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DISPERSED GENERATION AND ITS IMPACT IN EUROPE ON POWER SYSTEM STRUCTURE AND SECURE POWER SYSTEM OPERATION

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ABSTRACT

The paper discusses modern power system as a critical infrastructure. The expected insertion of Distributed Generation (DG) in the distribution networks entailed by environmental, regulation and economical aspects will modify the way the entire system is planned and operated. Due to its dispersed nature, DG will require a more flexible operated system. This situation will emerge through various applications and developments of distribution automation. In addition, DG has already showed some impacts on system security. Active user participation in energy markets through activation of distributed energy resources is considered, as is distributed generation towards an effective contribution to power system security and communication requirements and solutions for secure power system operation. Increase of the contribution of dispersed and renewable energy resources (D&RES) in the peak power balance up to 60 % in accordance with goals of the European Communities for the year 2010 requires innovative approaches to keep security of the power supply at the current high level.

Keywords: Distributed generation, dispersed generation, CHP units, energy markets, system robustness, fault handling, intentional islanding, energy markets, active loads, demand side participation, power system security, wind energy, decoupling protection, future power systems, communication.

1. INTRODUCTION

The power system is a critical infrastructure for which its secure operation has a decisive influence on the development of industrial nations. Changes in structure of primary energy resources will also modify the structure and operation of the power system in order to fulfil the high requirements of the infrastructure. One aspect is that dependency of Europe on imported primary energy increases from year to year. As a countermeasure, 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 for a sustainable electricity supply. Generally, the share of renewable energy sources has to be increased from 14% to 22% and the share of CHP has to be doubled from 9% to 18% by 2010. The question arises, how can the power system be operated securely with such a large share of mostly non-dispatched power sources? How can the reserve power that is required for compensation of power fluctuations and ensuring a safe network operation be limited?

In this context, a vision sees the power system of the future consisting of a number of self-balancing distributions network areas. In each of these areas a significant share of power demand will be covered by renewable and CHP generation. However, the power balance of these areas should be planned and dispatched in such a way that import or export of power from or into the higher-level network has to follow a schedule that can be predicted in advance with a high level of accuracy. 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 responsibility for system stability will be allocated in the future as well. This paper fits very well with the scope of the advisory council of the European Commission "Platform of the Electricity Network of the Future".

2. MODERN POWER SYSTEM AS A CRITICAL INFRASTRUCTURE

The anticipated insertion of Distributed Generation (DG) in distribution networks entailed by environmental, regulation and economical aspects will modify the way the entire system is planned and operated. Due to its dispersed nature, DG will require a more flexible operated system. This situation will emerge through various applications and developments of Distribution Automation.

In addition, DG has already had some impacts on system security. Thus, special attention should be paid to DG influence during emergency conditions such as the propagation of cascading failures or other major events.

During the last years, blackouts and cascading failures have occurred (USA, Italy, Sweden & Denmark, Algeria, …), and more recently a power shortage occurred in Europe following an initiating event in Germany that resulted in significant economic cost. The causes of these blackouts were different depending on nature of the failure but, in general, they were a consequence of heavier system loading and almost revolutionary changes in industry structure.

The decentralization of energy production in the system could help operators limit impact of these blackouts. The flows of energy in the transmission sub-system are reduced by insertion of DG. Saving parts of the system in autonomous sub-systems in case of very critical events in the whole system is favoured. Thus, a high amount of DG could improve the Electrical Power System (EPS) robustness [1]. However, the large-scale introduction of dispersed generation can result in more vulnerable situations and decrease system robustness on account of DG dynamic performance and integrated system controllability.

2.1 Plans for DG Installation

International agreements to reduce Greenhouse Gas Emissions and new rules such as the European directives to increase renewable energy sources have promoted creation of national plans to install new DG resources [2].

The rate of DG penetration in a country should be established considering:

- Possibilities of Renewable Energy Sources (RES) within the country: solar, hydro, and wind potential. This parameter befits the country's natural resources (cheap carbon, weather conditions, hydro reserves, etc.) and social (acceptance degree of nuclear power, acceptability paying for cleaner energy at a higher price…) characteristics of the country.

- Strengthening network costs.
- Defining technical criteria such as: static security and dynamic security.

The general tendency and goal in the EU is therefore as follows: Countries such as Denmark, Germany and Spain are promoting installation of wind energy. Germany is planning to increase its wind capacity from around 18 GW wind capacity installed to near to 30 GW by 2010. The Danish Government is planning to install 4GW off-shore and 1.5 GW on-shore before the year 2030 [3,4].

2.1.1 Impacts of large scale DG in EPS

The voltage level for DG connection (sub-transmission or distribution) depends essentially on the amount of injected power and the local network characteristics. The interconnection of DG units at lower voltage level includes advantages of economic and the energy point of view. By its small and medium size nature, almost all DG units are connected to distribution system which is the first that is influenced by DG penetration's phenomenon. When DG insertion becomes more excessive, its impacts will be more widespread and affect even the transmission system.

The direct impacts that DG could cause on the distribution system are [5,6]:

- Impacts on direction of energy flow
- Impacts on protection
- Impacts on voltage profile
- Impacts on stability
- Impacts on power quality
- Economic impact on the energy markets.

Most impacts on the transmission networks can be summarized:

- Incertitude in the EPS planning phase
- Incertitude in estimation of operation reserve margin
- Sensibility of system due to reactive management
- Sensibility of system due to unplanned DG off-loading.

In general, the authorized deviation limits are very restricted: (i) whenever voltage deviates over ±(10~15%) of nominal value; and (ii) system frequency rises above or falls below ±(0.5~0.6 Hz) from nominal value.

These requirements are necessary to protect against unintentional islanding for public safety reasons. However, if the grid is experiencing stress, it may also be experiencing voltage and frequency deviations. If these deviations force a large quantity of DG capacity off-line, the sudden increase in load (assuming the DG users revert to grid power) might trigger a blackout. The fact that DG is often installed as a peak-shaving strategy makes this scenario even more likely.

2.1.2 New adopted DG operation strategies in critical situations

DG units, as long as they are marginal sources, have no great influences on operation or on service quality of the networks. With the anticipated rate of DG insertion in coming years, critical situation management in EPS will be a new challenge for system operators.

One of the new strategies for more benefit of using DG in critical situations is suggested below based on the concept called "*intentional islanding*". Figure 1 illustrates a case of intentional islanding in a distribution network. The main idea is that, in case of failure, some DG could facilitate a lot of autonomous areas or cells thereby providing local service continuity and energizing the grid as much as possible by switching operations. Numerous parts of the system will be saved by autonomous sub-systems at the distribution level as well as at the transmission level that will be mutually synchronized.

The intentional islanding could be ordered in two ways: during disturbances if possible to limit its propagation; or after partial or total blackout using the black-start capability of DG units to accelerate restoration of the system.

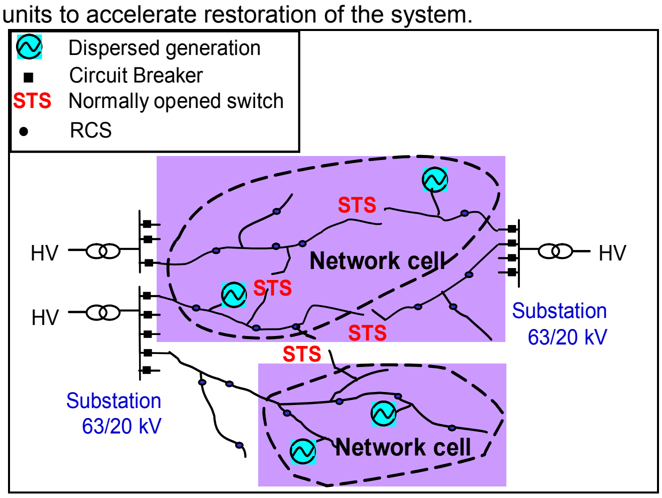

Figure 1. Intentional islanding operation mode in distribution network

This "*intentional islanding*" concept refers not only to an EPS topology but also to a distributed part of intelligence or in other words, a local decisional capacity associated to a network cell. This intelligence is comprised of several local coordination actions including DG unit controls, local demand controls, optimal switching sequence determination based on computing processors connected by communications means.

2.2 Necessary Network Infrastructure Upgrading

The concept of using DG to help the system in critical situation induces more complexities in the system exploitation plan, and requires more investments in existing electrical network infrastructures (measurements, remote controlled switches, fault path indicator devices, etc.) and operating tools (SCADA, WAMS)

The new requirements of electric power operation by means of increase in system observability and controllability imply development in parallel of communication and information network infrastructures. The use of the communication infrastructures will be spread not only to the control, protection and acquisition tasks but also to the maintenance and the metering. The communications must be then operated with high reliability and security to guarantee a high quality power supplies.

In summary, the connection of new DG leads system operators to carry out and to take into account new challenges. Distribution networks are therefore upgrading their role and actions within the whole EPS structure and operation. Political incentives, environmental concerns, electric market liberalisation, continuous progress in Information and Communication Technology (ICT), and the recent blackouts outline the need of supply reliability. These are some examples that are pulling the development and implementation of new distribution functionalities for monitoring and remote control, as well as advanced protection systems.

The main challenges are related to upgrading network infrastructures (including electric, communication and information) and new operating rules.

3. ACTIVE USER PARTICIPATION IN ENERGY MARKETS THROUGH ACTIVATION OF DISTRIBUTED ENERGY RESOURCES

Customers in liberalized energy markets do not have tools in hand to contribute to the balancing of undispatchable distributed generation and uncontrolled loads. Activation of loads that could make users more involved in energy markets and indirectly support the sustainable deployment of distributed generation often based on locally available renewable energy sources is now discussed.

3.1 The Energy Market and Distributed Energy Resources (DER)

3.1.1 The user's stake in the energy market

A good working market requires active suppliers and an active demand side. The latter lacks in energy markets. Communication between supply and demand is organized unidirectional, which makes it impossible for the customer to really take part in the market. The customer presently receives no real-time price information or indications on the origin of the electricity, other than difficult to understand very general tariff systems. These do not really offer any insight in the relation of demand-price and therefore do not provide any incentives to change his/her demand according to market fundamentals.

3.1.2 DG in the market

Distributed generation is a technology that has received widespread attention in recent years. Some technologies have proven to be successful, but can only survive without lots of direct and indirect support in a liberalized market. This is discussed through the three perhaps most popular DG types: wind power, photovoltaic conversion, and CHP [7-9].

Wind power in the market

In the past ten years many GWs of wind power have been commissioned in Europe (mainly Denmark, Germany, Spain and the Netherlands), in USA, and other parts of the world. Usually, wind power is given a financial benefit through, for example, installation subsidies or tax advantages, 'green energy' certificates functioning in a retail portfolio obligation, grid access priorities or lowered balancing costs. This cannot help as wind power has a fundamental handicap of being hard to predict on longer time scales as encountered in markets, for instance a market with a 24-hour gate closure periodicity.

Photovoltaics

Pholtovoltaic (PV) generation suffers from similar problems as wind power, be it rather on distribution than on transmission grid scales. It is to be integrated with existing (radial) distribution grids, next to loads having cycles that are entirely uncorrelated with the solar cycle. This causes local balancing inequalities eventually resulting in large voltage changes and protection (selectivity) problems when bidirectional flows occur.

CHP

CHP fundamentally is a heat demand driven generation of electricity with electricity as a by-product. There is the option to include thermal buffering, but this is in general not designed yet with a smooth electricity generation cycle in mind. CHP in fact links two markets: the primary resource markets which normally is natural gas and the electricity market, but these are usually not approached in parallel.

3.1.3. The reliability paradox

Questions are raised about the difficulties linked to further deployment of certain types of DG. Grid reinforcements are required and some operational practices need to be fundamentally reconsidered. On the economic side, the market is distorted or overly complicated by presence of certain types of DG [8].

3.1.4 Demand control as a solution?

A technology that allows shedding or modulation of some load locally on a small-scale following generalized price signals, indicated as 'active' loads, contribute to the solution of the balancing problem.

As an example, one can imagine a fridge being able to shift its off-take of electricity to cool at times following price signals as a control variable. Considering that on average every household owns at least one fridge and the number of households (which is about equal to the number of house connections (equal to about 50-75% of the population of a country)), this quickly becomes an important 'spinning reserve' for the local as well as for the global electricity system. This 'spinning' reserve can be addressed when there is a local overload on the distribution feeder as much as to contribute to smoother load shedding in case of contingencies.

As such, demand control impacts the security, adequacy and stability of supply in several senses:

- it allows to better utilize local energy opportunities replacing imported resources and therefore enhances resource diversification (security of supply)
- it offers additional ancillary services for system operators in the form of, mainly, (negative) reserve power that can be used in primary/secondary system control (adequacy and stability).

Demand control may in the future become an important enabler for the further deployment of distributed generation systems. However, two steps have to be taken in development of the local energy control.

3.2 Increased Energy Market Participation

3.2.1 Towards efficient and flexible small energy users

From a theoretical perspective, an optimal use of market forces and price mechanism can strongly improve efficiency of the whole energy system [10]. These efficiencies are not limited to increased consumer and supplier surpluses but can also include technological dynamics [11].

3.2.2 *Technology*

A real breakthrough of retail markets can only be initiated by active metering tools. By improving both internal and external communication with market players and devices, a better measuring of relevant data is possible. An intelligent system has to be developed to organize control and interaction, as transparently as possible. The use of real-time prices and information will be crucial. However, the economical feasibility remains to be investigated.

3.2.3 *Link to mobility*

On the electricity demand side, plug-in hybrid cars can also be considered an option for efficient energy use. Plug-in hybrid electric vehicles (PHEV) are the next phase in the evolution of hybrid and electric vehicles. Hybrid electric vehicles combine a conventional internal combustion engine (powered by petrol, diesel or biofuel) and electric motors.

Since PHEVs can be controlled in their charging process quite easily, they form an excellent candidate for a controllable load.

3.2.4. *Multi-energy approach*

In order to capture the larger-scale consequences of DG implementation or load activation; natural gas and electricity networks and the off-take profiles have to be considered in parallel as overlaid networks. An investigation of the parameters driving the profiles provides information about how they can be influenced accounting for impact of local renewable energy sources (Figure 2). Eventually the three resources have to be distinguished: electricity, natural gas, and renewables in a broad sense.

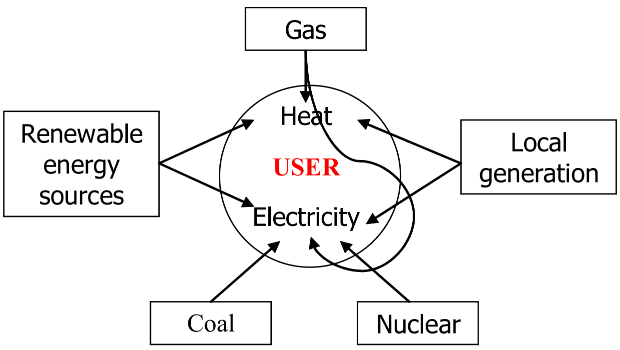

Figure 2. Multi-energy resource interactions.

In summary, activation of electrical loads with small users, the so-called demand-side participation, helps further deployment of sustainable types of distributed generation such as wind power, PV and CHP through a contribution to balancing locally as well as globally. As such it represents a contribution to the security, adequacy and stability of supply through the enlarged diversification of primary energy resources and the creation of necessary ancillary services, more in particular reserve provision. Unlike a blunt introduction of DG, a combined introduction of both types of DER, DG and complementary demand control may help to solve the 'reliability paradox'.

Further research is required into the technological implementation of demand control. A new class of active metering devices is required. Their communication and distributed control algorithms form a challenge.

4. DISTRIBUTED GENERATION TOWARDS AN EFFECTIVE CONTRIBUTION TO POWER SYSTEM SECURITY

DG is defined by CIGRE Working Group 37-23 as a generation not centrally planned (by the utility), not centrally dispatched, normally smaller than 50-100 MW and usually connected to distribution power systems (networks to which customers are connected, typically ranging from 230 V/400 V to 145 kV) [12].

Wind power, cogeneration, PV, small hydro and waste/biomass are considered as DG. Table 1 shows the DG installed in Europe according to [13].

Table 1. DG Installed in Europe [13]

Country (2005)	Power installed GW	COGEN GW	PV MW	Wind MW
Germany	116	19	1 600	18 400
UK	69	6,6	10	1 350
Denmark	13,6	4,9	36	3 100
Spain	54	8,1	15	10 000
France	115	3	2	750
Poland	34,3	5	15	70

The rates of development of the different forms of DG vary. At present the fastest one is wind energy with some 40 GW installed in Europe (2005) and a still increasing growth rate in some countries (up to 100% more each year). Wind-power in Europe is shown in Table 1.

Table 2. Wind power in Europe (EWEA)

Wind Power	2004 MW	2005 MW	growth %	2005 EU share
Germany	16 600	18 400	11 %	32 %
Spain	8 300	10 000	21 %	17 %
Denmark	3 100	3 100	0,1 %	5 %
Netherland	1 100	1 200	12 %	3 %
UK	900	1 350	52 %	3 %
Portugal	520	1 000	96 %	2,5 %
France	380	750	98 %	1,3 %
CE (25)	34 300	40 500	18 %	

The contribution of DG to power system security is now discussed in more detail. More precisely, the frequency behaviour of DG and its potential contribution to frequency support is assessed. Up to now, even though this generation is able to operate in abnormal conditions, unwanted disconnections may be observed due to protection tripping. Some possible reasons for unexpected tripping in case of frequency deviation, and possible improvements to remain connected and provide an active support to frequency control is examined.

4.1 UCTE Rules

The Union for the Coordination of Transmission of Electricity (UCTE) is the association of the Transmission System

Operators (TCOs) operating within the synchronous system of mainland Europe. This organization helps to coordinate the national transmission grids that serve a total of 500 million of users across 23 countries. To help maintaining security and quality of the electricity supply, each TSO has to provide some ancillary services according to recommendations of the UCTE. Among these services, frequency control maintains the balance between generation and consumption by keeping in reserve a certain amount of active power from some generators. The frequency is a measure of the balance between production and consumption. Several controls are usually used to adjust the system frequency [14]. Within the UCTE, the primary frequency control reserve is the production capacity that is automatically activated and fully deployed within 30 seconds after a sudden change in frequency. The primary frequency control reserve is 3,000 MW for the whole UCTE. This value has been chosen to respond to realistic incidents that could occur in the continental European grid. If the security of the system cannot be maintained anymore with the sole reserves, the TSOs use automatic load shedding according to the frequency reached. Load shedding starts at 49 Hz in order to stop any frequency drop before reaching the point of no return, which is the critical threshold of disconnection of production units (fixed at 47.5 Hz by the UCTE). Table 3 shows the load-shedding plans recommended by the UCTE (usually, the considered loads are those connected to distribution networks apart from priority loads).

Table 3. UCTE Recommended Load Shedding Plan

Frequency reached (Hz)	Load disconnection
49.0	From 10 to 20 % of all the load
48.7 or 48.5	Additional disconnection from 10 to 15 % of the remaining load
48.4 or 48.0	Additional disconnection from 10 to 15 % of the remaining load

4.2 Decoupling Protection Systems

In most of the European countries, the rules forbid islanded operation of DG on distribution networks in order to guarantee the quality level of the electricity supply, and more specifically to prevent DG units from:

- supplying power to customers under abnormal voltage and/or abnormal frequency conditions
- causing false couplings when isolated networks are reconnected to the main network of the distribution company.

More specifically, generating plants connected to distribution networks should be equipped with decoupling protection to:

- ensure that the protection and automatic control systems fitted by the Distribution System Operator (DSO) in the network are able to operate properly
- prevent operation of isolated networks under no-fault conditions, thus preventing the DG units from supplying power to other users under abnormal voltage and frequency values and avoiding false couplings when these networks are reconnected to the main distribution network
- instantly disconnect DG plants in the event of a fault occurring during special operating conditions which apply when live work is being carried out on the MV-overhead network.

These decoupling protection systems must be coordinated with the DSO's protection scheme and should be able to detect the following situations:

- islanded operation without fault
- phase-to-ground faults
- phase-to-phase faults for MV networks and faults between conductors (phase and/or neutral) for LV networks
- risk of false couplings
- faults on the HV network (transmission): when the sum of the maximum active power of all the generating plants connected to a HV/MV substation becomes significant (for instance larger than 12 MW), the DSO should take appropriate measures to ensure the safety of people and equipment in case of faults occurring on the HV side.

The DSO specifies to the producer the performance that is expected from the decoupling protection.

Presently, decoupling protections are mainly based on over- and under-voltage, over- and under-frequency criteria and in some cases on "inter-tripping", i.e. on the use of an automatic control linked with the protections implemented at the substation level (such as the feeder protection or other protections, which may lead to islanded operation of DG units on some parts of the distribution grid).

4.2.1 Operating principles

The decoupling protections comprise a group of relays with a certain number of functions among which are:

- "maximum zero-sequence voltage" function
- "minimum phase-to-phase voltage" functions or three "minimum phase-to-neutral voltage" functions (one for each of the three network phases)
- "maximum phase-to-phase voltage" function
- "minimum (and maximum) frequency" function
- "maximum (or minimum) active power return" function
- "inter-tripping" function.

When a frequency or a voltage threshold is reached, a decoupling order is transmitted to the decoupling switch of the DG.

Relays and functions actually implemented in a DG plant depend on the type of decoupling protection.

4.3 Risks of Decoupling Protections Tripping during severe Grid Disturbances

The DSO of each country specifies the settings of the decoupling protections according to the network protection scheme. In case of a major frequency deviation, the decoupling protections will react differently across European countries leading to possible unwanted disconnections.

As an example, during the Italian black out of September 2003, the sudden decrease of frequency resulted in the loss of 1 700 MW at a frequency of 49 Hz. In the same way, the outage on the European grid in November 2006 led to the tripping of a significant DG capacity in the western part of the

UCTE (e.g. in Spain with the loss of 2 800 MW of wind power) as the frequency dropped to 49 Hz.

A concerted modification of the connection rules could lower this risk. This situation is not optimal considering that, depending on the sources, DG could be used to provide some frequency support, since DG has the ability to remain connected during such grid disturbances if it is not disconnected by decoupling protections.

The design of decoupling protections may therefore be improved so as to distinguish a real islanding situation (disconnection expected) from a large-scale frequency disturbance. In the second case, power system security requires the ability to keep as much generation as possible connected to the grid.

Another solution would possibly rely on the use of more sophisticated protections, based on other criteria (e.g. rate of change of frequency or voltage, grid impedance, etc.), or taking into account a pre-defined reference frequency vs. time characteristic.

4.4 Wind Farms Production Management by Control Systems

For DG that has the ability to remain connected to the grid during major system frequency disturbances, further advanced control functions could be considered to ensure an effective contribution to frequency support. Here, new grid codes requirements on frequency control, and existing control systems for wind farms and possible contribution to frequency regulation in case of disturbance could be looked at.

To summarise, it can be seen that on one side, there is currently a common set of rules concerning load disconnection across Europe but, on the other side, there is a lack of harmonization on frequency behaviour of DG, especially concerning the decoupling protections. Generally, it is the DSO that specifies the settings of the decoupling protections according to the network protection scheme. In case of a major frequency deviation, the decoupling protections will then react differently across European countries leading to possible unwanted disconnections. Thus the risk of losing a significant part of dispersed generation following a frequency problem exists today. A concerted modification of the interconnection rules would have to be discussed to lower this risk. Moreover, instead of disconnecting in case of a frequency problem, DG can provide an active contribution to power system security by ensuring a frequency control. Wind farms are asked to contribute to frequency control, as required for other technologies: they are expected to change their active power output in case of frequency variations. Different improvements in grid connection rules and DG's technical specifications are under way in Europe, all aiming to favour DG integration to the grid and taking advantage of its presence to ensure an active contribution to power system security.

5. COMMUNICATION REQUIREMENTS AND SOLUTIONS FOR SECURE POWER SYSTEM OPERATION

Further increase of the contribution of dispersed and renewable energy resources (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 security of power supply at a high level. New communication facilities will be necessary to provide reliable data for decentralized energy management, integrated planning tasks, and to ensure the provision of system services by D&RES.

5.1 Secure Operation of Power System of the Future

The operation of todays power system consists of large, centralised power plants, a hierarchical network and a huge amount of dispersed consumers that have to be controlled by central control centres. The future will be characterized by a large amount of small D&RES, many of them with intermittent power output. All these D&RES have to be operated in parallel with conventional power plants. Furthermore, at the consumer side, there will be possibilities to influence the consumption by means of flexible tariffs and other mechanisms [15]. Demand side management will play a growing role for power balancing in the future. A coordinated energy generation, load management and integrated power system planning process will be necessary.

One possible solution is to transfer a part of the control intelligence close to the D&RES units and controllable loads by using "agents". Such an agent receives instructions from the higher-level control structure and has a certain range within which it can control its unit or group of units. For example, a household agent receives information about tariffs, electricity demand etc. from the superior control mechanism and information about heat demand, status of storage units etc. in the household. Additionally, the agent gets predictions for these parameters, based on weather forecasts, load profiles, etc.

6. PLANNING UNDER UNCERTAINTY IN DENMARK-- SECURING RELIABLE ELECTRICITY SUPPLY IN LIBERALIZED ENERGY MARKETS

A high proportion of DG and wind power plants characterize the Danish power system. Today, wind turbines generate about 24 % of electricity and CHP units generate about 19 %. Discussed is how the Danish transmission system operator (TSO), Energinet.dk, handles the tasks of providing secure system operation today and in future, using technical and market mechanisms.

The Danish power system consists of two electrical systems belonging to the two synchronous areas; UCTE in the west and Nordel in the east. Both Danish systems are not connected to each other yet, although an HVDC link between them is planned to be in operation in 2010. The national TSO runs the 400 kV and the 150 kV grids (as well as the natural gas grid) and is responsible for security of supply and well functioning energy markets.

Most of the dispersed generation units are located in the medium and low voltage grid. This is a situation which, on the one hand, complicates their control, but, on the other hand, encourages creating incentives for the operators of the units to control their output according to an overall system optimum.

The wind and CHP penetration (defined as the quotient of installed wind power, CHP-capacity, respectively divided by maximum (or minimum) load [16]) is different in western and eastern Denmark. Currently the wind power penetration is between 65 % to 189 % in western, and 29 % to 85 % in eastern Denmark. The respective values for CHP-penetration are 46 % to 136 % for western, and 25 % to 73 % for eastern Denmark. Looking at the energy, about 52% and 29 % of the consumed energy is produced by dispersed generation units in western and eastern Denmark, respectively.

Being a link between the hydro-based Nordel system in the north and the thermal based UCTE system in the south, Denmark faces high energy transits [17]. The neighbouring German power system is, especially in the north, also characterized by high wind power [17], which will significantly increase due to ambitious plans concerning the implementation of offshore wind parks. To secure also a future reliable energy supply at reasonable prices a careful and co-coordinated transmission system planning is required.

6.1 Aspects Concerning the Energy Market

To optimise overall usage of resources, to reach acceptable prices for the consumers and to find a good socio-economic solution, it is essential to provide market access for all production units [18,19]. The market structure has to enable discrimination free participation in the market. This idea is being followed at the different Nordic energy market places.

6.1.1 Nordic and Danish Power Markets

The Nordic Power Market consists of two main markets - the Nordic Power Exchange (NPX) - which itself is divided into three market places - and the TSO`s real time power market (Figure 3). The first part of the NPX is a market for financial contracts like futures and forwards covering periods from 3 years to hours ahead. The second part consists of the market places for physical contracts: the day ahead spot market (Elspot) and the hour ahead market (Elbas). Additionally the NPX works as clearing house for bilateral contracts (Elclearing).

The TSOs run two additional markets: one regulating the power market for trading balance power, and one system power market for trading system services. The TSOs exchange power within the operating hour based on trading on these markets, balancing load and generation every minute of the day.

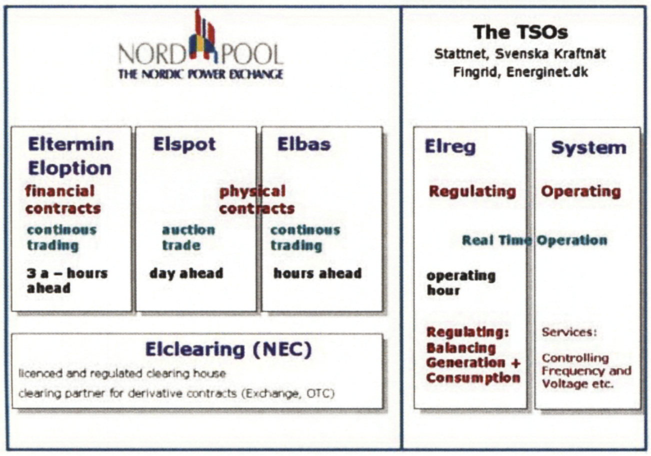

Figure 3. Structure of the Nordic Power Markets

6.1.2. Local Production on the Spot Market

To stabilize the market, a change of operational conditions for CHP units has been implemented. Before the year 2005 there were several hours during a year, where energy was - due to a production surplus during hours with high wind production - sold for a price of zero to foreign customers, which is socio-economically not optimal. It was decided to let CHP units participate in the spot market, to reduce the number of these hours.

Since 1 January 2005 all local CHP-units above 10 MW must operate on market conditions instead of producing according to fixed time tariffs. Before 2005 a three tariff system was used. These units comprise a production volume of about 1,200 MW. Effective from 2007 the limit was lowered to 5 MW. For units with a capacity below 5 MW no statuary provisions exist.

6.1.3 Local Production on the Regulating and Reserve Power Market

The Danish TSO has the task of balancing the power 24 hours a day. Fluctuations of loads as well as fluctuations of sources have to be equalized. The increasing amount of dispersed generation posed new challenges on the TSO with respect to his balancing task, as most of the units are located in the distribution grid and cannot be directly controlled. Therefore the use of market price signals for system control has been implemented, aiming at facilitating the optimal dynamic allocation of resources.

In Denmark balancing power can be bought from national as well as from international sources. The international exchange of regulating power is governed by an agreement with the Nordic countries [20]. Foreign resources seem to be more volatile than domestic resources. Especially in summer their availability can be considerably reduced due to energy transits or network maintaining activities. Reserving access to foreign up-regulating capacity from Norway and Sweden would reduce transfer capacity in the spot market and is therefore not a preferable solution. Thus, an increase of domestic sources is desirable.

6.1.4 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. This enables customers either to shift the time of consumption, or to shift the energy resource and thereby influence the slope of the demand curve [19].

6.1.5. Residual Market

A study made by Energinet.dk [21] investigated the effect of a further implementation of wind energy on the market. The result shows that new products have to be implemented to serve the so-called residual markets: which is one market on the demand side and another one on the production side.

6.2. Handling Uncertainty as a TSO

6.2.1. Necessary Analyses

In a liberalized market not only market analyses, but also several other kinds of analyses concerning further areas are necessary to provide a secure infrastructure and a functioning market

Usual analyses with respect to short and medium term developments concern five main areas:

- Market (e.g. congestion analyses; exchange of power and energy; prices; strategic market behaviour, i.e. execution of market power).
- System Planning (e.g. medium to long term planning, i.e. new transmission lines, sufficiency of power, energy and network; development and testing of a new system

architecture integrating local grids and consumers into system operation)

- Loadflow and stability analyses: (e.g. stationary and dynamic analyses of the power system)
- Environment: (e.g. requirements according to the Kyoto protocol, emission quotas of CO2, SO2 and NOx)
- Natural Gas Transmission System (e.g. planning of infrastructure).

6.2.2 Developing Modelling Tools

For each of these areas several modelling tools are used to cover all relevant aspects. Due to the rather unique composition and structure of the Danish power system with a large amount of CHP units and wind turbines and strong electric international connections some of these tools are self-developed. SIVAEL simulates the optimal scheduling of power and CHP production including wind power and foreign exchange, taking into account the heat buffering characteristics of the units. This tool is also used for environmental analyses.

To summarise, running a system with a high proportion of dispersed generation requires measures that include technology and technical guidelines as well as a suitable market structure. Strong interconnections to neighbouring countries are essential for the well functioning of the system and the market as well.

The Danish transmission system operator uses the opportunities of the liberalized market to optimise the national power balance at reasonable prices. The measures on the production side include CHP units operating on market terms bidding into different markets instead of being governed by a static three tariff system, while on the demand side demand response is considered.

To ensure reliable electricity and gas supply in future, it is of important to simulate variants of future developments. Thus different kinds of analyses are made trying among others to identify indicators for system upgrades necessity or find future markets that have to be prepared. The overall target is to optimise the respective socio-economic surplus.

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