DEMYSTIFYING SMART GRIDS
DIFFERENT CONCEPTS AND THE CONNECTION WITH SMART METERING

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ABSTRACT

The topic of Smart Grids is widely debated. It seems, however, that in the international arena a broad range of quite different concepts are referred to with this notion. Further, there is much confusion about the relation between Smart Grids and smart metering. This paper aims at structuring the discussion on Smart Grids by distinguishing three fundamentally different Smart Grid concepts and introducing corresponding terminology. These concepts serve different goals, affect different actors in different ways and require different technological solutions. Finally, smart metering is embedded into the developed framework.

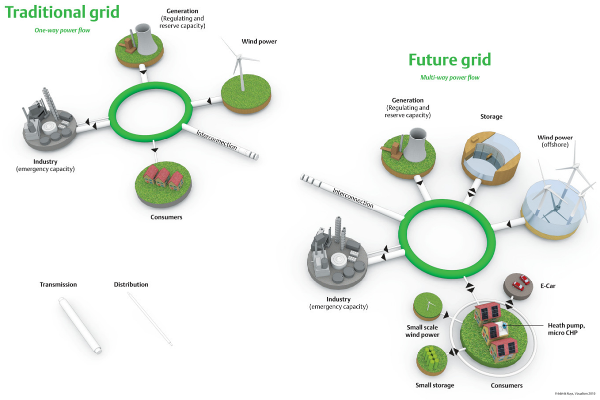

Fig. 1. Traditional and future grid (TenneT)

INTRODUCTION

The development towards more distributed generation connected to the electricity distribution grids, as well as changes on the demand side, such as the rising number of heat pumps and the advent of electric transportation lead to changes in power systems. Consumers and distributed generators become part of the power distribution system. Besides the application of new loads like heat pumps and electric vehicles, there are more developments providing opportunities for managing the demand. The developments in Smart Grids and smart metering can support further integration of demand-side management in the electricity supply system and hence increase consumer awareness and improve the electricity market through consumer participation. Figure 1 depicts the traditional and the future grid.

Another advantage of (partly) controlling flexible loads, distributed generators and applying demand-side management is that the operation of the grids can be optimized and maximum utilization of all resources connected within them can be achieved [1]. Because the current electricity distribution systems have a relatively low ratio of used capacity to available capacity [2], a great potential for transferring extra energy with the current grids exists.

These developments lead from electrical distribution grids with very little embedded automation to grids that will intelligently control loads and integrate distributed generation and energy storage devices in the operation of the grids by application of new technologies. The grids will adapt from a passive to a more active system. It becomes increasingly clear that to cope with future developments active management of the distribution grids is the only feasible solution to continue reliably delivering electricity and to facilitate the integration of distributed generation, which drives the development towards Smart Grids [3].

DEFINING SMART GRIDS

Opinions differ as to what a Smart Grid actually is. Many definitions circulate and a generally accepted definition lacks. As an example, the definitions of the European Technology Platform for the Electricity Networks of the Future (1, [4]), the Smart Grid Dictionary (2, [5]), the US Department of Energy (3, [6]) and the IEEE (4, [6]) are given below.

1. *A smart grid is an electricity network that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.*
2. *The Smart Grid is a bi-directional electric and communication network that improves the reliability, security, and efficiency of the electric system for small*

to large-scale generation, transmission, distribution, and storage. It includes software and hardware applications for dynamic, integrated, and interoperable optimization of electric system operations, maintenance, and planning; distributed generation interconnection and integration; and feedback and controls at the consumer level.

3. *A smart grid is the electricity delivery system (from point of generation to point of consumption) integrated with communications and information technology for enhanced grid operations, customer services, and environmental benefits.*

4. *The Smart Grid has come to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy.*

In all definitions in some way or the other the Smart Grid concept boils down to adding information and communication technology (ICT) to today's electrical grids on a large scale, in which so far not many of such technologies are present. Of course, these technologies are not an end in themselves but a means to *some* end. *Which* end to a large extend determines the functionality of the Smart Grid.

GOALS OF SMART GRIDS

Goals of integrating information and communication technologies in today's electrical power systems that can be derived from the definitions mentioned above are:

- (technical and financial) *efficiency*
- *sustainability* by stimulating energy savings and by supporting an efficient grid connection and system integration of decentralized, renewable generation
- improved *reliability* of supply
- increased *customer services*, in particular more advanced *information* increasing consumer awareness and enabling more advanced tariff structures or pricing signals allowing consumers to act more *actively* with respect to their electricity consumption (and production); in economic terms, this enables more differentiation between suppliers, thus increasing consumer choice and improving functioning of liberalized electricity markets

The US Department of Energy (DoE) distinguishes six goals pursued by creating smarter electricity grids, namely:

- Enabling Informed Participation by Customers
- Accommodating All Generation and Storage Options
- Enabling New Products, Services, and Markets
- Providing the Power Quality for the Range of Needs
- Optimizing Asset Utilization and Operating Efficiently
- Operating Resiliently to Disturbances, Attacks, and Natural Disasters

The six goals distinguished by DoE can be mapped onto the four goals derived from the cited definitions. Together, they give a clear view on the various drivers for Smart Grids. In the end these boil down to balancing and fostering the values of sustainability, reliability and affordability.

SMART GRID CONCEPTS

The focus on specific goals results in different ways of the Smart Grid to develop. These different directions can be indicated by three universal types of Smart Grid concepts, which will be described in this section.

Market oriented Smart Grid concept

The goal of the market oriented Smart Grid concept is to enable retail consumers (possibly also generating electricity, in that case called 'prosumers') to participate in the electricity market. Instead of paying a fully flat or only slightly differentiated tariff (e.g. daytime and night/weekend) for their electricity, consumers receive more advanced pricing schemes, such as day ahead tariffs per 15 minute interval based on power exchange prices or real time prices derived from unbalance markets or reflecting the availability of energy from renewable sources.

In this way, prices much better reflect the cost structure of electricity production and the availability of energy than in the traditional situation, where price fluctuations and risks associated with the output of intermittent generation are managed by the trade floors of electricity companies in order to meet the demand of the company's consumers at least cost through optimizing the portfolio of its own generation in combination with trading on the market for bulk power.

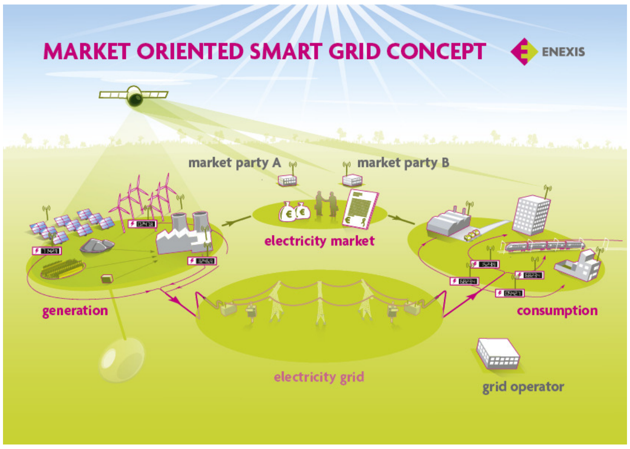

Fig. 2. Market oriented Smart Grid concept (Enexis)

Grid oriented Smart Grid concept

More or less the opposite of the market oriented Smart Grid concept is the grid oriented Smart Grid concept. The grid oriented Smart Grid concept only concerns the grid operator. Aims of this concept are reducing investments in grid reinforcement, supporting and accelerating outage restoration and determining condition, remaining lifetime and failure risk of grid components as well as semi-automated restoration of the network after outages. The concept consists of equipping electricity grids with measuring and monitoring equipment for monitoring the condition of components and the voltages and currents in the grid. Examples of monitoring and measuring equipment are on line temperature measurements on transformers and cables, on line measurements of partial discharges in cables and joints and monitoring of switches.

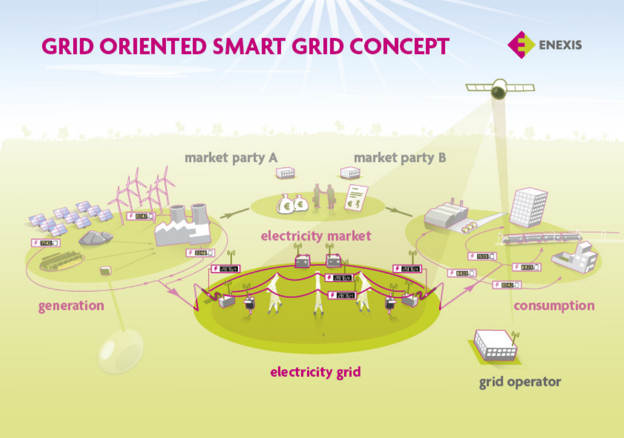

Fig. 3. Grid oriented Smart Grid concept (Enexis)

System oriented Smart Grid concept

The third Smart Grid concept is the system oriented Smart Grid concept. This aims at optimizing the system as a whole, both from the perspective of keeping the energy balance as well as from the perspective of grid operation. The combination of the actual, global energy balance on the one hand and the locally produced electricity and grid capacity on the other, results in a signal that incorporates both global and local quantities. This enables actions that take into account both the global and the local situation. These actions can be either taken by energy companies and/or grid operators directly, or the situation can be translated into tariffs, enabling the consumer to act accordingly when desired. The system oriented Smart Grid concept extends the market oriented Smart Grid concept to also include the grid operator, and thus integrates the market oriented and the grid oriented Smart Grid concepts.

The described and mentioned Smart Grid concepts will facilitate and help in discussions and dialogues amongst involved stakeholders and practitioners. It helps to make clear the scope and functionalities of their individual Smart Grids projects. By making the different functionalities more explicit and defining three fundamental concepts the risk of function creep is reduced.

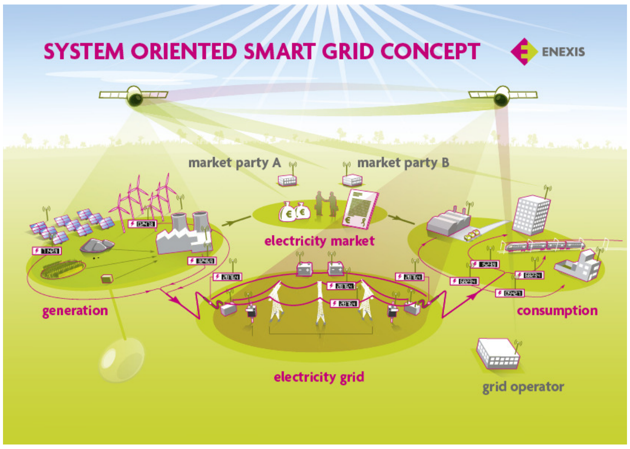

Fig. 4. System oriented Smart Grid concept (Enexis)

SMART GRIDS AND SMART METERING

Another example of confusion and function creep relates to the different perceptions on smart meters, smart metering and Smart Grids. The relation between Smart Grids and smart metering is not well established. Sometimes, smart metering is positioned equal to Smart Grids, thus ignoring the various additional functionalities of Smart Grids listed in the earlier description of the Smart Grid concepts. On the other hand, in other analyses of Smart Grids, smart metering is not even taken into account.

Using the Smart Grid concepts described above, it can be stated that in its most simple form smart metering is a rudimentary implementation of the market oriented Smart Grid concept. Because consumption is measured with a high resolution (normally somewhere between 5 minutes and 1 hour), smart meters enable advanced tariff schemes. Theoretically, the number of tariff zones can be equal to the measuring frequency, which is a major step compared with the traditional flat or only slightly differentiated (day, night/weekend) tariff.

With smart meters, however, tariffs are still static. Dynamic tariffs, taking into account such factors as the local availability of renewable energy, day-ahead or real time electricity market prices and actual network loading are generally not supported by smart meters. Reason for this is that smart meters in most cases do not enable bi-directional data transfer, but only mono-directional data transfer with the smart meter transmitting.

Some smart meter devices do not only transmit measurement data to the grid operator and/or energy company, but are also capable of communicating data locally using wireless communication. This enables informing the consumer about his energy consumption in real time and/or with a high resolution. It also supports the consumer in actively shifting his demand to optimize his electricity consumption (and if available his generation as well) according to the tariff scheme. The consumer can do this himself, buy smart services or use electronic devices to this end. The latter two cases, are examples of smart metering which takes the road towards a full market oriented Smart Grid concept one step further.

Further, some types of smart meters are capable of detecting outages and signalling the grid operator if one occurs. When the grid operator combines the signals received from such devices with his network topology, it becomes possible to determine which network component has caused the outage. All consumers "behind" the failed component (or actually behind the switch which has operated to disconnect the failed component) after all no longer have electricity, whereas other consumers in the direct vicinity are not affected by the component failure.

Smart meter devices with this functionality enable a rudimentary form of a grid oriented Smart Grid concept. This is another example of smart metering, but within the grid oriented Smart Grids concept. Particularly when combined with other technologies in this category, they can accelerate outage restoration and even open (for the time be it mainly theoretical) perspectives on automated supply restoration.

Concluding, it can be stated that the relation between smart meters, smart metering and Smart Grids is rather complex and is for a large extent, as with the different concepts of Smart Grids, determined by the functionality of the applied smart metering devices, which is not rigidly and uniformly defined. Generally, it can be stated that *smart metering without a smart grid is possible, but a smart grid without smart metering is not.*

SMART GRIDS AND ANCILLARY SERVICES

Services supplied to the market by the electricity supply system are referred as "System Services". Services supplied by the market to the electricity supply system, excluding electrical energy, are referred as "Ancillary Services" [7], [8]. Ancillary services are services necessary for the operation of an electric power system provided by the power system users. Ancillary services may include the participation in frequency regulation, reactive power regulation, active power reservation, etc. Smart Grids do not affect the necessity of ancillary services; in a traditional, as well as a smart grid, frequency and voltage must be kept within strict limits for the power system and the connected devices to function properly, reliable measurement data must be acquired and exchanged and fault restoration capabilities must be available to restore the system in case a wide spread outage might occur.

However, Smart Grids can and highly probably will affect the *provision* of ancillary services, particularly of ancillary services regarding the balance between supply and demand. In traditional grids, maintaining the required balance between electricity production and consumption, or generation and load, is the responsibility of the Transmission System Operator (TSO). To this end, the TSO somehow acquires regulating power. This can be done through a real-time market for balancing power or by capacity contracts, giving the TSO access to generation capacity to be controlled in order to maintain the balance between generation and load within the designated area of the TSO. In most cases, both options are used in combination.

The financial and administrative requirements for parties to participate in unbalance markets and to be eligible for capacity contracts generally are such, that only large power plants can qualify. In liberalized markets, commercial energy suppliers also mostly use their large power plants to manage their portfolio.

Smart Grids, however, enable retail consumers, or "prosumers" to take part into these schemes, thus fundamentally changing balancing approaches. They offer much more advanced metering than traditional meters, which are being read only few times a year, and enable appropriate control mechanisms of domestic loads and of decentralized generators. Therefore, traditional, rather basic metering ancillary services will be affected by the introduction of smart meters and Smart Grids. The latter enable new services, such as storing data locally or centrally for further analysis, feedback to the consumer and higher resolution meter readings.

In the longer term, large scale distributed electricity storage may become available (stationary or in electric vehicles). Together with the expected increase of distributed generation, and flexible loads (such as electric vehicles and heating) this enables *local instead of global balancing*. For local balancing locational dependent network tariffs would make sense, however, this implies discriminating, which will probably be the subject of intensive political debate.

With respect to more grid oriented ancillary services, such as voltage control, congestion management and fault restoration capabilities, it can be observed that as a consequence of local balancing, Smart Grids will under certain circumstances facilitate islanded operation of distribution grids. As for now, no fundamental impacts are expected on this category of ancillary services.

CONCLUSIONS

From an overview of definitions of Smart Grids, it was concluded that the core of Smart Grids is to combine electricity distribution grids with ICT. It was, however, also concluded that completely different goals are pursued with this ICT. This finding led to the distinction of three distinct Smart Grid concepts, namely *market* oriented, *grid* oriented and *system* oriented.

The relation between smart meters, smart metering and Smart Grids was analysed. It was concluded that the functionality of the devices used to implement smart metering determines to which extent specific smart meter devices deserve the qualification of Smart Grids and also which Smart Grid concept they enable.

Finally, the impact of Smart Grids on ancillary services was analysed. It was concluded that Smart Grids particularly affect the ancillary services related to balancing generation and load. More grid oriented ancillary services, such as voltage control and fault restoration, are affected to a lesser extent.

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