on the complementarities of two companies related to the electrical activities and a university academic laboratory of research. EDF, Schneider Electric, and LEG university in Grenoble, are the three partners of this joint venture.

The objectives of this partnership are to achieve common researches and develop innovating solutions for the new distribution system including distributed energy resources.

Today, the electrical networks are deeply changing because of the electric power system deregulation in Europe, the increase of the environmental considerations in our modern societies, the saturation of large transmission networks, the evolution of generation and stocking technologies add to the developments of the new Information and Communication Technologies.

In this context the emerging of the distributed generation is characterized by its dispersed localisation, its small size (contrarily to the centralized generation) and its closeness to the final users.

Distributed generation introduces radical changes among electrical energy professions at the level of production, treatment and distribution. It changes the way the networks are planned, designed and operated.

Finally, more than the introduction of the distributed generation, it is all the distribution network which will deeply change; there will be new materials, more automatisation, new remote control system, new architectures, new intelligent protection systems, new control systems and more and more technologies of information and telecommunications.

IDEA's research activities cover various technical fields such as fault detection, distribution grid architectures, optimal management of buildings energy system, photovoltaic connection and inverters, voltage control by centralised and decentralised controllers, ancillary services provided by DG, load control, D-FACTS, and generation aggregation.

-Example of European Commission R&D Projects:FENIX

The objective of FENIX is to boost DER (Distributed Energy Resources) by maximizing their contribution to the electric power system, through aggregation into Large Scale Virtual Power Plants (LSVPP) and decentralized management.

The project is organized in three phases:

1. Analysis of the DER contribution to the electrical system, assessed in two future scenarios (Northern and Southern) with realistic DER penetration
2. Development of a layered communication and control solution validated for a comprehensive set of network *use cases*[1], including normal and abnormal operation, as well as recommendations to adapt international power standards.

We envision a threefold R&D effort:

a. the key component is the Large Scale Virtual Power Plant (LSVPP) which is an aggregation of DER taking into account the actual location of individual DERs in the network. LSVPPs will have flexibility and controllability to provide different services to energy and ancillary services markets.

[1] Use case: Functional requirements

b. the bottom level is the local solution at individual DER itself, responsible for managing the unit in connection with the LSVPP
c. and finally the higher level, which consists of a new generation of EMS and DMS tools to be developed, placed respectively at the TSO and the DSO, with the new ability to manage LSVPP capacities for network operation; and the markets that will put a value on these capacities

Validation phase through two large field deployments, one focused on domestic CHP aggregation, and the second aggregating large DER in LSVPPs (wind farms, industrial cogeneration), integrated with global network management and markets

To achieve these multi-discipline objectives, the FENIX consortium incorporates: Research Centres and Universities with high involvement in previous and current EU projects in this area (CRISP, DISPOWER, MICROGRIDS, EUDEEP…); Transmission and Distribution Utilities, which today hold the responsibility of the networks where DER are being integrated; equipment and ICT manufacturers, with large presence in the energy sector; DER owners, that bring to the project their business view; and finally organizations responsible for regulation, standardization, etc., that will be managed in the project through a Stakeholders Advisory Group, absolutely needed for the future effective widespread exploitation of the project results.

- ***Example of International Partnerships: IntelliGrid***

The IntelliGrid^{SM} Consortium is a broad-based collaboration of energy, high-tech, and government leaders, working together to address these looming industry issues and set us on a migration path towards the intelligent, self-healing power system of the future.

The foundation of this new system is the Intelligrid Architecture—an open-systems-based comprehensive reference architecture for the energy enterprise of the future. Intelligrid enables the integration of intelligent equipment and data communications networks into a managed enterprise and industry-wide distributed computing system. It is the fundamental basis for enabling enhanced system capabilities, such as the self-healing grid, integrated consumer communications, and real-time energy information and power exchanges.

IntelliGrid partners have defined the overall technical framework for the underlying architecture that will support data communications and equipment interoperability. They are contributing to the development of relevant open system standards and creating a shared infrastructure to enable the envisioned power system of the future.

Some of the results and benefits of the Intelligrid project are already in place. For example, opportunities to leverage research and technologies have been defined. With open systems and shared standards, overall costs are lowered, opening the way for additional investment and innovation in the energy sector. Intelligrid has also defined the requirements and standards for a variety of advanced applications from wide area measurement and controls of transmission systems to utility distribution operations.

VIII. European Technical Platform Smart-Grids

The Technical Platform, composed of representatives of Stakeholders of the value chain of Electricity business, started in 2005 to define a vision for Europe's grid networks by 2020.

The goal is to move Europe's electricity grids into the 21st century for the benefit of consumers, companies and society. The effort takes technical, commercial and regulatory issues into account.

IX. Conclusions

It is now widely accepted that the present architecture and operations of power systems will be considerably be changed over the next decades. Several factors will push in new technologies and new organizations. Liberalisation is now widely implemented, allowing a variety of players to move into the power industry. These players may be generation providers, but also service providers (for instance load management to take advantage of variation in electricity price). Dispersed generation will have a larger share, but mainly new types of generation, less predictable (wind, solar) will increase its share in the overall mix. The greenhouse gas limitation will boost these renewable sources, as already seen by the present regulatory decisions.
The system will have to bear with increased flexibility, increased uncertainty, and also higher quality requirements.

All these changes ask for new technology, new controls, news ways to design and operate power systems. We have seen here, through the French and European cases what research areas should be favoured to face the challenge. But the task is enormous, and we believe further development, led through international collaboration will be the main key to have in the future a system with increased power security, with more flexibility, at the lowest possible prices, and environmentally responsible

X. Acknowledgements

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XI. Biographies

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7. Wind Power in Greece – Current Situation, Future Developments and Prospects

J. Kabouris and N. Hatziargyriou[#]

Abstract**—** This paper describes the current status of wind power in wind Greece focusing on the future developments and prospects. The exploitation of the verified wind potential of the country faces significant difficulties (public acceptance licensing, environmental, financing etc) resulting in considerable delays. Most of the applications for new wind farm installations refer to three specific areas of high wind potential in the Greek mainland. Due to the geographical distribution and the size of wind farms (10 to 40 MW installed capacity), wind integration in these areas will be highly concentrated and the wind farms will be connected mainly to the high voltage network. Since the areas of interest are connected to the bulk transmission system through weak transmission corridors there are specific plans for reinforcing the network in order to alleviate constraints and accommodate future wind farms. The expected impact of the large wind penetration will impact significantly on the ESI and the new challenges arise are also reported.

Index Terms**—Wind power penetration, security assessment, transmission reinforcement**

I. INTRODUCTION

The Electricity Supply Industry (ESI) in Greece serves the electricity needs of the mainland and numerous isolated islands. As shown in the map of Fig. 1, significant wind potential exists in the Aegean islands, Crete and the east part of continental Greece (Evia island, South-east Peloponnese and Thrace) due to the high winds predominant in the N-NE direction, mainly influencing the Aegean sea. Mean annual wind speeds in many sites of these areas are very favorable for exploitation (7-11 m/sec).

The development of RES has been among the current energy policy lines for Greece during the last 10 years. One major goal for the country is the compliance with the Kyoto protocol commitments to reduce Greenhouse gases between 1990 and the compliance period 2008-2012; based on a fair distribution of responsibilities adopted by the European Union (EU) Council of Ministers, Greece's commitment is to restrict in 2010 the emissions to the +25% level in comparison to 1990 [1]. This target is expected to be achieved through the large penetration of RES and the increase of the share of natural gas against fossil fuels. Concerning RES-electricity, an ambitious target has been set by the European Council [2] for Greece, aiming at 20.1% RES contribution to electricity supply by 2010, including large Hydros. Among available RES technologies, wind power is expected to contribute the largest part.

Liberalization of the electricity markets [3] foresees the opening of the generation sector to private investors and the establishment of competition among generators. Although RES are excluded from competition, the challenge for large-scale exploitation of wind energy should be considered under the new competitive environment. Since RES are, in most of the cases, not yet economically competitive to the conventional thermal generation, they are promoted through various motivations which include satisfactory fixed feed-in tariffs correlated with the retail kWh prices (70% of the retail consumer price for the mainland and 90% for the isolated systems of the islands), guaranteed access to the grid, long-term contracts (10 years), subsidies on capital investment (up to 50%), tax exceptions etc [4]. The cost for the connection to the grid or any “shallow” reinforcements required in the transmission network is carried by the IPPs by 50%. Additionally, for every IPP applying for the development of a wind farm, the respective transmission capacity within the grid is reserved on a first-come first-served (FCFS) basis. RES units are not required to pay any Transmission or Distribution Use of System fees.

These policies have been proven quite efficient constituting a major breakthrough in wind energy development. As a result, applications for more than 14,500 MW of wind farms (WFs) have been filed to the Regulatory Authority for Energy (RAE). Despite the strong interest by private investors however, the wind power installed capacity in the country does not exceed 500 MW. The main barriers for the deployment of wind power are the strong public opposition to wind turbines, and the complicated administrative procedures for WFs licensing. Political interventions are expected soon to overcome these problems. From the technical point of view, wind power integration into electricity grids is restricted mainly by the limited transmission capacity in the mainland and the penetration limitations in the islands. This paper presents the current and foreseen developments in the area of wind energy in Greece, the impact of large-scale wind integration to the ESI and the technical problems under the view of large penetration. Mainland and isolated island systems are reported separately due to the differences in the system structure and market organization.

II. MAINLAND INTERCONNECTED SYSTEM

2.1. Brief System Description

The Hellenic interconnected system serves the needs of the mainland and some interconnected islands. The gross electricity demand during 2004 was about 51.7 TWh. The mean annual increase rate of energy demand is about 4% during last decade.

The transmission system under the responsibility of the Hellenic Transmission System Operator - HTSO serves the mainland of Greece and some interconnected islands. It consists of 400 and 150-kV networks. The system is interconnected to the Balkan countries (Albania, Bulgaria, and FYROM) via three 400-kV tie lines of total Available Transfer Capacity of 600 MW and to Italy via an asynchronous 400-kV AC-DC-AC link with a transfer capacity of 500 MW.

The demand is served mainly by thermal power plants and large hydros of total installed capacity in the order of 10,100 MW. The main production center is in North-west Greece in the vicinity of a lignite rich area. Significant hydro production exists in the North and Northwest of the country, while another lignite production is available in the Southern peninsula of Peloponnese. There are also WFs of total nominal capacity ~415 MW, installed at the island of Evia and Thrace (about 200 MW in each region), while another ~65 MW are under construction. These WFs are equipped mainly with stall controlled WTGs and they contributed at about 1.5 % of the electricity needs during 2004. Table I summarizes installed capacity figures and the energy balance for the year 2004.

TABLE I. INSTALLED CAPACITY OF THE MAINLAND GENERATION SYSTEM

Type	**Net Capacity (MW)**	**Annual production (2004) (GWh)**	**Contribution (%)**
Thermal	7045	43216	83.56
Lignite fired	*4795*	*32491*	*62.82*
Oil fired	*718*	*2687*	*5.20*
Gas fired	*1532*	*8038*	*15.54*
Large Hydros	3060	4927	9.52
With Lake	*2445*	*3827*	*7.41*
Pump-storage	*615*	*1100*	*2.13*
Renewables	450	758	1.47
Wind	*415*	*735*	*1.42*
Small hydro	*35*	*22*	*0.05*
Net Imports		2821	5.45

Nevertheless, there are a lot of prospects for exploitation of the wind potential. More specifically, a large number of applications have been submitted to the Regulatory Authority for Energy (RAE) accounting more than 12,500 MW nominal capacity in the mainland. More than half of the applications refer to the windy areas of Evia, Southeastern Peloponnese and Thrace (encircled in Fig. 1). Until July 2004, authorities had issued licenses for 395 WFs of total capacity 3421 MW.

In windy areas there is a lack of transmission infrastructure to transfer future WFs generation to the bulk transmission system. HTSO has specific plans [5] to reinforce the congested corridors. Nevertheless, HTSO has provided access to the grid to more than 1850 MW of WFs and about 200 MW of other RES projects. Due to the geographical distribution and their size (15 to 45 MW installed capacity) most of these WFs will be connected to the high voltage network through 30 to 40 new HV/MV substations. WFs of nominal capacity up to 5 MW may be connected to the local distribution networks.

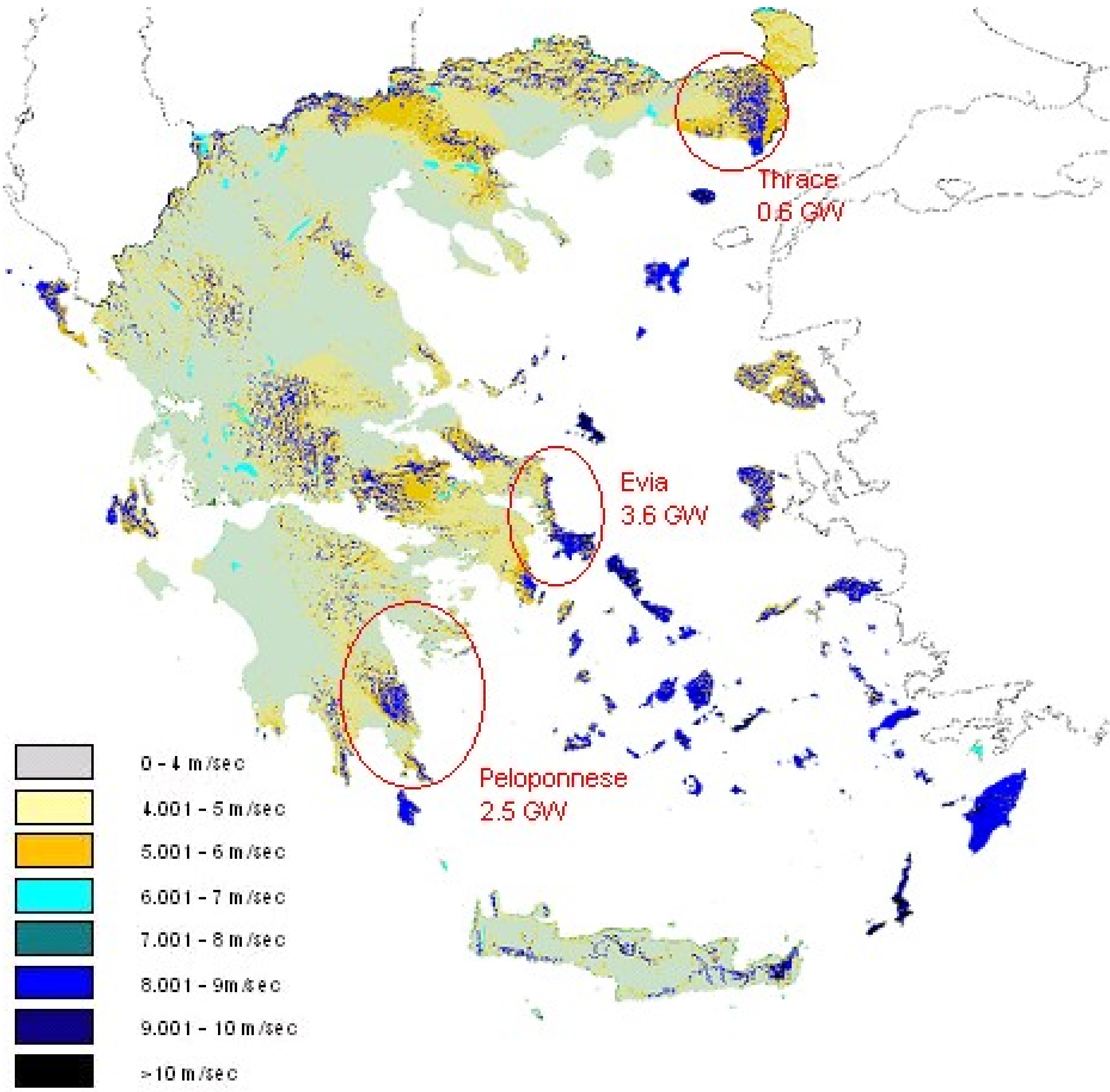

Fig. 1. Wind Potential and geographical distribution of applications for wind farms

The electricity market is organized on a "pool" type; thermal producers are remunerated at System Marginal Price (SMP); SMP is calculated on an hourly basis and represents the price of the marginal generator to meet the load. RES energy is bought by HTSO at a fixed price (currently 68.42 €/MWh) related to the retail electricity price. Since SMP is much lower than RES fixed tariff, the excess cost is distributed to all consumers as an "uplift" cost.

2.2. Planned Transmission Reinforcements

Due to the limited transmission capacity in windy areas, HTSO has carried out specific plans for HV network reinforcements to accommodate future wind farms. Also, a major project to interconnect the north Cycladic islands is under development. These interventions (included in the "5-year statement") will drastically increase the network potential towards large wind power penetration, as reported next. It should be underlined that transmission projects face long delays in Greece due to the time consuming licensing procedures and the strong public opposition.

Evia: This area has a large verified wind potential especially in the south. Currently, about

200MW of wind farms have been installed along a radial OHL connected to 4 new s/s. The applications in the area exceed 3.5 GW. Evia is connected to the mainland through 2 submarine cables and one OHL operating at 150 kV. The limited transmission capacity to the mainland is a major barrier for wind exploitation. The planned network reinforcements include (see Fig. 2):

- A new connection of south Evia to the mainland through two new submarine cables (20 km each).
- The upgrade of the existing 150kV single-circuit OHL to a double-circuit one.
- The erection of 11 new s/s at the south part to accommodate future wind farms
- The construction of OHL on the island (total length about 80 km)

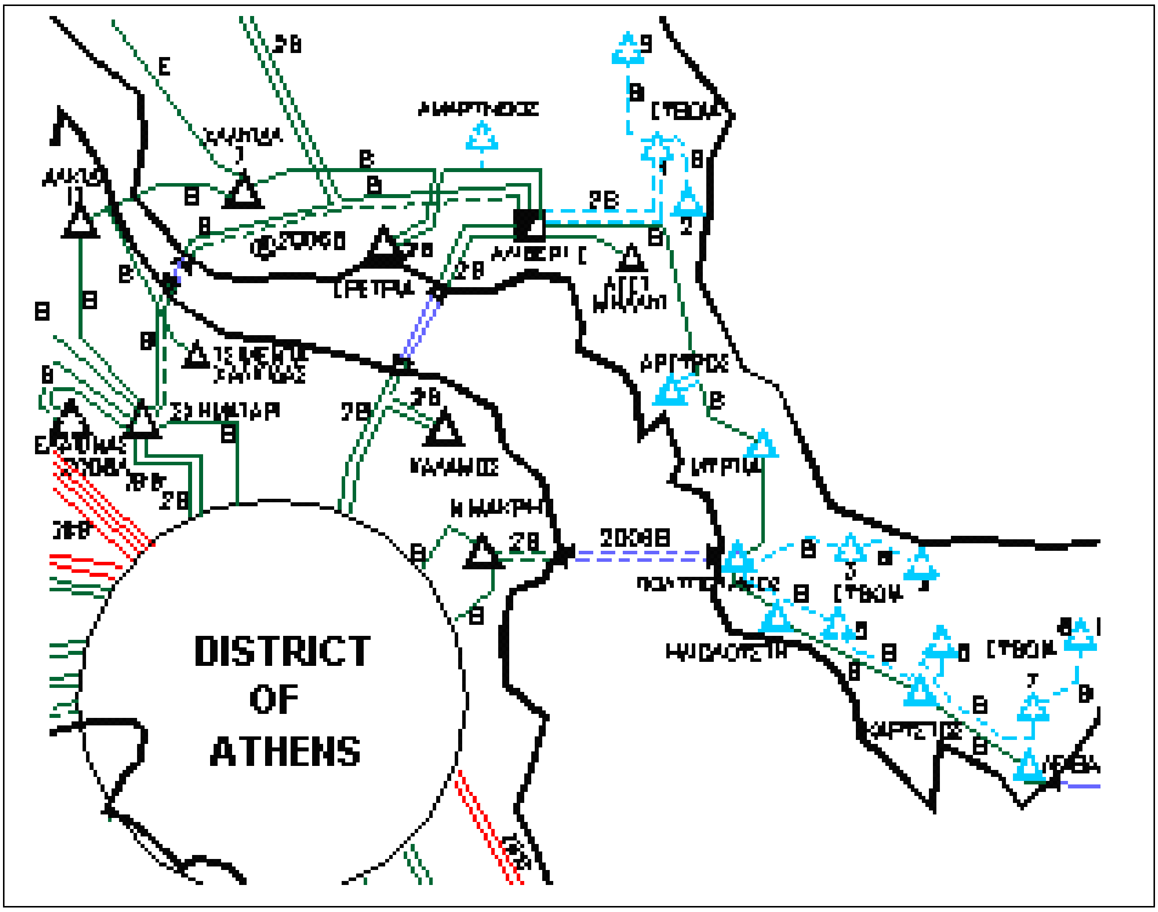

Fig. 2. Existing and planned transmission network in Evia

These projects have already been licensed (except small parts) and are expected to be committed during 2006-2007. These interventions will increase the network capability by about 500MW and will also serve the future interconnection of the Cycladic islands.

<u>SE Peloponnese</u>: Southeast Peloponnese is also a region of high wind potential, especially the south part that is currently served by a radial 150kV transmission line. No wind farms exist in the area, but the applications exceed 2,5 GW. The capability of the existing network to absorb wind power is about 80 MW. The planned network reinforcements include (see Fig. 3):

- The construction of a new 150 kV double-circuit OHL (ASTROS-MOLAI - length about 80

km)
- The upgrade of an existing 150kV single-circuit OHL to a double-circuit one.

The former project is under construction and it will be committed by June 2006, while the latter is expected to be committed by 2008. Furthermore, a new 150kV double-circuit OHL to the south has been planned for 2010.

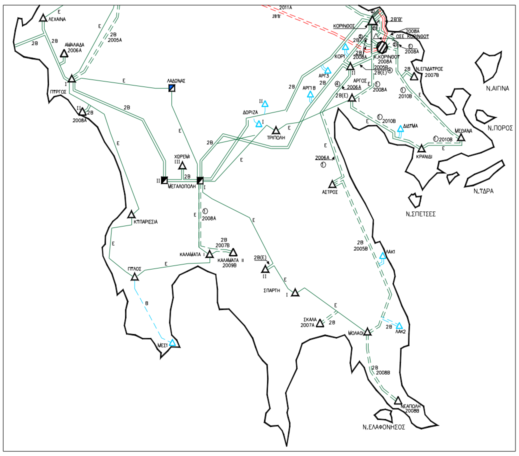

Fig 3. Planned reinforcements in Peloponnese

<u>Thrace</u>: The area of Thrace has a satisfactory wind potential, but also -and more important- enjoys the public acceptance of WFs. Currently, the area is fed by a 150kV system and there are 200MW of wind farms installed in the area through 4 new s/s. Although the total network capacity is in the order of 100 MW, a special control scheme, reported in the next section, has been applied to allow a higher penetration. In order to increase the wind penetration in the area and to facilitate the future connection of the Greek system to Turkey, major transmission projects have been planned in the area which foresee the construction of a new double-circuit 400 kV OHL from the Thessaloniki area to the Turkish border and an EHV s/s at Thrace (see Fig. 4). These projects will allow the absorption of excess wind capacity of at least 500MW. Said projects are under licensing procedure and they are expected to be realized by 2008.

<u>Cycladic Interconnection</u>: Recently, a major project has been adopted that foresees the interconnection of the northern Cycladic islands (namely Andros, Tinos, Myconos, Syros, Paros and Naxos) to the mainland. These islands are currently fed by autonomous systems of high fuel cost and limited wind power penetration. The connection will be performed through Evia through an existing 150 kV cable and the Lavrion (in Attica region) through AC or DC link. I is expected that the project will be realised by 2010-2012 and it will allow the installation of 150-200MW of WFs in these islands.

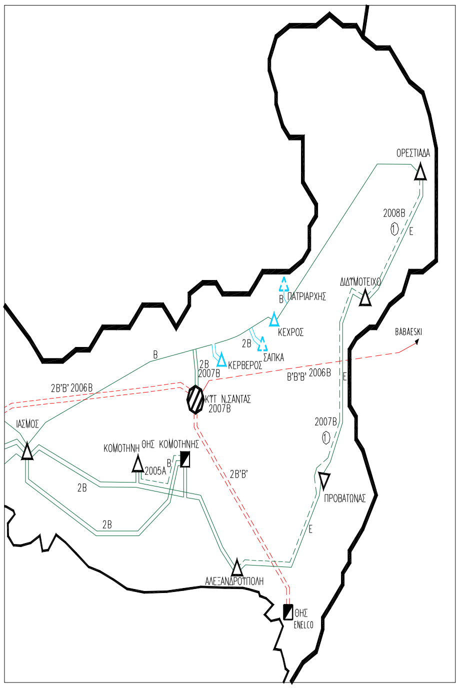

Fig. 4. Planned reinforcements in Thrace

2.3 Special Control Scheme for Thrace

In Greece, the Hellenic Transmission System Operator (HTSO) has adopted a special operational practice in order to increase the wind power penetration into the windy area of Thrace in the North East part of Greece. The main concept is the introduction of "interruptible contracts" and the continuous monitoring and control of the power flow through the congested corridors by issuing a setpoint to each Wind Farm (WF) to reduce its production, whenever system security is endangered.

This practice implies both regulatory and technical amendments [10].

Figure 5 depicts the transmission system in the region. The existing generation comprises a combined cycle thermal plant (natural gas fired) at KOMOTINI. The maximum capacity of this plant is 480 MW while its technical minimum is 280 MW. The region of Thrace is connected to the transmission system through four overhead transmission lines through the boundary bus of IASMOS; the thermal limit of each line is in the order of 170 MVA during summer and 200 MVA during winter. The wind penetration is limited by the available transfer capacity (ATC) from Thrace to the system; static security is the limiting factor. The KOMOTINI power plant is usually bidding successfully in the power market and therefore Thrace is usually an exporting area. Moreover, for large portions of time, it is a "must-run" unit since it is necessary to provide local voltage support. Under these conditions, the possibility of adjusting local thermal power generation, in order to increase wind penetration is not considered, because of the impact this would have on the electricity market (increased uplift costs). Furthermore, the KOMOTINI power plant contributes to the Automatic Generation Control and the provision of this ancillary service is sometimes very important for the quality of the entire system operation.

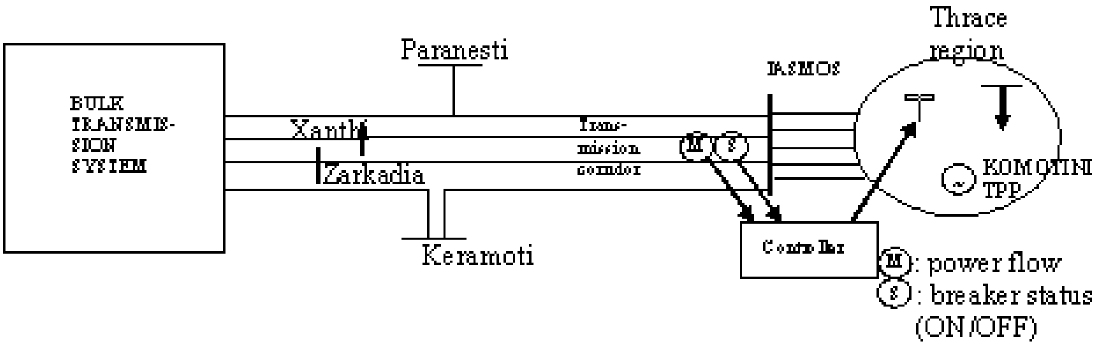

Fig. 5. Schematic diagram of system configuration

HTSO should guarantee the absorption of all the power produced by the WFs installed in the country. According to the existing planning practices, the maximum wind power penetration in the area should not exceed 100MW. The application of "interruptible contracts" allowed HTSO to double this limit without compromising system security, or IPPs economic feasibility. From the regulation point of view, the new practice of "interruptible contracts" required the issue of a new Ministerial Decree in 2003 which allows HTSO to violate the "priority in dispatch" rule for RES by curtailing power output of WFs, when necessary; it also sets the mutual obligations between the HTSO and IPPs.

The control is based on the continuous measurement of the total power flow from Thrace to the bulk transmission system through the corridor. The control concept is applied according to the following rule: "the power flow through the interconnecting lines is not allowed to exceed a predefined security limit". This limit is calculated with respect to the N-1 security criterion according to the Grid Code regulations. If this limit is violated, the controller sends setpoints to the WFs with interruptible contracts to reduce their production and consequently the power flow through the congested corridor by the necessary amount. These setpoints represent the upper limit of the power output by each WF that can be securely injected to the grid. The necessary power reduction is to be shared by all WFs with interruptible contracts.

The control scheme [8] is implemented using an autonomous system comprised of Programmable Logic Controllers (PLCs) communicating to each other through two different and independent telecommunication lines. Two independent PLCs (main and backup) are installed at the boundary substation to monitor the operating status and the power flow through the interconnection lines and implement exactly the same algorithm. One PLC is installed at each substation where WFs with interruptible contracts are connected, in order to provide the necessary interface to the WF supervising control system. In each WF the respective PLC collects real time data, transmits the limiting setpoints (if any) to the WF supervising control system and communicates with the PLCs installed at the boundary substation. In addition to the above described autonomous control system, the supervision and control of the WFs by the Energy Control Center is always enabled via the existing Remote Terminal Units (RTUs).

The operation of the control system will be necessarily monitored by the Control Center through the SCADA for security and settlement purposes. Whenever a WF does not comply for reduction according to the setpoint issued by the control system, the dispatchers are alerted and they should communicate (through the telephone) with the authorized WF personnel to execute manually the command. In cases of emergency the WFs, which did not comply with the commands will be disconnected from the grid using the remote control facilities of the SCADA.

In all cases the control system operation and the WF response is recorded in the EMS databases for settlement purposes. The WFs that did not comply with the reduction commands are penalized and furthermore, the power injected to the grid above the issued setpoints is not remunerated. Also, the curtailed energy by each WF is recorded since it must not exceed the 30% of WFs annual potential according to the Ministerial Decree.

2.4. Impact on ESI

The economic impact of the large scale wind penetration on ESI is a crucial issue; large RES penetration will impact on emissions, energy balances and generation mix, electricity economics, electricity markets, etc. A major issue is that it will change the generation mix against conventional thermal generation (mainly the load following generators) and it will reduce proportionally their market share. This impact seems to be significant for the new natural gas combined cycle generators in most of the cases. In this sense, it seems that the targets for market opening and large-scale wind penetration may conflict each other. This section presents results from preliminary studies [11] for the assessment of the impact of the high wind penetration on:

- Emissions reduction and contribution to environmental targets
- Security and diversity of supply (capacity credits)
- Cost of electricity, energy balances and generation mix
- Repercussions to the electricity markets and specifically on the new combined cycle generators

The study covers the period 2005-2015. An average annual energy demand rate of 2.9% for the period 2005-2010 and 1.5% for the period 2010-2015 was considered. According to the Strategic Planning [6], it has been considered that new thermal units are introduced to the system as follows:

- 2 peak units of 125 MW in the year 2005

- one combined cycle unit of 400 MW each year of the period 2005-2012, and one in the year 2015

Regarding the evolution of WFs, two main scenarios (shown in Fig. 6) have been examined. The basic scenario is a moderate one, representing the "business as usual" case. It is based on realistic estimations concerning the anticipated penetration of wind projects in the interconnected system resulting from the progress of licensing procedures and considering network limitations. The optimistic scenario is more environmental oriented, aiming to the achievement of the Kyoto goal. Such a scenario has been provided by RAE in the framework of Strategic Planning [6]. Additionally to each wind penetration scenario, a small penetration of other RES (mainly small hydros) has been considered (Fig. 6).

In order to assess the impact of each scenario, results are compared to a hypothetical case where no RES production is available (namely "No RES scenario").

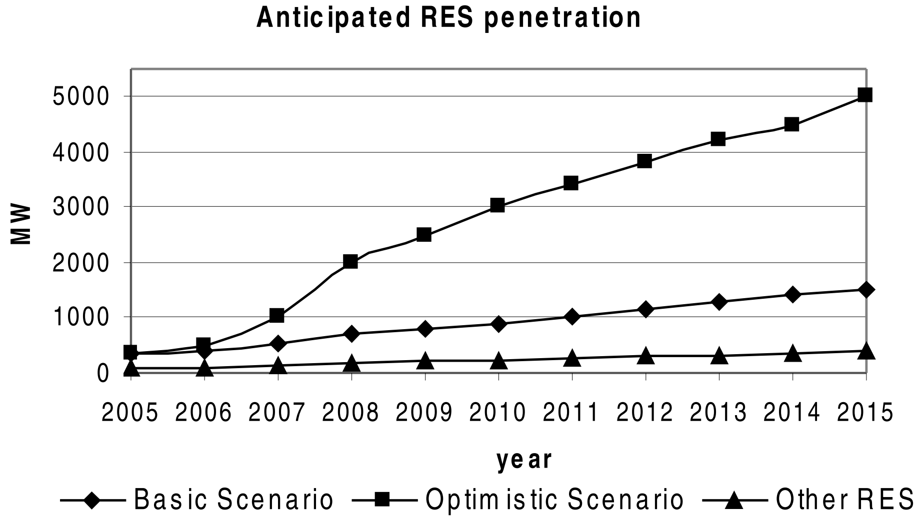

Fig. 6. Anticipated RES penetration scenarios

Historical data regarding the operation of existing wind parks, correlated with typical wind velocity time series, are processed in order to obtain typical wind production time series for each region within each scenario. Operation of wind projects is simulated by adjusting the load demand time series with the resulting wind production ones. Based on the statistics of previous years, large Hydros have been considered to contribute about 3000-3200 GWh annually.

Figure 7 depicts the expected evolution of the energy balance for each scenario. It seems that it is hard to achieve the EC target (20.1% of the total electricity by 2010 should be produced by renewables, including large hydros), though the optimistic scenario comes very close. For the basic scenario (which seems to be the most realistic) renewables contribute only 10.7%, while the respective contribution for the optimistic scenario is 19.8%.

Figure 8 depicts the evolution of CO_2 emissions for each scenario. Only the optimistic scenario leads to the achievement of the set target, but in the year 2015; for the year 2010, the optimistic scenario leads to a reduction of CO_2 emissions by 4.6 Mton compared to the 'No RES scenario'.

Figure 9 illustrates the variation of the country's dependency on imported fuels (natural gas and oil). It is clearly seen that the country's dependency on imported fuels can be decreased only if the optimistic scenario is realized.

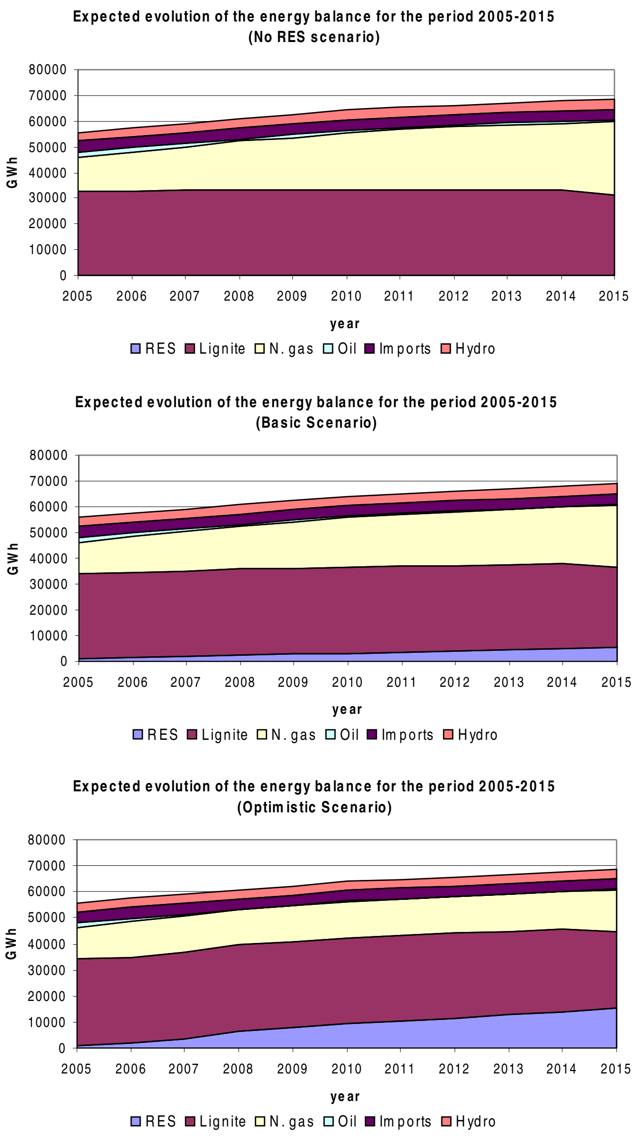

Fig. 7. Anticipated evolution of the energy balance for each scenario

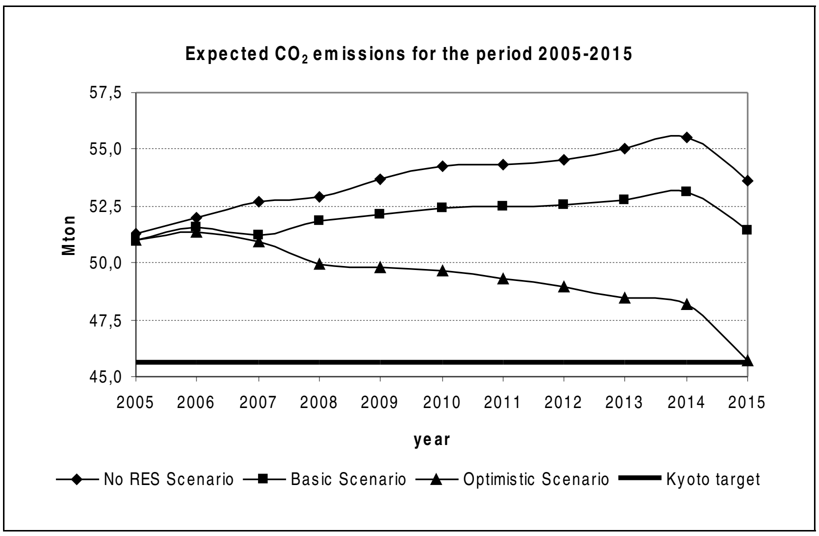

Fig. 8. Expected CO_2 emissions for each scenario

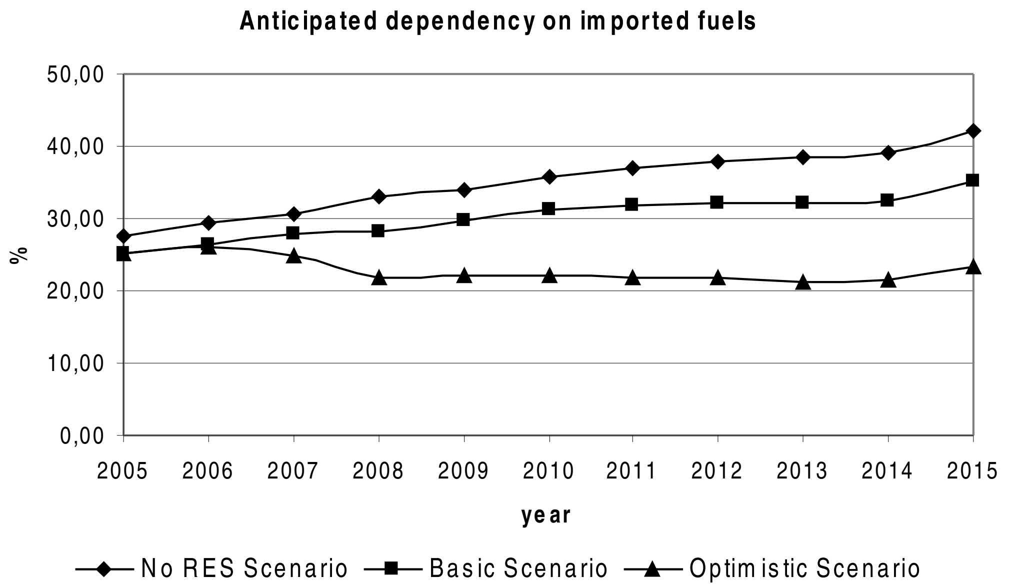

Fig. 9. Anticipated dependency on imported fuels for each scenario

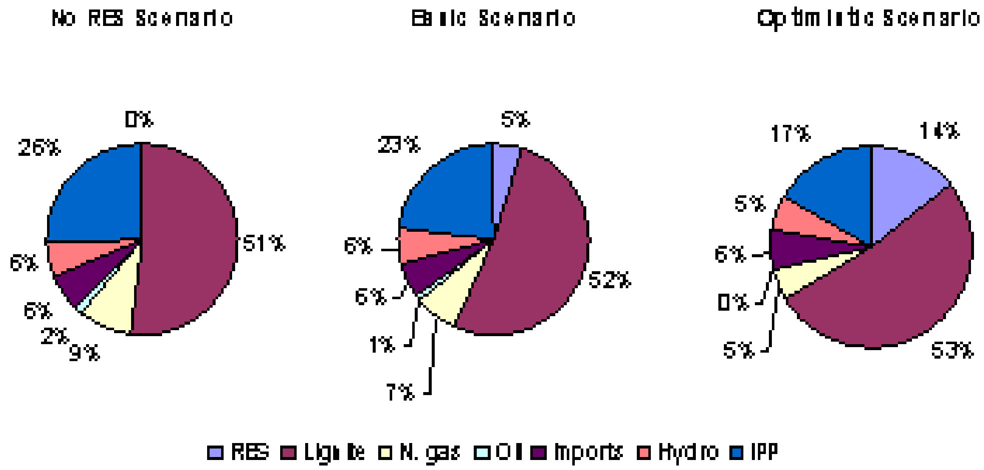

Fig. 11. Market share of thermal IPPs for each scenario (year 2010)

Fig. 10 presents the estimated cost components of electricity (i.e. the expected production cost, the remuneration of RES production, the cost of expected CO_2 emissions and the cost of the expected unserved energy) for the year 2010 as percentages compared to the ‘No RES scenario’. RES production is priced at 69 €/MWh. The cost of emissions has been considered to be equal to the penalty set if the expected emitted quantities exceed the adopted limit (40 €/Mton). It should be noted that the penalty for emissions exceeding the Kyoto targets is expected to increase to 100 €/Mton by 2008. Finally, the cost of the expected unserved energy is assessed to be 2000€/MWh. For the basic scenario the total cost is reduced by 5.9%, while for the optimistic scenario the total cost increases by 6.9%. Figure 11 shows the market share that the thermal IPPs hold in the year 2010 for each scenario. A drastic reduction in the expected market share of new generators is observed due to the large-scale wind penetration. It seems that there is a conflict between the efforts to attract investments in thermal units and RES simultaneously.

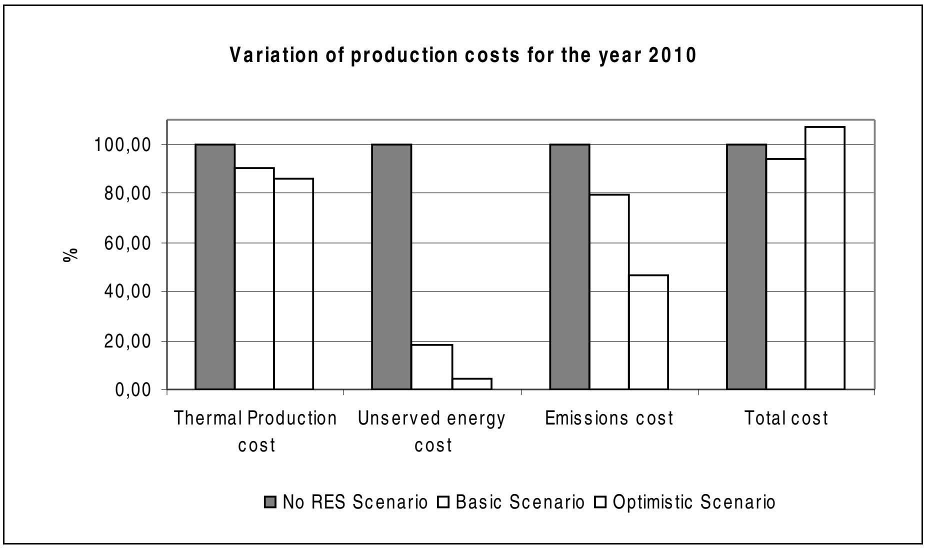

Fig. 10. Expected electricity cost for each scenario

2.5. Future Challenges

From a technical point of view the large scale wind integration raises a variety of technical problems and challenges which can be classified to the following:

1. **Long-term Planning and transmission investment plans**

Due to the uncertainties in the location of future WFs the transmission expansion planning is a crucial issue. Lack of infrastructure may lead to further delays. On the other side, stranded investments should be avoided. Also, the optimization of connection interfaces is a crucial issue.

2. **Power System Performance**

A number of actions concerning the every day generation should be revised. The most critical issue is the load-frequency control, which is based on the monitoring of the Area Control Error through the interconnections. Because of the stochastic aspect of wind power and due to the spatial concentration of the wind parks improved prognosis methods and tools must be applied based on meteorological predictions [7]. Only WFs equipped with WTGs using power electronic interface can contribute to frequency regulation.

Robustness against voltage variations: Since future WFs are expected to be concentrated in specific areas, the fault ride-through capability is a crucial issue in order to avoid simultaneously the loss of all WFs in these areas due to short circuits

Voltage regulation: WFs using induction generators without any power electronic interface to the system can not ensure satisfactory performances, as far as primary regulations (voltage as well as frequency) are concerned, particularly when there is no wind. Concerning voltage control or VAR control (reactive power), WFs using conventional alternator type generators and generators using power electronic interface can provide good performances and hold a variable unit power factor.

System Voltage stability does not seem to be affected by the large wind penetration [9].

Dynamic Performance: The assess of system dynamic performance following contingencies is under study in order to estimate the restrictions imposed to wind penetration level. Detailed dynamic models for each WTG type should be adopted. On-line Dynamic Security Assessment seems to be the best solution.

3. EMS functions

Large wind penetration implies the need to revise and/or upgrade specific EMS functions such as Load Forecast, Unit Commitment, Primary and Secondary Control, Security Analysis, Training and Emergency Control.

The most critical issue is the primary and secondary frequency control since it will remain difficult to forecast the power gradients arising in the wind power production within a quarter of an hour. The HTSO carries studies to define the ways these power gradients are compensated for via the secondary control, either by central production facilities or by cross-border exchanges. This gives rise to a number of important questions, for instance: Who will be establishing and financing data acquisition and remote control facilities as such? Who will be paying for the lost production? Who will be refunding the loss if the production margin is lowered before a particular time of operation – resulting in the wind turbine owner being unable to deliver the production offered to the exchange? How will the priority between several wind farms be administered – whose production is going to be restricted?

4. WF monitoring and control

There will be a need for continuous monitoring and control of at least large WFs for security purposes. The spatial distribution of WFs will require severe interventions and expansion of the existing SCADA and telecommunications. These interventions require high costs since there is not telecommunication infrastructure in windy areas. The distribution of these costs is an open issue.

5. Market Organization

Considerable regulatory interventions are required in the Grid Code for the issues mentioned above. These regulations and rules are under investigation by HTSO in coordination with the RAE. Also, it can be stated that, to comply with the E.U. treaty rules, new support schemes for RES must be in order to introduce competition (and such achieving the resulting benefits). Also, some problems concerning organisation issues encountered so far must be resolved (acceleration of licensing procedures, monitoring of progress for the licensing projects, etc.). These schemes must be examined in the view of efficiency, compatibility with E.U. rules, and simplicity in the regulations level.

III. ISLANDS

In the following, an overview of the current wind power status in Greece is provided for the sake of completeness.

In Greece there are about 35 autonomous power systems, most of them in the range of few MW, supplying the load demand of small islands in the Aegean Sea. The generation units of these systems are usually oil-fired (burning diesel or mazout oil) resulting in high production cost. In most of these islands a high wind potential has been verified presenting strong correlation with the peak loads (especially during summer time). Besides, these systems exhibit some special characteristics associated with generation, transmission and load profiles. Usually there is only one power plant, while the produced energy is transmitted to the consumers through medium voltage radial networks. The load factor of these systems is usually very low (0.25-0.4) due to high peaks of short duration occurring during summer (high tourist season) and low valleys during the rest of the year. The low load factor requires increased generation capacity and consequently high investment costs. The penetration of wind power into exploitation of the high wind potential of these islands faces severe technical limitations due to the low loads and technical minimums of existing diesel generators. As a result a small number of WFs of capacity up to few MWs (totally ~35 MW) has been installed on these islands; this capacity cannot be significantly increased due to technical penetration limits. Also, the limited size of WFs is not economically attractive for private investors, although they enjoy a very attractive feed-in tariff (84,58 €/MWh). The future interconnection of some islands to the mainland is expected to increase significantly the wind exploitation (see sec. 2.2).

Crete

Crete is the largest isolated power system in Greece with the highest rate of increase nation-wide in energy and power demand (about 8%). In 2004 the peak load was about 530 MW and the annual demand 2540 GWh. The load curve is characterized by large daily and seasonal variations (summer and evening peaks). The conventional generation system consists of three thermal power plants of total installed capacity of 690 MW in three power plants Chania, Linoperamata and Atherinolakos. 25 thermal units of various types are installed, i.e. steam turbines, gas turbines, combined cycle units and diesel units. Being an isolated system, there is no real market operating, instead a "Single Buyer" organization is operated by the Public Power Corporation (PPC) of Greece. Currently, there are 14 WFs in operation comprising 160 WTs with a total capacity of 87 MWs. It is expected that during 2006 the WFs installed capacity will reach ~105 MW. This high wind power activity has been encouraged by the very favorable wind conditions prevailing in the island, public acceptance, the attractive policies and the satisfactory fixed feed-in tariffs (84.58 €/MWh. Moreover, Crete is characterized by a well structured Transmission grid, consisting of 150 kV OHL, and a good on- line monitoring system. Under this regime, Crete is a system of very high wind penetration. Contribution of WFs reached ~10 % of total energy demand during 2004.

Considering that the low load in Crete is little above 100 MWs, this increased wind power activity may lead operation of the system with high wind power penetration, especially during off-peak hours, e.g. in 2000 the hourly wind penetration has reached about 40% [12-13]. In order to operate an isolated system under such high RES penetration conditions, it is very desirable to have advanced EMS functions, in order to advice operators of possible actions. MORE CARE is adaptable, advanced control software that can achieve optimal utilisation of renewable energy sources in medium and large size isolated systems, that has been developed within EU research projects [15, 16] and has been installed in the EMS system of Crete. A number of modules based on Artificial Intelligence and conventional methods have been developed and incorporated in the MORE CARE software, in order to provide short-term (up to 8 hours ahead) and long-term (48 hours ahead) Load and Wind Forecasts and Unit Commitment and Economic Dispatch functions modules. In this way, the operator is given advice on the possible switching on/off of the units and their production set-points, in order to minimise the operational cost satisfying operational constraints. In addition, Dynamic Security Assessment functions provide on-line monitoring of the system in the event of pre-specified disturbances and detect insecure dispatching recommendations to the operator in preventive mode [16, 17]. MORE CARE has been interfaced to the on-line SCADA Data Base and is installed in the Control Center of Crete, since July 2002. The evaluation of this installation has shown satisfactory forecasting results, clear economic gains provided by the economic dispatch advice, timely and accurate assessment of dynamic security [18].

IV. CONCLUSIONS

This paper presents the current and foreseen developments in wind energy in Greece, the impact of large-scale wind integration to the Energy Supply Industry and the technical problems under the view of large penetration. Current solutions and requirements in order to operate the system under high wind power penetration are briefly outlined.

V. ACKNOWLEDGEMENT

The authors would like to thank Dr Dimitrios Bechrakis of HTSO for his assistance.

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VII. BIOGRAPHIES

John Kabouris received the Diploma of Electrical Engineering in 1985 and the Doctor of Engineering degree in 1992, both from NTUA. From 1991 until 2001 he was working in the System Studies Department of PPC. Currently, he is assistant Director in the System Expansion Studies Department of the HTSO. His research interests include power system analysis, generation simulation and renewable energy sources.

Nikos D. Hatziargyriou is professor at the Power Division of the School of Electrical and Computer Engineering of NTUA. His research interests include dispersed and renewable generation, artificial intelligence techniques in power systems and power system dynamic analysis and control. He is a senior IEEE member, member of CIGRE SCC6 and the Technical Chamber of

8. Application of Wind Power Prediction Tools for Power System Operations

Kurt Rohrig, Bernhard Lange

Greece.

Abstract: The wide use of wind energy in Germany results in a lot of new power system operation problems corresponding especially to the stochastic character of the wind speed and to the not controllable production of energy. The significant amount of installed wind power in the German power system (currently more than 17 GW) make the traditional scheduling of the power generation for the next day very unsure. Consequently the costs of the power system operation are high because of a large scale provision of spinning reserve power coming from the traditional power plants. The

decisive rule in the decreasing of these costs plays the exactness of the wind energy transformation modelling process which starts with the forecast of wind speed.
In Germany since more than ten years the knowledge how to solve this problem is available. Based on more than 100 representative wind farm power measurements all over Germany very exact models for the determination of the current and expected wind power are developed. The models are in operation at the control stations of the Transmission System Operators.

Index terms -- Distributed generation, renewable energy, system services, forecasting, wind farm operation, design, optimisation, modelling

I. INTRODUCTION

By the end of October 2005, more than 16,900 Wind Turbines (WTs) with an installed capacity of 17,500 MW generated approx. 21.5 TWh and supplied about 4.5% of the German electricity consumption [1], [2]. Today, the electrical power generated from wind already covers the total grid load in some grid areas temporarily. According to Federal German Government planning, in the medium-term (2015) wind turbines will be erected with a total power of 36 GW on- and offshore which would cover around 15% of the German electricity consumption [3]. This large intermittent generation has growing influence on the security of grids, the operation of other power plants and on the economics of the complete German supply system. In frame of governmental funded projects, an in co-operation with the German Transmission System Operators (TSOs) E.ON Netz (ENE), Vattenfall Europe Transmission (VE-T) and RWE Transportnetz Strom (RWE), solutions for an optimized integration of the large amount of wind power into the electrical supply system have been investigated.

One task of the TSO is the permanent grid balancing within it's control area. The grid load and the feed-in from conventional power plants is available in form of power exchange balance group schedules and is calculated with adequate accuracy. The need for balancing power arises; therefore, from the difference in the predicted feed-in from WTs and the actual feed-in values. Therewith, the accuracy of the wind power prediction has direct influence on the amount of control power to be procured.

II. PREDICTION METHODS

The model for the determination of the instantaneous wind generation (online-model OM) delivers time series of the aggregated wind power for grid areas, control zones as well as for the whole German grid by using online measurements of representative wind farms.

The prediction model delivers the temporal course of the expected wind power for the control area for up to 96 hours in advance. To achieve this, the exact co-ordinates of the representative wind farms or wind farm groups in Germany were determined For these locations numerical weather predictions are used to deliver meteorological parameters in one hour intervals for a forecast period of up to three days. The corresponding predicted wind farm power is calculated using artificial neural networks (ANN).

A. Intermediate wind generation calculation

The determination of the intermediate wind generation is calculated by transformation of online measured wind farm power values of the representative wind farms [4]. The transformation algorithm is based on the sub-division of the related control zone (or sub-grid area) into small sections analogue to the finite element method. For each section the associated rated power, roughnes parameters and control types of the WTs are determined and converted into parameters.

The current wind power feed-in is determined by the summation of the wind power feed-in of all sections.

$$P_{sum} = \sum_i P_i \qquad (1)$$

where P_i is the current wind power feed-in of section *i*. The wind power feed-in of each section is then calculated by a differently weighted summation of measured wind power signals of the representative sites.

$$P_i = k_i \sum_j s_j * A_{ij} * P_j \qquad (2)$$

with

P*j*: standardized measured wind power of site j
S*j*: status of measurement (0 := wrong; 1 := o.k.).
A*ij*: weight factor.

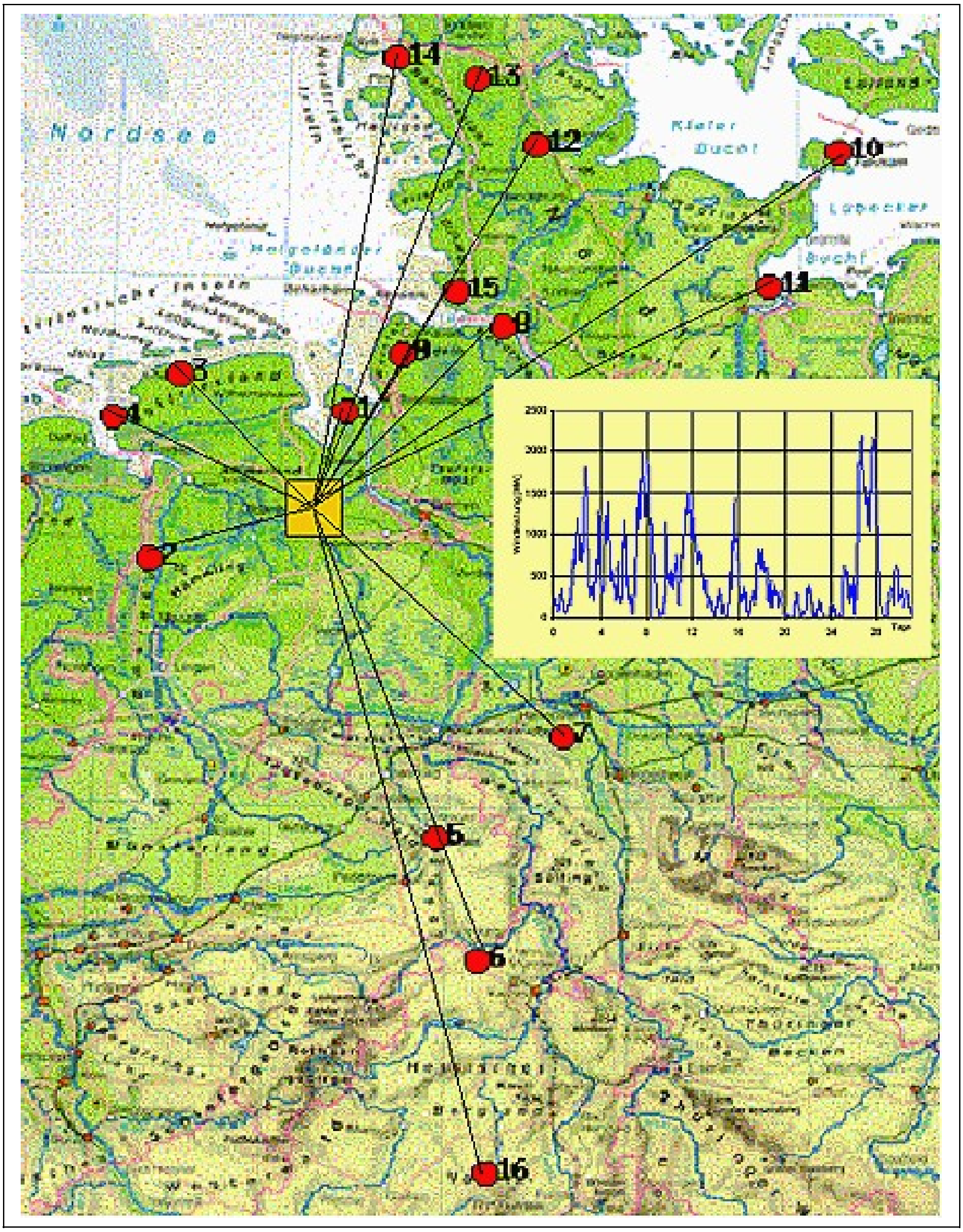

Fig. 1. Schematic view of transformation algorithm

This algorithm allows the calculation of sum curves for the intermediate wind generation as well as for predicted wind power. Furthermore, the wind generation time series for arbitrary future scenarios can be calculated. For instance, ten years of wind generation have been calculated for different future scenarios and denaotes the fundamental groundwork of the dena grid study [3].

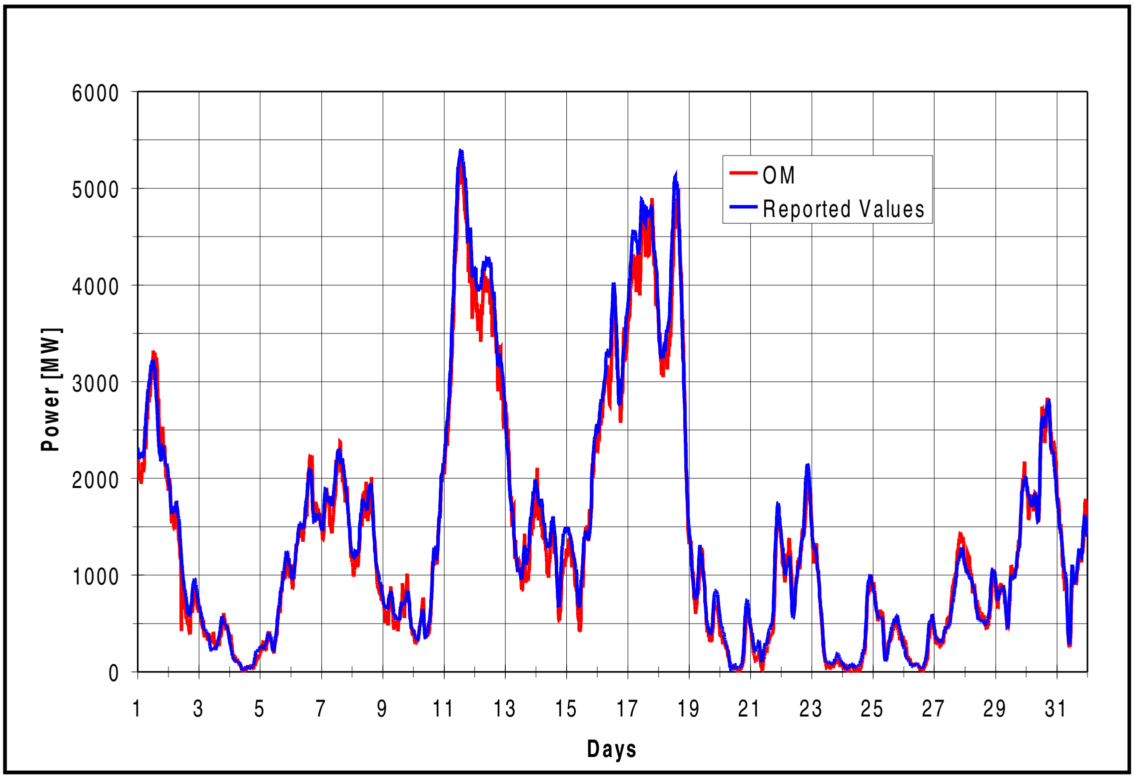

Fig. 2. Wind generation in the control zone of VE-T – calculated by OM and reported values.

The figure shows the wind generation in the control zone of VE-T in March 2005, calculated by the online model (OM) in comparison to reported values. The deviation (RMSE) between the curves is 2.3% of the installed capacity.

B. Day ahead wind power prediction

The artificial neural network consists of nonlinear functions g which are combined by a series of linear filters with weights [5]. In this study we use a neural network with one hidden layer, so that we have a network with two weight matrices A and a :

$$\hat{P}(t)=g\left[\sum_{j=1}^{m} A_{ij}\, g\left(\sum_{i=1}^{m} a_{jk}\, x_k\right)\right] \qquad (3)$$

where x_k are the k input values and $\hat{P}(t)$ denotes the output value, i.e. the predicted power at the time t. We train the ANN by gradient descent with the back propagation algorithm. It minimizes the least square error E between the measured power P_n and the predicted power $\hat{P}_n$ at time step n over a training data set with N data points:

$$E=\sum_{n=1}^{N}\left(\frac{P_n-\hat{P}_n}{P_{rated}}\right)^2 \qquad (4)$$

where P_{rated} is the rated power of the wind farm. For the training of the ANN historical NWP data and historical measured power data for the same discrete time steps is used. As input data for the time step n we use the NWP data for the location of the wind farm, namely 3 values of wind speed $ws(n-1)$, $ws(n)$, $ws(n+1)$, 3 values of the wind direction $wd(n-1)$, $wd(n)$, $wd(n+1)$ and 2 values related to the time, i.e. the sine and cosine of the time with a period of one year. The ANN provides then the power value for the time step n. For the training of the ANN we take one half of the whole data set and the other half is used for the test of the model. The prediction errors are related to this test part of the data.

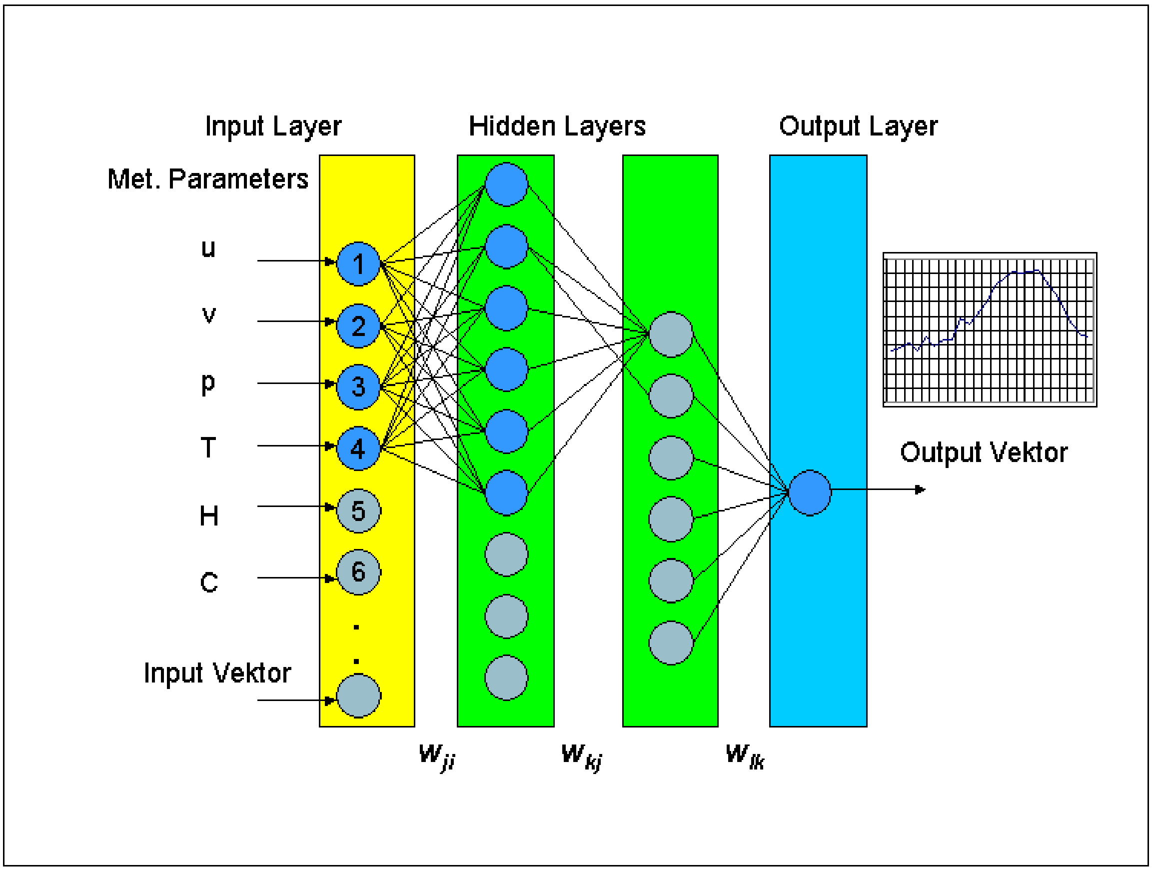

Fig. 3. ANN layout of prediction module

The ANNs are trained with predicted meteorological parameters and contemporaneous measured power data from the past, in order to learn physical coherence of wind speed (and additional meteorological parameters) and wind farm power output. This method is superior to other procedures, which calculate the relation between wind speed and power by the use of power curves of individual plants, as the actual relation between wind speed (and other meteorological parameters) and wind farm power output depends on a multitude of local influences and is therefore very complex, i.e. physically difficult to describe. The advantage of artificial neural networks over other calculation procedures is the “learning” of connections and “conjecturing” of results, also in the case of incomplete or contradictory input data. Furthermore, the ANN can easily use additional meteorological data like air pressure or temperature to improve the accuracy of the forecasts. The deviation (Normalized Root Mean Square Error NRMSE) between the (day ahead) predicted and actual occurring power for the control areas of ENE, VE-T and RWE currently is about 6,5 % of the installed capacity. The prediction error for the total German grid amounts to 5,7%.

C. Short-term wind power prediction

In addition to the forecast of the total output of the WTs for the next days (up to 72 hours), short-term high-resolution forecasts of intermittent generation in separate network regions or for wind farms and their clustering are the basis for a secure power system management. Apart from the meteorological values such as wind speed, air pressure, temperature etc., online power measurements of representative sites are an important input for the short time forecasts (15-minutes to 8 hours).

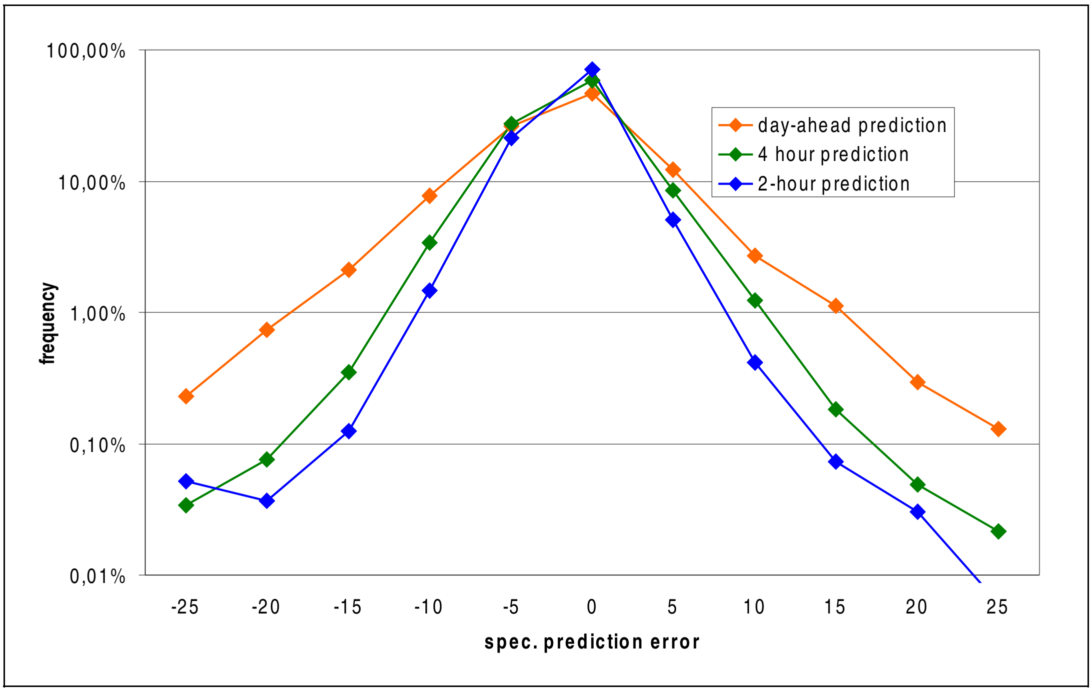

Fig. 4. Frequency distribution of prediction error

The figure shows the frequency distribution of the prediction errors of the day ahead prediction in comparison to the 4-hour and 2-hour short-term forecast. For the day ahead forecast, the prediction error ($P_{meas} – P_{pred}$) of -10% was recognized in 7.7% of the total period (8760 hours), the 4-hour prediction counts this deviation in 3.6% of the duration and the 2-hour forecast in only 1.5% of the year. In addition to the expected value of power, the forecasting system also provides a tolerance band (i.e. a reliability measure), which is determined from the experiences (prediction errors) of the past and from the data of the meteorological services.

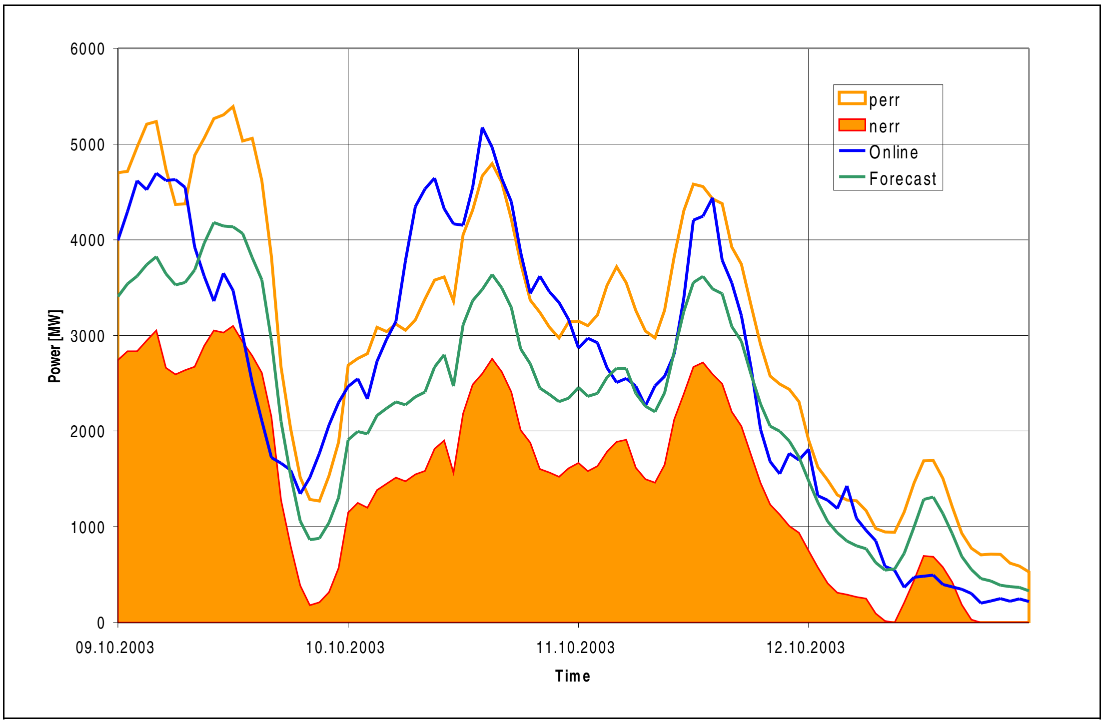

Fig. 5. Measured and predicted wind generation with associated tolerance area

III. EMPLOYMENT OF PREDICTION TOOLS

In Germany, the integration of renewable energy sources in the energy supply system is regulated by law. The total amount of renewable energy and the achieved proceeds are equally distributed to all end customers of energy.

In accordance with the Renewable Energy Act, electricity transmission companies, in whose control areas more renewable energy is fed-in than the corresponding average portion of energy sales to final consumers in German control areas (ENE, VE-T), can give up this excess to TSOs with lower average quota of renewable energies (horizontal exchange). In this way, the portion of renewable energy accepted in relation to final consumer sales is the same size in every control area after distribution is carried out. The question of how directly this balancing should occur was not regulated in the Renewable Energy Act since 2004. The horizontal exchange of available wind energy currently occured in the framework of daily bands, which are fixed on the previous day on the basis of wind power forecatst by ENE and VE-T. In summer 2004, the Renewable Energy Act was modified. One modification committed the TSOs to equalize the amount of the wind caused regulation power immediately. Based on the Wind Power Management System (WPMS), a hard- and software solution, verified by the combination of online-determination and day ahead forecast of wind power, the wind caused regulation power is exchanged and distributed equally between the TSOs every 15 minutes.

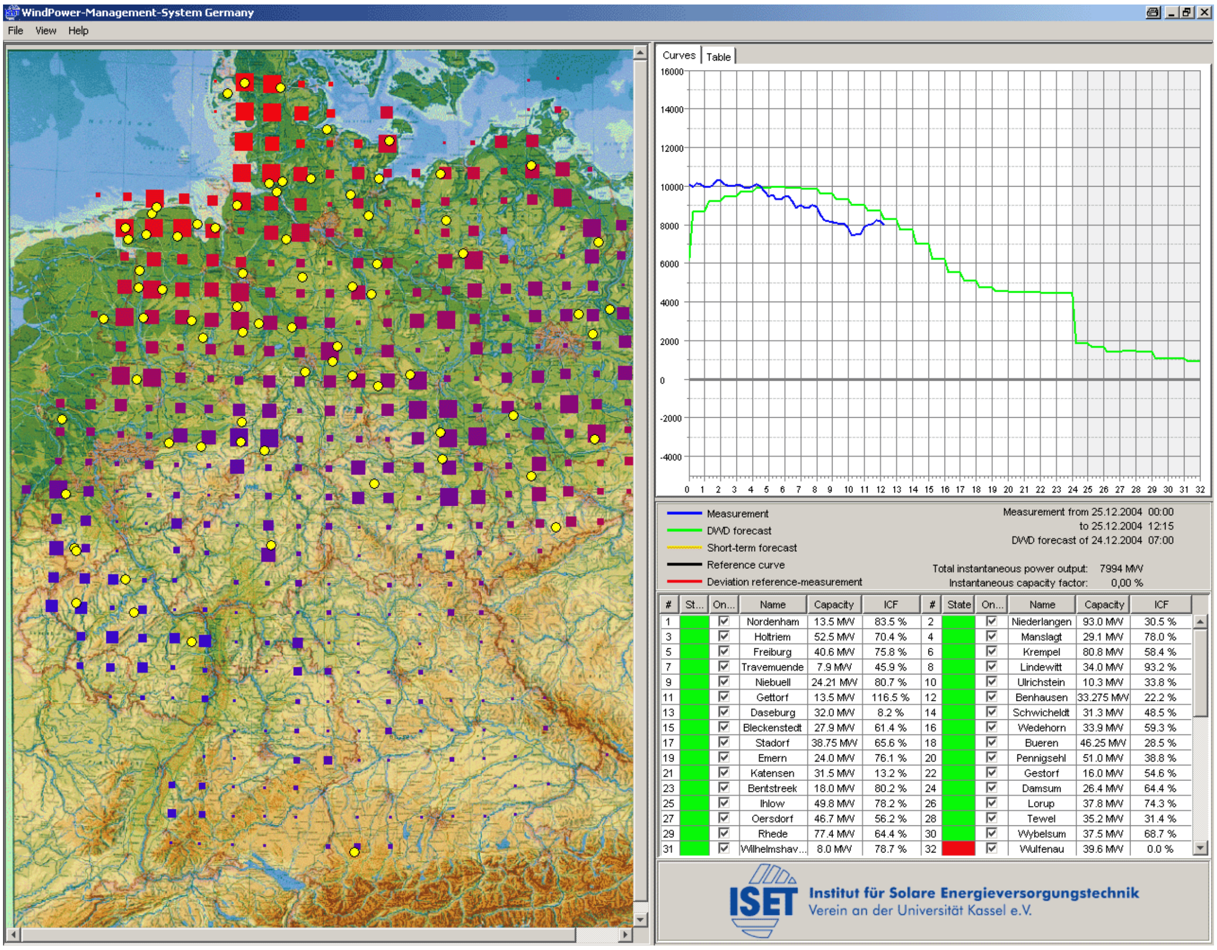

Fig. 6. GUI of Wind Power Management System

IV. ACTIVE CONTRIBUTION TO SYSTEM RELIABILITY

Since 100% accuracy of wind power forecasting is not realisable, the difference between the forecasted and actual supply must be minimised by means of control strategies of Wind farm Cluster Management (WCM) to ensure generation schedule. Power output in this case will be controlled in accordance to the schedule determined by short-term forecasting. This strategy has a large impact on wind farm operation and requires matching of announced and actual generation on a minute-to-minute basis [5], [6]. The schedule execution should be realised within a certain (determined by forecast error) tolerance band. Time-variable set-points should be constantly generated and refreshed for an optimum interaction of wind parks with WCM. A continually updated short-term forecasting for wind farms and cluster regions is assumed for this kind of operation management based on the following control strategies:

- limitation of power output;
- energy control;
- capacity control;
- minimisation of ramp rates.

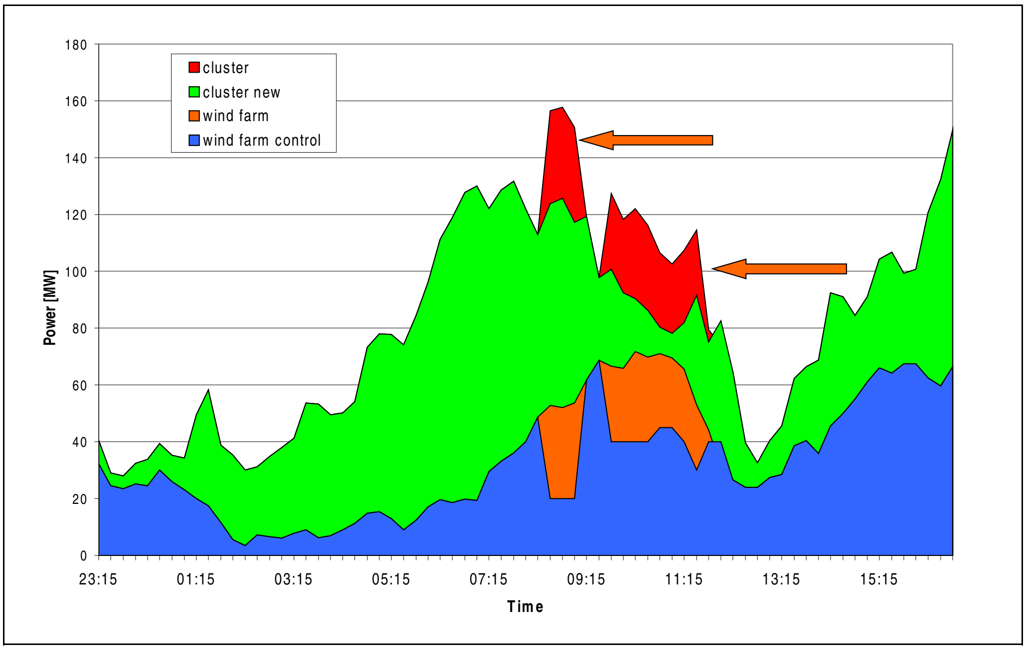

Fig. 7. Profile based operation

Non-controllable wind farms can be supported by controllable ones of that cluster. So, the strategy allows hybrid clusters to meet their requirements.

V. CONCLUSIONS

The energy sector is under strong pressure to integrate renewable energy sources (RES), particular wind power to meet the requirements of the Kyoto Protocol. The relatively low level of predictability of wind power is one of the main barriers to increase the share of these energy source. In Germany, research institutes like ISET developed reliable and precise algorithms to increase the predictability of wind power. The tools are in operation at all four TSOs to prevent imbalances caused by fluctuating wind generation. Furthermore, the software is used to organize the immediate equalization of reserve power between the control zones. These approaches can be very helpful for other countries to increase the share of RES. The prediction tools are also basic elements for advanced wind farm control strategies to integrate the expected wind power in GW range for the future scenarios.

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VII. Biographies

Dr. Kurt Rohrig is head of ISET's Program Area Information and Energy Economy. Dr. Rohrig worked with ISET since 1991 and has been the scientist-in-charge for projects handling the online monitoring and prediction of wind power for large supply areas – operated in co-operation with large power transmission utilities. The computer models and approaches, developed in frame of his work are in operation at all German transmission system operators with high wind power penetration. Furthermore, Dr. Rohrig is head of the thematic network "Energy and Communication" which consists of 12 partners of industry, universities and research institutes.

Dr. Bernhard Lange is head of Information and Prediction Systems of the Program Area Information and Energy Economy at ISET. He is a physicist with MSc from the University of Oldenburg. After graduating he worked in Denmark with Risø National Laboratory and Wind World A/S. 1998 to 2002 he prepared his PhD about offshore wind power meteorology at Risø National Laboratory and University of Oldenburg. His main research interests for the last 10 years are wind power meteorology and wind farm modelling.

9. INTEGRATION OF NEW SOURCES OF ENERGY IN THE ITALIAN DISTRIBUTION NETWORK

Livio Gallo, Eugenio Di Marino, Christian D'Adamo and Simone Botton – *Enel Distribuzione – Italy*

Abstract--In last years, Italian distribution network is registering a progressive diffusion of distributed generation (DG), in both HV and MV grids, driven by European and national incentives, especially for renewable energy sources (RES).

The increase of generation in MV network may produce several problems in a regulatory context with high focus on quality of service and costs reduction. In fact, MV grid is conceived to be operated in a radial scheme, with a unidirectional flow of energy.

The connection of DG is defined both by the Regulator and the Distribution Companies. However, to allow a higher penetration of DG, the "connect and forget" philosophy should evolve in a "full integration" one, through a local energy management.

Distribution companies are acting both at generators' and at customers' side, through new ICT systems and electronic metering.

Clear, stable and uniform rules should be applied in a system approach.

Index of terms--Dispersed generation, Power distribution planning, Power generation dispatch, Power industry, Power distribution, Power system measurements, Energy resources, Power system communication.

I. STATE OF THE ART

The Italian electric system, as well as many other ones all over the world, is experimenting a growing diffusion of Dispersed Generation (DG) and Renewable Energy Sources (RES). Although dispersed generators are already connected to LV and HV networks, provisions show that in next future the majority of the Italian dispersed generators will be connected to MV networks.

Heavy penetration of these generators into an electric network that was designed to be operated in a passive way, with a unidirectional power flow, may produce several problems.

In fact, in case of reverse power flows protection systems may not operate in a selective way. Moreover, automation techniques and MV/LV substation remote controlling systems could experiment problems in selection of faulted sections, with a worsening of actual quality of service for Customers connected to the MV feeder.

Other well-known concerns related to integration of new distributed sources of energy at MV distribution level are:

- Short circuit currents increase;
- Difficulties in voltage and reactive power regulation;
- Protection and fault selection procedures;
- Intentional islanding and safety problems;

- Investment remuneration.

However, more than technical concerns, quality of service, economic issues and regulatory aspects seem to be the most important limits to a widespread of dispersed generators. Especially electric regulation plays a steering role, fixing rules and economic criteria for electricity market.

The dynamic of Italian HV and MV connection requests and final connections to ENEL distribution network is shown in Fig.1.

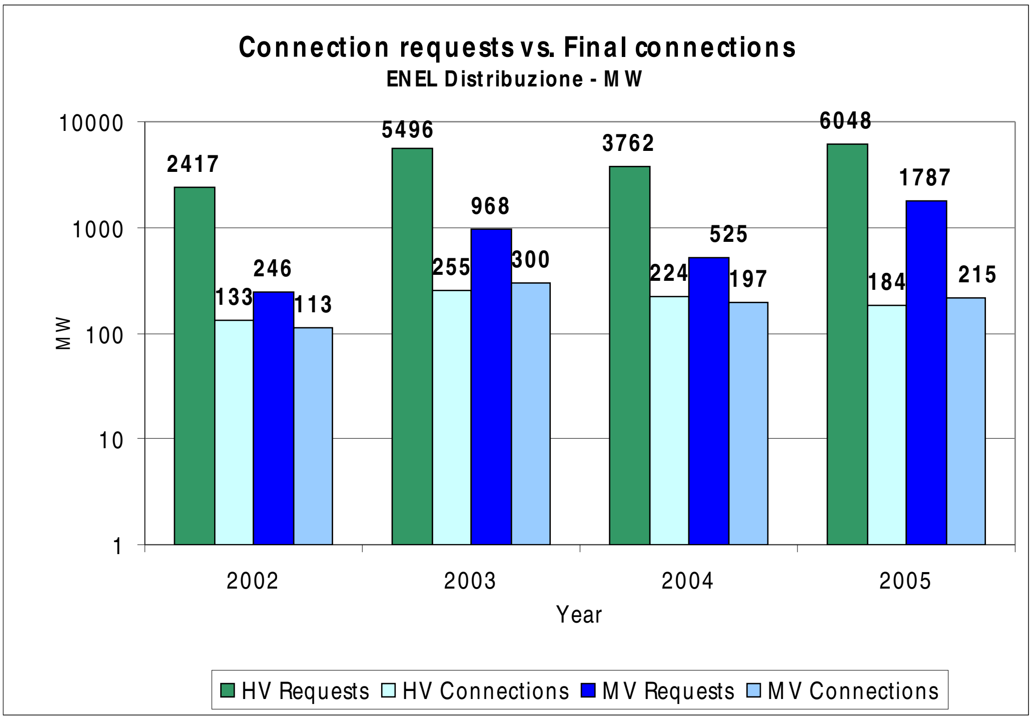

Fig. 1 Requests vs. final connections in Enel distribution system

As shown in the figure, only 5-10% of the total HV requests become effective connections to distribution networks. This happens mainly because of the difficulties in obtaining authorizations and licenses.

Moreover, even network planning is affected by external elements (licences, environmental impact evaluations, authorizations, etc.) which are not totally under Distribution Company's control.

The new sources of energy connected to MV distribution network are mostly Renewable Energy Sources (RES). The breakdown of connected capacity by type of source is represented in Fig. 2.

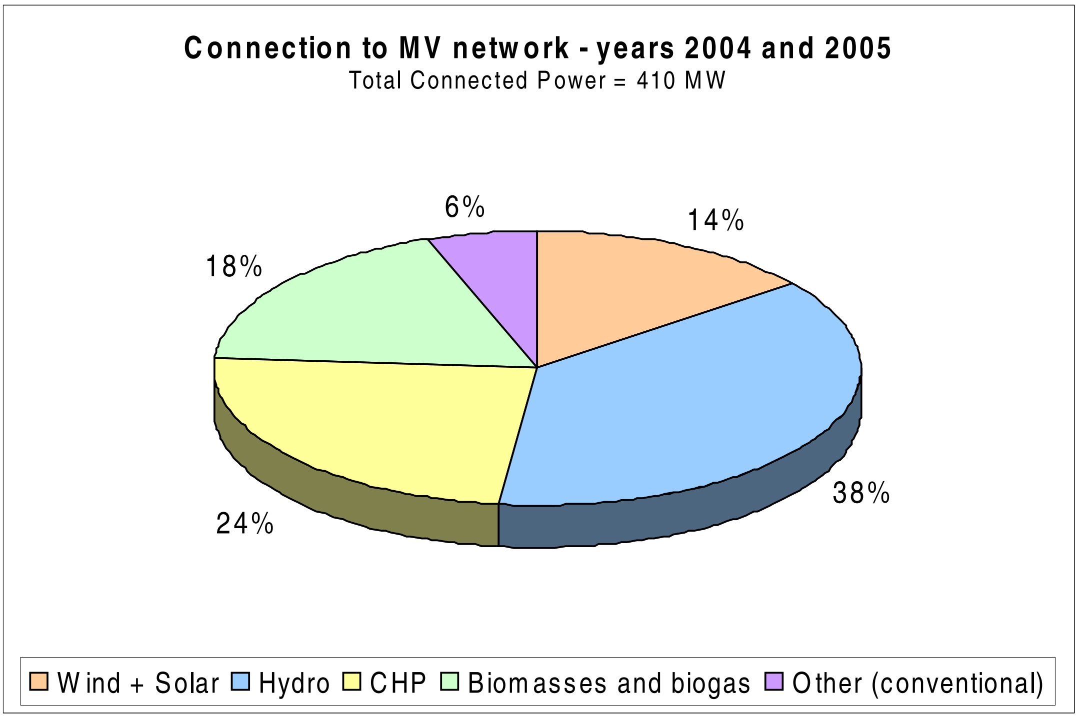

Fig. 2 - MV connected power by source of energy

II. ITALIAN ELECTRICITY MARKET REGULATION

Since 1999, Italian electricity sector was liberalized and Italian Electricity Authority (AEEG) was established. In first and second regulatory periods the technical regulation focused on continuity and quality of supply. A premium-penalty system was introduced in order to achieve target quality levels for high, medium and low Customers concentration areas. Moreover, connection rules and criteria both for Customers and generators have been updated in order to assure access to the electric grid in a non-discriminating way.

No clear rules have yet been established for the operation and management of dispersed generation in MV networks.

In particular, Distribution Companies can not operate energy dispatching and local load control. This represents a great limit to the operation of GD on MV network because:

- power quality (e.g. voltage regulation, failure restoration, automatic reclosures, etc.) could be affected;
- intentional islanding is not possible (neither generation nor load can be controlled);
- operation and maintenance of islanded network could be dangerous (safety problems).

On the other side, subsides to Renewable Energy Sources (RES) are facilitating their diffusion in a passive network context.

At the moment, a “connect and forget” policy is generally followed in order to facilitate, assure equal opportunities and reduce the cost of the connection.

In next future, the challenge for distribution networks will be the full integration of growing DG and the evolution towards “active network” model.

A change of mind should be faced from a “connect and forget” strategy to a “whole electric system” one, considering expectations and needs of all Customers and stakeholders.

For this epochal leap a clear and stable regulatory framework is necessary and local energy dispatching for Distribution Companies must be allowed.

III. DISTRIBUTION NETWORK EVOLUTION

To meet the challenges made available from new sources of energy, especially those widely dispersed in the network, Distribution Companies may act in two main directions:

- At customer’s side: using new technologies and opportunities made available from Demand Side Management and Automatic Meter Management systems;
- At generator’s side: giving the opportunity to remote control and regulate active and reactive power flows to the grid.

First strategy is currently being implemented by Enel Distribuzione. In fact, a huge meters replacing plan has been undertaken in order to provide, at the end of 2007, all Italian Customers with Electronic Meters. Over 30 millions of Electronic Meters are being installed. Contemporary, flexible contract management and different tariffs have been proposed to Customers for a better use of energy and peak shaving actions.

Second strategy is actually impracticable due to regulation framework that does not allow local dispatching functions to the Distribution Companies.

Moreover, both actions need consistent investments to be faced in order to adequate or replace existing systems and provide necessary redundancies to assure a high level of quality of service to all Customers. Clear and certain remuneration criteria must be assured to all the stakeholders involved.

Generators connected on MV networks should be equipped with communication systems and regulation devices in order to be aggregated and remotely controlled by the Distribution Company.

Manufacturers should provide new solutions in order to improve flexibility and connectivity of generators in an economic way. Especially ICT systems for aggregation and remote control of dispersed generators will be necessary at competitive costs. Feasibility and costs associated with the integration of dispersed generator management and control systems and with the provision of an adequate reliable communication infrastructure need to be evaluated for any of the potential solutions proposed.

Finally, Distributed Generation regulatory framework should be harmonized in a European context, in order to assure equal opportunities in a liberalized market.

IV. CONCLUSIONS

In a regulated marked, Distribution Companies are squeezed between quality of service and costs reduction needs. A clear and stable regulatory framework allows making investments and having adequate remuneration.

During last years a progressive growing of DG has been experimented and in next future more and more connections will be requested, especially in MV and LV networks.

The evolution of distribution system from passive to active should be accompanied by a change of mind from a “connect and forget” strategy to a “whole system” one.

To this aim relevant investments will be necessary both for Distribution and Generation Companies.

More that technical aspects, a clear and stable regulation framework will play a steering role in this direction. System’s research should be addresses to assess the effectiveness of DG in terms of: quality of service, costs reduction and environmental aspects.

DG energy dispatching could be performed using communication and information technology in large scale to aggregate and control generation; load control can be operated through Demand Side Management policies, thanks to the current deployment of Electronic Meters and AMM systems.

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