Liberalized markets and technical boundary conditions

Summary

This report defines the potential network problems that can arise in the different scenarios of the future. Scenarios that are especially demanding for the transmission grid are scenarios with a lot of renewables (which will largely be wind) and scenarios that rely on import to secure supply. Scenarios that are especially demanding for the distribution grid are scenarios with distributed generation and demand response programs to manage demand with real time metering and balancing. Furthermore it should be underlined that transmission grids are not islands. They are actually more and more interconnected to create an Internal Electricity Market in the European Union (IEM). This implies that policies from other countries and especially neighboring countries compete for scarce transmission network capacity, and are often conflicting due to a lack of coordination.

1 Introduction: liberalization in the European context

1.1 IEM Directives and market development

The liberalization of the electricity market in the European Union (EU) is a top down process driven by the Directives of the European Parliament and of the Council (Directive 96/92/EC, 1996; Directive 2003/54/EC, 2003). The second Directive 2003/54/EC can be characterized by shorter-term deadlines and less freedom for market opening, third party access and the unbundling of the system operator, which should result in more convergence between Member States. Note however that the Directives do not provide any explicit provisions on the regulation of cross-border electricity trade. This has resulted in different kinds of bilateral cross-border access arrangements. Therefore, Regulation 1228/2003 issued together with the Directive 2003/54/EC in 2003, establishes a compensation mechanism for cross-border flows of electricity, the setting of harmonized principles on cross-border transmission charges and the allocation of available capacities on interconnections between national transmission systems (Art 1 Regulation 1228/2003).

- The main elements of the second directive, in comparison with the first one, are the following:
- Unbundling of the grids (both transmission and distribution) at least legal unbundling has to be foreseen (ownership unbundling is not required, management unbundling is taken to be insufficient)
- Security of supply has to be assessed (different approaches for capacity improvements are provided: obligation to TSO, tendering, capacity payments or purely market based)
- A regulator has to be put into operation
- All consumers must be able to choose their supplier by Jan 1, 2007.
- A number of public service obligations may be introduced: general obligation to supply all consumers, pre-payment meter, social welfare system, social tariffs, universal service

In the whole of the directive, no provision is given for the energy source to be used.

Besides the European Commission, the following organizations are driving the liberalization process:

- the Directorate-Generates of the European Commission (EC) responsible for developing and implementing European policies in their overlapping fields: DG Energy and Transport (DGTREN), DG Competition and DG Environment;
- the Florence forum, which is now in Rome, where parties involved discuss twice a year the creation of the IEM;
- the European Regulators Group for Electricity and Gas (ERGEG);
- and voluntary European associations like Eurelectric (industry: generators and suppliers), ETSO (transmission system operators), IFIEC (consumers), EFET (traders), Europex (power exchanges), the Council of European Energy Regulators (CEER) and UCTE, Nordel, GBTSO, ATSOI and IPS/UPS (transmission system operators part of the respective synchronous areas).

Even though, the Directives refrain from designing a concrete market architecture, the IEM consists of 25 Member State submarkets with similar architectures. Wholesale markets are mainly bilateral, but in most Member States, there is the possibility for anonymous auction trade organized by power exchanges one day before delivery. This market organization differs from most other liberalized markets world wide, where authorities, inspired by the pools as long time used by vertically integrated utilities to reach an optimal technical dispatch, have often chosen to design a mandatory power pool for wholesale trade.

At this moment market structure is more European than market architecture. The industry has consolidated into a few big European players, while the market consists of Member State submarkets weakly linked by limited interconnector capacity markets. A vehicle for harmonization is improving the links between submarkets gradually. There are some regional developments in this direction and it is important that enough interconnector capacity is available for such initiatives. The so-called "Mini –Fora" are intended to be an intermediate solution, being regional markets as a step towards a full European market.

1.2 Decoupled investment decisions

In a liberalized market, electricity is a number of services offered by different players. The Transmission System Operator (TSO) provides the critical coordination service: he balances power input and supply, keeps the voltage at the correct frequency and value, and invests in the grid to secure the supply, to facilitate the market and to connect renewables.

Before liberalization, investment decisions were taken centrally and coordinated with linking generation and transmission. Based on demand forecasts, governments chose to build plants of a certain fuel type domestically or to contract long term imports. Grid investments were done in function of generation decisions, import needs and load locations. In a liberalized market, grid and generation investments are legally decoupled due to the unbundling. Grid investments are done facing uncertain generation decisions (both for installing new capacity and for closing or mothballing) and accounting for sometimes unstable regulation. An important question is how independent the future grid should be of the current load flow context. In other words, how much should be invested in congestion alleviation relative to interconnectivity? Investing in flow control is very interesting in a liberalized context because of the implied grid flexibility. The current regulatory framework does not ensure that congestion revenues are used for transmission investments that are in the long run beneficial to the market, because regulators are biased towards a short-term tariff reduction. More investment coordination is clearly needed in Europe, either pushed by European regulation or driven by coordinated regulatory actions, because projects presented to national regulators hardly mention the common European interest involved, even if they have received funding on that basis

1.3 Current system

The European grid is made up of 5 synchronous areas, all containing Member States of the European Union but also non Member States are part of these areas. In other words, there is not one 'Europe', but a lot of voluntary or/and technical cooperation of different groups of States, in combination with different national implementations of the Directives. This situation evidently complicates cross-border investments in Europe severely.

The European national grids are weakly interconnected. In the past, they have been interconnected for technical stability reasons and to pool generation reserve capacity and not to become the backbone of the IEM. The balancing region of the Belgian TSO Elia is Belgium and a part of Luxemburg. Note that the other part of Luxemburg is connected to the German grid and that the two parts are normally not interconnected. For the time being, France has excess cheap nuclear generation capacity. Therefore, Belgium regularly imports from France for economical reasons but also because local generation capacity is not adequate. Also Germany and the Netherlands import large amounts of energy from France causing transit flow through the Belgian grid. Such transit flows are often not contracted but do pass Belgium. The system adequacy forecast 2002-2010 of the Belgian regulator CREG advised the reinforcement of the interconnection with France. In response, the development plan 2003-2010 of the Belgian TSO ELIA sums up the necessary grid investments by 2006 and 2009. ELIA also reports estimates of the effect of the grid investments on the Belgian import potential, taking into account the negative effect of the Dutch import level. By 2006 import potential is forecasted to be up to 3700 MW and up to 4700 MW by 2009, assuming a Dutch import level from France of 2500 MW.

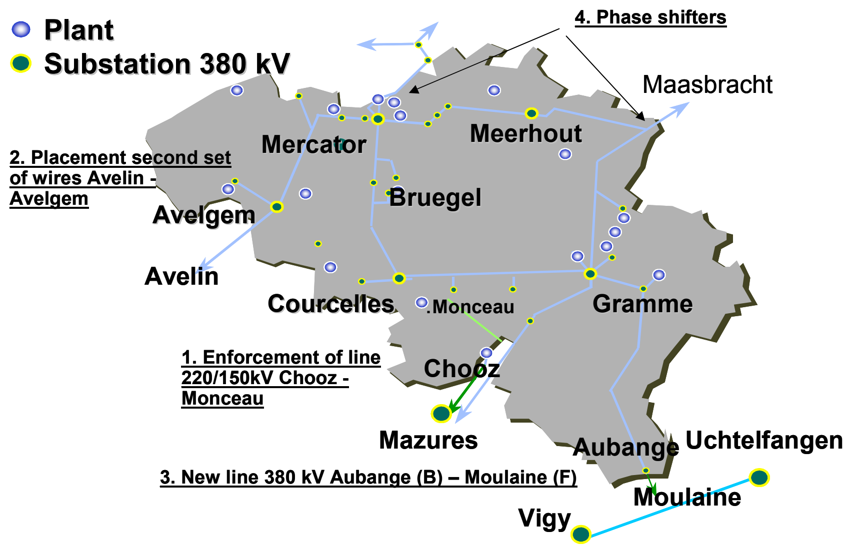


Figure 1: Grid development plan Elia

2 The international network context

2.1 Belgian situation

In Belgium, the high voltage grid is operated by Elia, the transmission system operator. The grid is coupled with France via 4 lines, with total thermal transmission capacity of 2914 MVA (reinforcements planned for 2006 and 2009). In the North it is coupled with The Netherlands by means of 5 high voltage lines (thermal capacity of 4542 MVA). In Luxemburg, there is a possible coupling with Germany on the 220 kV level. However, the circuit breaker is normally open. No direct link with Germany or the United Kingdom exists.

2.2 Zonal network model

The continental interconnected European UCTE network is the most relevant element for Belgium, even though electric energy is increasingly exchanged with other, non-synchronously connected areas (Norway, UK) influencing the Belgian situation. The UCTE network, or any interconnected meshed network for that matter, consists of thousands of nodes and lines. Each of the UCTE member states controls its own part of the network, called a control area. The control areas are usually, though not necessarily, consistent with countries political borders. Due to the freedom given to the member states by the European Commission there is no common market design in Europe and often different rules are applied by the member states. However, one thing is common in Europe – a flat transmission tariff system. This means that there is no differentiation between the location of injected power, nor any limits of power that can be injected or withdrawn in a given point of the network. The internal grid of a control area is supposed to be strong enough to cope with any scenario of internal dispatch. Rare cases of technical infeasibilities are solved by the Transmission System Operator (TSO) and its costs are socialized among all users of the domestic transmission system. This model has been adopted in order to avoid discrimination between network users, and as long as the internal grid can indeed handle all possible internal dispatch scenarios, or costs of re-scheduling of production units to achieve a feasible dispatch are within an acceptable range, the market functions well. However, the organization of a local market has repercussions for the global one. Each commercial cross border transaction between two areas can be physically realized in a virtually infinite number of ways. Obviously the resulting cross-border flows on individual lines can vary significantly depending on the physical location of the transaction's sources and sinks. This means that even changes in the internal dispatch of a zone do influence the cross-border flows. Moreover, the larger the control zone, the more cross-border flow variation is possible. Especially the geographical shifts of generation can cause very significant changes in cross-border flows.

2.3 Loop flows

One of the most significant consequences of the zonal approach to network management is the phenomenon of loop flows. These are the power flows that were unannounced to the system operator. There are two major causes of loop flows, both linked with cross-border congestion management. One is the applied network model where hundreds of nodes of a given zone are substituted with one equivalent node. What follows is a loss of information on the actual nodal dispatch within a zone. Therefore even though the control zones are balanced and there are no imports or exports scheduled, there will always be cross-border flows as the electrons follow the laws of electricity. Moreover, in the European interconnected grid the interaction between the zonal imbalances and cross-border flows is not modeled. Though the correct modeling of such interaction in the presence of a zonal network model is extremely difficult if not impossible, a much worse solution is relying on a contract path approach, where the transaction path can be contractually chosen. This implies loop flows resulting from the mismatch between the contracted path and the actual current path, and the loop flows resulting from the lost information when going from zonal to nodal realities.

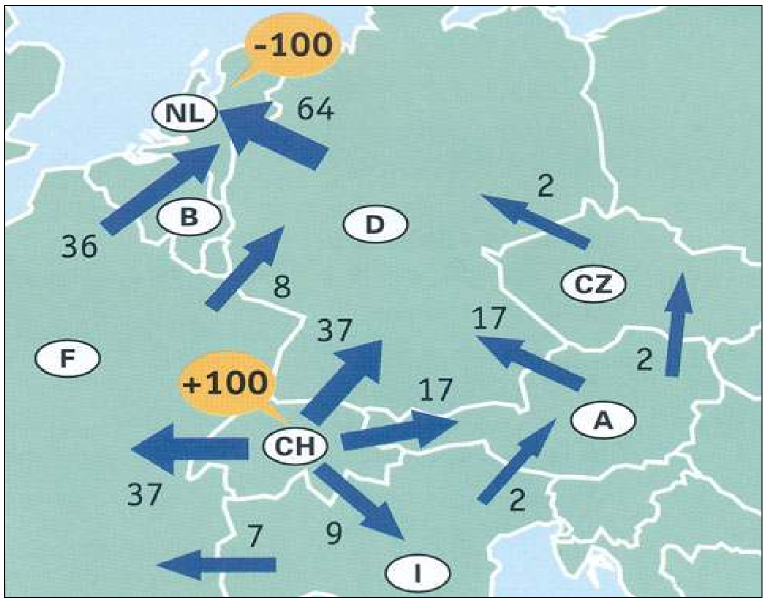


Figure 2: Interdependency of power flows in the European Network

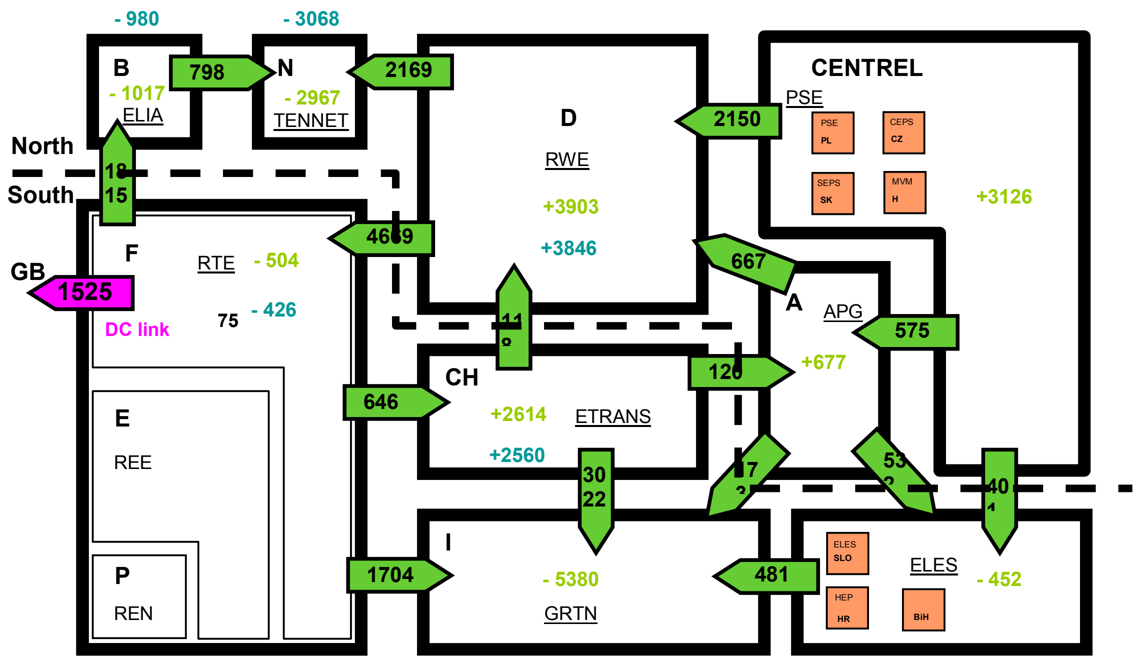
Zonal network model implies losing information contained in the internal zonal dispatch. Therefore the predictability of the zonal dispatch becomes a key issue. However, some sources of electricity are unpredictable, such as wind generation. Wind fluctuations can often cause a geographical shift of generation from one part of the zone to the other, influencing the cross-border flows, and consequently power flows in other zones. The changing internal dispatch of the control zones, increased cross-border trade and the applied zonal network model can form a dangerous mix, making international regulation and coordinated control inevitable.

2.4 Wind power

Wind power constitutes a significant problem for the Belgian grid. The massive installation of wind energy systems in The Netherlands and Germany (more than 16 GW generating capacity installed already, foreseen to be doubled although the political situation may change by the end of this year with parliament elections in Germany) is responsible for the difficulties in the grid operation. Two extreme situations may be experienced in practice:

- high wind speeds in Germany leading to high power outputs from wind farms,
- very low wind speeds leading no power output from wind farms as the wind turbines stop due to the under-speed protection. The same holds for very high wind speeds, due to the over-speed protection.

In case of high wind speeds and consequently high power production in North Germany, the power has to find its way to the Southern Germany where the load centers are located. As the German grid itself is unable to carry these power flows, a significant part of it passes via The Netherlands, Belgium and France, back to Germany. These flows add to the usual Germany-The Netherlands exports, and stress the already often fully loaded Eastern Dutch border. The often congested south Belgian border is in turn relieved as the flows caused by German winds generally flow in the opposite direction than the scheduled France-Belgium exports. On the other hand, in case of no or very little wind in Germany the wind turbines come to a stop and there is no relieving effect on the southern border of Belgium. However, the most severe situation occurs for very high wind speeds. The turbines come then to a stand as a result of over-speed protection. Consequently, the power output of such turbine drops from full power to zero in a matter of seconds. As the region where the majority of wind farms are installed covers a rather limited area, the increase or drop of generated power happens virtually instantaneously.



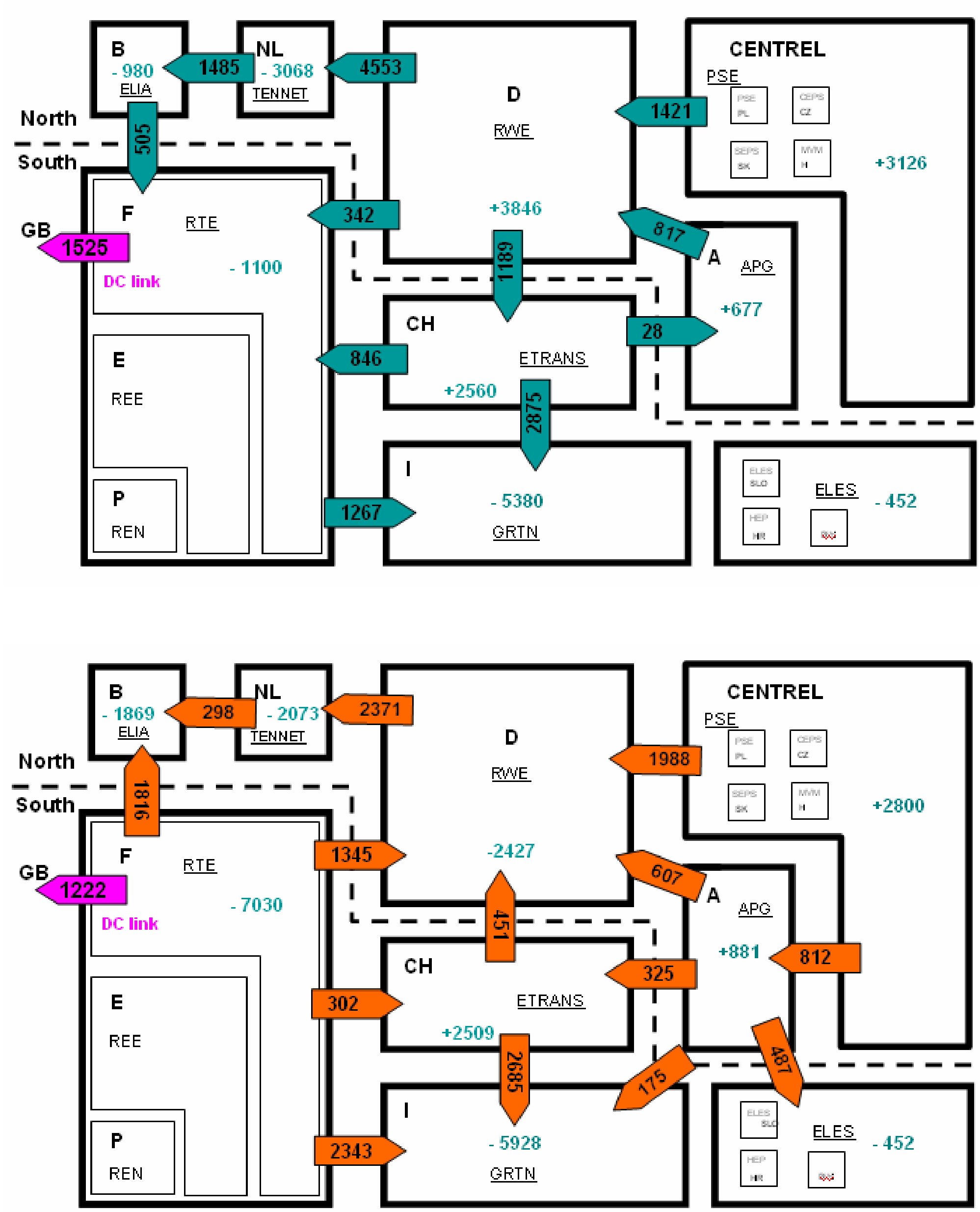


Figure 3: Changing patterns of European cross-border power flows [MW] as a result of wind power (top figure: exchanges as scheduled, middle: exchanges as measured, bottom difference between actual flow (metered) and scheduled ones)

The possible installation of an off-shore wind farm on the Thornton bank (up to 2000 MW) will cause a need for backup reserve power in case of wind fluctuations. One of the most significant sources of the reserve power is the Franco-Belgian border, meaning that a part of the increased capacity of the reinforced Avelin-Avelgem cross-border line would need to be withheld, limiting to a major extend import and trade possibilities needed for market opening.

3 Future technical development in the transmission grid

The ongoing liberalization process, and the herewith associated rise in international energy flows, are responsible for a rising stress on the transmission grid. This occurs in a consumer environment that expects the reliability of supply to increase, or at least remain at its current level. This mismatch between trends and requirements can in principle be solved by building new transmission lines. However, this is unacceptable in most cases due to social and political circumstances. The use of power flow controlling devices can alleviate the stress on the network at a significantly lower cost and a very limited social cost.

3.1 Power Flow Control

Traditional power flow control is realized by means of phase shifting transformers, where the energy flow through a line can be controlled by altering the phase angle between two nodes[1]. The phase shifting transformer technology is similar to the more frequently used under-load tap changing transformer, and therefore well known and reliable. Phase shifters can be controlled within a time period of minutes. Belgium is currently installing four of these devices in order to alter the power flow of its main congested lines and consequently increase the cross-border transfer capacity between France and Belgium, while improving reliability. These devices will be operational by the end of 2006.

The development of switchable thyristors (GTO, IGCT) for high power applications was the basis for the creation of FACTS (flexible AC transmission systems) devices, making the power electronic flow control possible. The FACTS devices, such as the TCSC (thyristor controlled series compensator) and the SVC (static VAR compensator), are based on power electronics and enable rapid power system control due to the fast switching time of the power electronic switches (within one period of the supply). Therefore, these devices can also be used as power system stabilizers, which can improve the reliability of energy supply.

Another group of power electronic technologies is the voltage (or current) source converter based power flow controllers which use IGBT (Insulated Gate Bipolar Transistor) switching technology. This technology allows for the full control of the voltage at its terminals. Examples of this technology are already available and include STATCOM, SSSC (solid state series compensator) and UPFC (unified power flow controller). Voltage (or current) source converters have the fastest response time and are ideal for power system control, both static and dynamic. However, this technology is currently quite expensive and experiences higher losses than more traditional FACTS. New semiconductor technologies such as silicon carbide, Gallium Nitride, or even artificial diamond, could provide a significant improvement.

Control actions of power flow controllers are not local but influence the entire network, including neighboring networks. This could lead to conflicting control actions, lowering overall network security. This implies the need for international coordination of power flow control. A project to study this in the Benelux is being carried out (TUDelft, KULeuven). Using advanced metering of currents and power flow (phase angles) at different network modes, combined with geographical information, an advanced flow control system can be established, trying to optimize the overall power flow in the meshed grid with respect to for instance increased reliability or improved energy efficiency.

3.2 Developments of the transmission technologies

New materials will allow the construction of overhead lines with composite cores, which are lighter than steel core conductors and could increase the line capacity up to three times. For cable technology, much is to be expected from HTS (High Temperature Superconduction) cables, which would reduce losses up to a factor of 5. Superconductors can also contribute in switching and grid protection, leading to an improved reliability.

Another technology having a significant potential is High Voltage Direct Current (HVDC) transmission. HVDC applications are already used for 50 years, especially for interconnection of non-synchronous networks and long distance transmission of electric energy. Lately, this technology has gained renewed interest by the industry due to the lower power electronic cost, improving microprocessor control possibilities and the rising need for long distance power transfer (e.g. the Three Gorge dam – Beijing project). The emergence of voltage (or current)

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[1] Active power transferred between two nodes can be expressed as $P = \frac{U_1 \cdot U_2}{X} \sin(\delta_1 - \delta_2)$

source converter based applications has also provided new applications to HVDC because of the possibility to deliver ancillary services, provide black-start capability and the possibility to be operated as a power oscillation damper. The latter technology is generally referred to as HVDC light, with IGBT based power electronics converters combined with advanced underground cables. It allows to have controlled power flows between nodes. Specific examples are feed-in of cities, linking grids in an asynchronous way and connecting off-shore generation.

3.3 Energy storage

Electric energy is regarded as non-storable with the consequence that there has to be an instantaneous balance between consumed and generated electric power. This puts large strains on the power production from less controllable energy sources such as renewables. However, recent developments have provided some possible solutions. Supercapacitors and SMES (Superconducting magnetic energy storage) are two examples of these new developments that can provide a solution to the problem of electrical energy storage. Both are in a far state of development and prototypes are already installed. The link between hydrogen and electricity may be important too.

3.4 Advanced metering in Distribution Networks

One of the important changes in the philosophy of the future network management will be the ever more occurring bi-directionality of the electrical energy flow. If an increasing number of Distributed Energy Resources (DER) are connected to the electrical grid, a significant portion of the electrical energy might be produced near to the consumption, resulting in an excess of power being injected in the grid. However, some of these energy sources have limited availability, often depending on different meteorological circumstances or external factors such as heat-demand-driven CHP-units. This is responsible for the reversing of the power flows. Several types of DER are renewable energy sources, for which special tariffs or benefits are applicable in order to encourage sustainability of energy supply.

In order to globally optimize generation scheduling within the distribution system, a large amount of information needs to be exchanged among different entities. Both energy and information flows need to be dependable: reliability, availability and integrity requirements are to be fulfilled. Consequently, fault prevention and fault tolerance are key issues in such an environment.

In order to optimize consumption, next to optimizing generation, active Demand Side Management (DSM) is introduced. DSM implies that loads respond to external signals such as prices. This requires real-time pricing and real-time measurements. The price of the should electricity vary continuously, putting more requirements on metering. Furthermore, the amount of data to be exchanged increases.

Distribution networks may become to a certain extend similar to transmission networks. Parameters derived from safety or power quality limitations, such as voltage fluctuations caused by local mismatches of generation and consumption, can be seen as equivalent of congestion for transmission networks as they constrain energy movements on distribution level and affect the market operation. Furthermore due to the large-scale use of power electronics, by both consumers and suppliers, the overall level of disturbances on the power system will increase. As at the same time an increasing number of sensitive devices is connected by the grid, especially information and communication technology equipment, power quality standards need to be redefined. Traditional energy meters have proven to be subject to errors as the distortion level rises. Moreover, the appreciation of the quality of electrical power is not uniform. An extended measuring capability for adapted power quality parameters at the customer site is therefore necessary.

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