10

Smart grids put into practice

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The transition towards a more sustainable energ y supply system causes changes in the supply and demand of energ y. It requires a more flexible and efficient operation of the electricity distribution grids. It calls for a smart grid with intelligent control embedded in the grids to incorporate electricity storage and controllable loads. This will ensure cost-effective development of an efficient and reliable electricity system that allows the integration of distributed generation. To realize this smart grid, a holistic approach is needed. The issues which need to be addressed to make smart grids a successful reality are addressed in this chapter. It is illustrated that these aspects are much broader than developing and implementing technologies: a holistic approach involving all parties affected by the required paradigm shift is needed.

Now and in the future, a reliable electricity supply is of utmost importance for satisfying the needs of individuals and enabling the functioning of societies and economies. However, various developments lead to an increasing complexity of the design and operation of electricity grids. One consequence of the liberalization of the energy market is that all consumers and producers must be given unrestricted access to the grid. This increases uncertainty with respect to the future demand for capacity with respect to volume as well as to location compared to the past where vertically integrated utilities controlled both the grids and the generators. This uncertainty is amplified by the development towards more distributed generation connected to the electricity distribution grids and changes on the demand side, like the rising number of heat pumps and the advent of electric transportation. This challenge is further increased by the ageing of the existing infrastructure and the ever increasing demand for electricity. Despite all these changes and uncertainties, grid operators are legally and morally obliged to provide their consumers with a reliable power supply.

The consequences of these developments can be mitigated by enabling a more flexible operation and efficient use of the (existing) electricity distribution system,

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without compromising the reliability of supply. To realize this, the medium and low voltage grids need to be adapted. A high penetration of distributed generation and the integration of electricity storage and controllable loads in the operation of the grids can be supported by applying more active network management. Making the distribution grids more intelligent and flexible than they are nowadays is often referred to as smarting the grid. It is generally accepted that making the grids smarter is necessary in the light of future developments. Making this a reality, however, asks for a paradigm shift and is still quite a challenging task. It not only asks for technological innovation in various respects; but the public interest must be visible for all parties involved. Governments must make choices and set out clear and holistic policies. To make the necessary changes possible market mechanisms and regulation must be adjusted, and also social acceptance is an important condition. Therefore, consumers must understand the need for changes affecting them. The challenges we face are global issues, and, therefore, knowledge exchange can support the search for solutions to address these challenges. Policies and regulatory and market arrangements must be discussed on as well a national as international level. The fact that there exists a global market for network components, including those enabling smart grids, requires an international approach in order to realize economies of scale.

The different issues which need to be addressed to make smart grids a successful reality are addressed in this chapter. While the future grids will be based on the existing electricity grids, it is first set out what led to the grids of today. The developments which influence the electricity grids are then discussed. Subsequently, it is explained how grids should develop and it is made explicit what smart grids in this perspective mean. The chapter concludes with a description of the aspects which should be regarded to make the next steps forward. These aspects are much broader than developing and implementing technologies: a holistic approach involving all parties affected by the required paradigm shift is needed.

The power system of today

As in most Northwest-European countries, the electrical power system was introduced in the Netherlands at the start of the 20th century. After the introduction, the scale increased and the system developed to the extensive electricity supply system of today. Due to historical developments, the electricity power system consists of a transmission system, which transports large amounts of power from large-scale generation over large distances, and a distribution system, which delivers the electricity from the transmission substations to the consumer (see Figure 10.1). The transmission systems faced many challenges, because power plants became larger

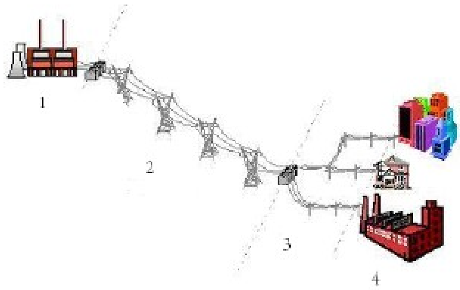

Figure 10.1: A vertically integrated power system. Legend: 1 generation; 2 transmission; 3 distribution; and 4 consumption.

and larger and operation of interconnected grids became ever more complex. Meanwhile, the distribution systems only delivered power from the transmission systems to the consumers, so that the requirements on the grids were quite obvious and uncertainty was limited.

In the past, utilities have designed their grids to meet demand. The electricity grids were dimensioned on peak demand, and the equipment capacity was designed for peak load conditions. Besides that, the engineers made various assumptions to make the design and operations manageable and not to rely on very detailed modelling and analysis. Protection and control were adjusted to ensure reliable service during the worst case conditions. These efforts have been quite successful and led to a reliable system in the Netherlands (see Figure 10.2). As a result of these design philosophies complemented with the policy to invest for future demand generously, distribution systems were typically designed with overcapacity. This overcapacity is nowadays utilized for a great part, although in some regions, grids are still profiting from this.

These past developments led to the current electric distribution systems, with very little online automation and a relatively low ratio between the used and available capacity. An analysis of the used capacity of the medium voltage distribution grids of Enexis showed that a vast amount of currently unused grid capacity is available (Veldman 2009). As a result, the grids offer a great potential to transfer extra energy without increasing the capacity of the existing grid.

Besides the developments of the energy supply system itself, in many countries the energy sector went through fundamental organizational changes. In the last decades, liberalization of the energy market transformed the sector. In the late 1970s and the early 1980s the energy sector was fragmented in a lot of small companies owned by provincial and municipal authorities. The sector had the image of inef-

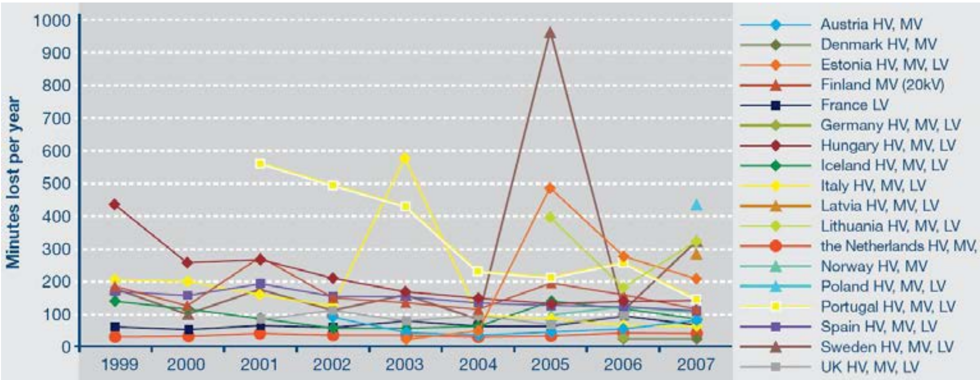

Figure 10.2: Unplanned interruptions including all events (*Source*: Council of European Energy Regulators 2008)

ficiency and tended not to be very customer-orientated. The objective of market liberalization was to grant consumers free choice, and to enable more competition between companies in the European Union (eu), which should lead to lower prices and a better service level of energy related issues. One measure to realize this objective was to separate generation activities from distribution activities. Therefore, the present role of grid operators is to fulfil a pure market facilitating task in order to physically link power producers to consumers. In practice, this means that every generator and consumer should be given unrestricted access to the grid. In order to guarantee free and non-discriminative market entrance and competition and prevent abuse of monopoly power by grid operators, network operation is supervised by national regulators.

A changing environment

The environment in which distribution system operators (dsos) are evolving is changing rapidly. The last decade the energy market is liberalized and the gas and electricity system operators of today have the responsibility to contribute to the transition to a more sustainable energy supply besides delivering reliable and affordable energy. The transition to a more sustainable energy supply not only means that the grids need to be used more efficiently, it also brings a lot of changes in the supply and demand of energy. The penetration of decentralized generation of electricity (wind turbines, combined heat and power generators, photovoltaic solar panels, etc.) is accelerating in the Netherlands. These technologies take a growing share in the energy supply. As a consequence there is no longer a strict separation between consumers and suppliers. Other developments in supply and demand affecting the distribution grids are developments like heat pumps, electric vehicles and self-supplying households. These developments make operating the grids more complex and require changes in the operation.

Some developments provide possibilities for operating the grids differently than historically has been done. Due to changes on the demand side (the increasing number of controllable loads) and developments in technologies for electricity storage, it becomes possible to shift the transport of electricity in time. This makes it possible to balance supply and demand without the need for grid capacity for high peak loads. More energy can be transported and the grids can be used more efficiently and flexible.

These aspects are treated in this section. First, the condition of the existing grids is addressed, while these are the starting point for a future grid. Then, the different developments we are facing that influence supply and demand are described by postulating the developments due to the energy transition to a more sustainable energy supply, and by describing the opportunities provided by the development in storage and load management of controllable loads.

Ageing assets

The largest part of the population of the electricity grids is from the period 1950–1980, with a peak in the 1970s (see Figure 10.3). This is caused by the strong growth in energy consumption in this period and the replacement of low and medium voltage overhead lines for cables in rural areas. The average age of different types of primary assets of Enexis lies between 20–40 years (Essent Netwerk 2007). The inevitable consequence of the ageing of the infrastructure is an increase in failures of components and will result in a rising number of outages. To prevent this and to maintain the high reliability of the grids, it is required to develop a replacement strategy.

On the one hand, the need to replace assets makes changes in the grids possible. On the other hand, improving the reliability in other manners and more efficient use of the grids can delay necessary replacements.

The energy transition

Besides delivering affordable and reliable electricity, the dsos have a responsibility to facilitate the transition to a more sustainable energy supply. As a consequence of the transition, the distributed generation is developing quickly and grids should be operated efficiently. Moreover, the liberalized energy market implies that

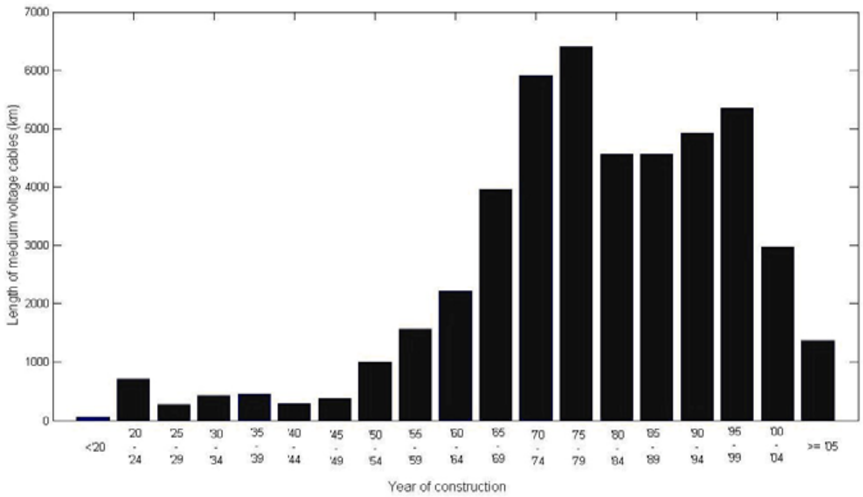

Figure 10.3: The age of medium voltage cables owned by Enexis

the utilities have no to little influence on the location of consumers and suppliers connected to the distribution grids. This makes the balancing between supply and demand more complex. The changes due to the energy transition on the supply side (decentralised generation located near end-users on the distribution level of the grid) as well as on the demand side, are treated in this section.

Distributed generation

The depletion of fossil fuel reserves urges for more efficient use of these resources and for the use of renewable energy sources. Stimulated by governmental incentives greenhouses connect combined heat and power (chp) plants and wind power and photovoltaic solar panels take a growing share in the energy supply. All generation connected to the distribution system is called distributed generation (dg). Each different type of dg has, however, its own technical and commercial characteristics. Similar for all types of dg is that they have independent producers and often, the source is not located close to the demand. This especially accounts for wind power which is usually generated remote from the more populated regions. chp is usually connected closer to the consumer but often primarily sized to the local heat demand and not to the local electricity demand. Another aspect of dg is the intermittent and fluctuating nature of the resource. For instance, solar power is dependent on the abundance of sun and absence of clouds. This makes the amount of solar power difficult to predict. Wind can be predicted better, however, wind can

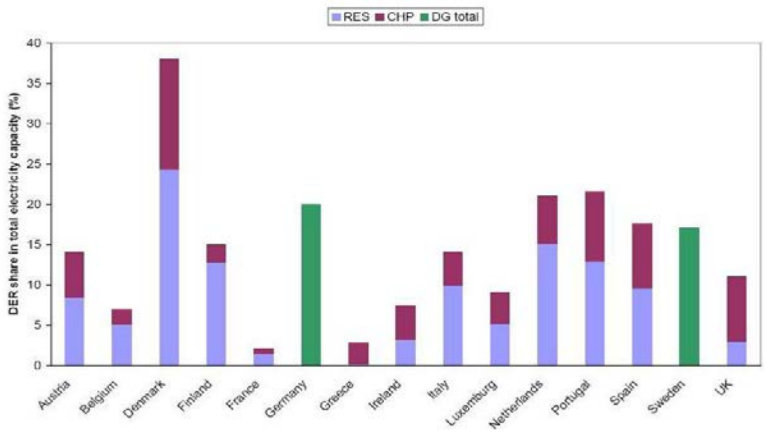

Figure10.4: The amount of distributed energy resources in European countries (*Source*: ECN 2007)

fluctuate a lot. Figure 10.4 depicts the growing amount of dg in the Netherlands and other European countries.

The connection of dg to the distribution grids can lead to operating problems, such as voltage rise and an increase in network fault levels. This in combination with the intermittent and fluctuating characteristics makes the optimal use of these resources rather difficult and hampers their integration in the power system. Without any changes to the grids a high penetration of dg can only be reached by major grid reinforcements (Roland Berger Strategy Consultants 2008; Djapic 2007).

Changes on the demand side

Next to the changes on the supply side, the demand side changes as well due to the energy transition. Consumers start to produce energy themselves, and in that case need less energy from the grids. However, if they use for example solar energy and the resource is absent, they may still need to be fully supplied by the grid at peak moments. This means the load profiles of the consumers will be less predictable and differ more.

Other developments on the demand side include smarter household appliances, like a washing machine that may start running when the electricity prices are low, or the application of efficient technologies to save energy. Although these technologies may reduce the overall use of energy, they may lead to a growing demand for electricity. For example, the demand for electricity for heat pumps and especially electric vehicles would mean a substantial additional load for the electricity grids.

This does not inherently mean that it is difficult for the grid to cope with the load added by loads like electric vehicles or heat pumps. The reason for that is that an important characteristic of these loads is that the exact moment at which the demand is fulfilled is less important than for normal loads. Processes with long thermal time constants can store the thermal energy for a long time and cars are on average standing still for at least 90 percent of the time. Therefore their demand for electricity is not time critical. This provides the supplier the opportunity to manage the demand in time. In the next section, the advantages of controllable loads are described in more detail.

Besides the application of flexible loads like heat pumps and electric vehicles, there are more developments providing opportunities to manage the demand side. The developments in and application of smart meters can support further integration of demand side management in the electricity supply system.

Controllable loads and storage

The grids are designed on peak demand. This is inevitable due to the fact that storage of substantial amounts of electricity has been technically and economically infeasible. However, new technologies become available for energy storage and the storage densities in storage devices have grown and costs have lowered. Moreover, the developments on information and communication technology make an optimal use of these storage techniques possible.

A large advantage of storage can be found in the fact that much can be gained by using the right resources at the right time and place within the grids. To this end, it must be possible to shift demand for electricity in time or, more precisely, to shift the transport of electricity in time. Distributed electricity storage provides opportunities to do this and it can also be realized by management of controllable loads as electric vehicles and heat pumps which were introduced in the previous section. The advantages that storage and load management of controllable loads offer in the changing energy supply, make it worthy to examine the possibility to integrate distributed electricity storage and load management in the distribution system.

An additional advantage of enabling distributed electricity storage or load management would be that it supports the integration of decentralised renewable energy sources into the electrical power system. To facilitate the integration of intermittent, distributed generation energy storage can store the energy produced by dg when the source is abundant and demand is low, and release the power during peak periods. This supports a higher penetration of distributed renewable energy sources without requiring major grid reinforcements.

Several other advantages of (distributed) electricity storage can be distinguished. From the broader perspective of the transmission system operator and/or commercial energy companies, an advantage of energy storage would be that it supports maintaining the power balance within a control area or an energy portfolio. The fulfilment of this global, system wide requirement can as well be achieved by large-scale storage technologies, such as pumped hydro accumulation storage or compressed air energy storage.

Also storage, especially distributed storage which is applied closer to the customer, makes the system less dependent on the failure of network components and hence requires less redundancy of the system. This could improve the reliability of supply and thus counterbalance a reliability decline due to the ageing of the infrastructure.

A last benefit described here is a financial benefit. Besides the possibility to delay grid investments due to load growth or connection of dg, energy storage can generate value by charging the storage assets with cheap electricity in the off-peak periods and using this electricity during peak periods. It is, however, likely that the grid operator will not be allowed to exploit this benefit in a restructured energy sector although the technical and a commercial optimization of the operation of storage facilities overlap each other.

It can be argued that as long as load management by the dsos does not lead to any inconvenience for the consumer, no (financial) compensation for the customer should be required. However, to put this in practice, in most cases regulation will have to be adapted because in most cases customers are given an unconditional right on using grid capacity and because the electricity market is based on the assumption that time shifting electricity demand is not possible due to lack of significant storage possibilities. Therefore, the exact description of how owners of storage assets are embedded into the energy market frameworks of the future is crucial for the quantification of benefits introduced by distributed energy storage (Klöckl et al. 2009).

Future grids

As a consequence of the energy transition, it becomes more difficult to balance supply and demand. Moreover, the grids must be operated efficiently. The grids need to support dg and integrate more flexible demand. To adapt to these changes the distribution systems will have to evolve into a more dynamic system. Concurrently, developments in storage provide opportunities to manage the grids more flexible and efficiently. Management of as well controllable loads as dg close to the end-users can increase the capacity usage of the system and result in more efficient use of our energy resources. The current status in power electronics, and in information and communication technology (ict) can support this. The system will have to integrate controllable loads and storage facilities into the operation of the power system and adjust (a part of the) demand to the fluctuating distributed supply of energy. The controllability of the loads and/or storage will allow for greater flexibility of the grids.

In this section, it is described in further detail how the electricity distribution grids need to prepare for the future. Furthermore, the definition of a smart grid is given and it is addressed that implementing these smart grids is more than adopting technologies in the grids.

Prepare for the future

The investment and replacement strategies which have been successfully deployed to the distribution grids until now, do not longer fulfil future requirements. The long-term optimization programme of Enexis showed that if the current replacement strategy is continued, the reliability will drop to an unacceptable level (Wijnia 2006; Essent Netwerk 2007). To maintain the high level of reliability, an intensive replacement programme is needed which will mean enormous investments. However, another possibility is to improve the reliability through increasing the speed of restoration after an interruption. This can be realized by the large-scale deployment of remote control on certain points in the medium voltage grids to detect and localise outages due to component failures. This makes it no longer necessary to rely on phone calls of people whose light and televisions turn off for outage detection and makes restoring the interruption much quicker. In this way, the increasing use of automated monitoring and control of the electricity distribution system can encounter the expected dropping reliability caused by an increase in component failures due to the ageing of the system.

A similar argumentation accounts for dg. Studies on this subject show that the penetration of these resources in the existing distribution grids is limited due to operating problems caused by them. To support a higher level of penetration of dg, the grids must be adjusted. One way is to invest in the capacity of the grids, but another solution can be provided by continuously monitoring and controlling the grid and the generators. With active management the penetration grade can be much higher (Zhang 2009). In several studies it is demonstrated that the costs for the needed ict investments are much less than the investments for reinforcements of the infrastructure; automation technology is mature enough to justify investment in appropriate metering, communication and control (Djapic 2007; Berende 2008; Bell 2008).

Simultaneously, distributed electricity storage and controllable loads can be incorporated in the grids by applying more active network management. This contributes to a more efficient and flexible use of the grids and storage can also improve the reliability of the grids. Additionally, network losses can be reduced by applying automation in the grids.

It can be concluded that the grids need to be adapted from a passive to a more active system to facilitate the transition of the distribution grids to sustainable power systems of the future. More active network management will ensure cost-effective development of an efficient and reliable electricity system that allows the integration of dg. With intelligent control embedded in the grids to incorporate distributed electricity storage and controllable loads the operation of the grids can be optimized and maximum utilisation of all resources connected within them can be achieved (Ilic 2006).

The definition of a smart grid

The term smart grids is a common denominator for a wide range of developments that make medium and low voltage grids more intelligent and flexible than they are nowadays. The term is gratefully utilized by developers of all kinds of intelligent devices to smarten the grid to address the capabilities of and need for their products. However, until so far, these developments tend to root in technological possibilities, rather than in a sound problem analysis and a structured approach towards its solution. Many of them have not found wide application, which can be at least partly be attributed to the fact that there were no problem for which they provided a solution, so that it was not possible to draw up a positive business case. In summary, there was too much technology push and too little market pull.

From the perspective of the dsos, it now becomes more and more clear that active management of the grid to adapt the grids to future developments is the economic feasible solution to be able to keep reliably delivering electricity and to facilitate the integration of dg. In these smart grids, controllable loads and distributed storage facilities are integrated in the operation of the grids, and also dg is controlled (see Figure 10.5). Enexis believes an effective deployment of smart grid technologies requires a top-down approach. Therefore, Enexis is developing a vision on the role of the medium and low voltage grids in a sustainable energy future. With Enexis' vision becoming clearer over time, ever greater efforts will be spent on developing the appropriate and necessary smart grid technologies in cooperation with commercial energy companies, other grid operators and suppliers, as well as on increasingly focused discussions with the regulator and the government on the future energy supply and the role of smart grids in it.

A paradigm shift

Although the future grid builds on the existing infrastructure, the smart grid approach to operate the power system is completely different from how distribu-

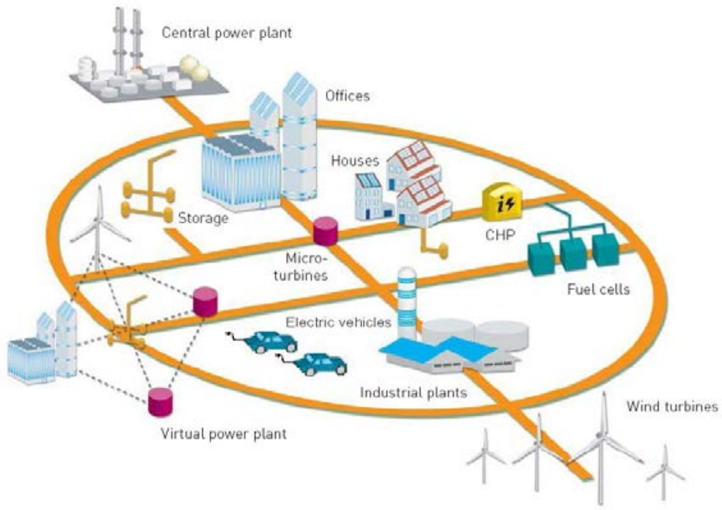

Figure 10.5: The smart grid is a grid with active network management to control integrated distributed generation, storage and flexible demand (*Source*: European Commission 2006)

tion grids have been approached for decades. It provides a greater level of integration of as well generation as demand in the operation of the system. For the dsos, this adaptation of the grids not only means that they have to equip the grids with technological innovations; but it also asks for a change in how they look at a set of technologies that can enable both strategic and operational processes. This not only accounts for the utilities, but also for policy makers and regulators who shape the environments in which the utilities can make the best strategic decisions. It is not a one-time solution but a long-term process towards a fundamental change affecting all actors, including consumers and suppliers.

A smart grid is an integrated solution of technologies delivering benefits for the dsos. It can reduce costs for investments needed to address problems caused by ageing of the infrastructure and the energy transition. It adapts the grids to facilitate a growing share of dg and to the change in the demand of energy; it enables the grids to operate more efficiently and to keep reliability on a high level. But because of the higher level of interaction with generation and demand it also addresses customer and societal benefits. The integration and optimized utilisation of the renewable resources, the integration of storage to improve efficiency and reliability, and finding the economically best solution for the consumers and for suppliers of dg are all possible benefits. Commercial as well as technological optimization can be realized by a smart grid. However, the benefits may not necessarily be equal for the different parties. For example, the goal of energy suppliers to economically optimize the utilisation of their generation units by balancing generation and demand may not necessarily equal the goal of the grid operators to optimize grid utilisation. In the end, the grids should facilitate the market, not constrain it. The overall cause will be to leverage the benefits of all parties involved and find the best solution for society.

While dsos have a pure facilitating task they are at the moment not allowed to control generation and demand. The advantages of demand response and generation control by the operator must be seen by as well the owners of the distributed generators, the consumers and the governments which shape the market and regulatory mechanisms. So, on the one hand network management will evolve to include advanced applications to monitor, control, and optimize the grids and on the other hand to support these developments market and regulatory frameworks need to be addressed. All publications which write that smart grids are the solution to future challenges conclude that priority should be given to the necessary changes to meet market and regulatory requirements. Current commercial and regulatory arrangements often prevent appropriate automation measures from being implemented and without suitable adjustments it is not certain that benefits will indeed be achieved. This shows that solving questions related to the future power system calls for a holistic methodology, incorporating technical, market and regulatory aspects.

The next steps

The previous sections showed that a lot needs be done to transform the electricity supply system. This transition process to the energy supply system of the future will take many years. Nevertheless, it is time to make progress to evolve to this future system and to focus on the first next steps to get there. This section is divided in three parts to describe the most important aspects to address at this moment. From a technological viewpoint it is important to focus on improvements in the field of storage technologies. Storage can bring a lot of benefits for future grids, but is not yet mature enough to be implemented. Subsequently, it is revealed that it is necessary to adjust regulatory frameworks to support investments and to make technological innovations in the grids possible. Also it is described in more detail what the role of market mechanisms is or may be in the deployment of smart grids. Finally, (international) cooperation is treated in this section. The importance of cooperation between all parties involved was already touched upon, but to realize an effective transition to smart grids it is a very important aspect. Fundamental and decisive choices have to be made and a lot of issues need to be considered from the points of view of all parties.

Further development of storage technologies

The integration of distributed electricity storage in the electricity system plays an important role in the smart grids of the future. While energy stored in storage systems can provide consumers with energy in case a fault in the grid occurs, it can contribute to the reliability of the grids, and, therefore, it will make the grid less dependent on the components, the redundancy of the system and the time it takes to restore an interruption. Besides that, storage can facilitate the large-scale introduction of renewable electricity. A high penetration of dg without the need for large investments requires controllability. Distributed electricity storage creates this by adding an extra degree of freedom in the grids; it enables shifting the transport of electricity in time. This provides the possibility to flatten the load profiles to supply consumers from the storage facilities with electricity at peak moments and to charge the storage units when the generation of electricity is available but the demand is low. In this way, the efficiency of the utilisation of as well grid capacity as the resources available is improved. The principle of electricity storage allows for much more controllability and flexibility in the grids and is therefore an ultimate driver for successful smart grids.

Technological developments in the field of electricity storage, driven by its large-scale application in mobile ict, have until so far led to batteries with a high specific energy density, high specific power density, high reliability and long lifetime becoming available as can be concluded from Figure 10.6. However, the technology is not yet easily available. Moreover it is not mature enough for wide application of storage in the operation of the grids. At the moment, the different techniques are still expensive. But new developments grow fast and will ultimately be an integrated part of the distribution grids. An important development towards economic availability of batteries is the development of electric vehicles. Although these cars are still expensive, because of the battery packs, large-scale application in electric cars will definitely lower prices. In this way, the contrast of applying electricity for powering cars are effectively overcome, and, while the advantages of electric mobility still hold, the electric cars are on the verge of breaking through (Enexis 2009). Subsequently, a growing share of electric vehicles connected to the grid will add a substantial controllable load that can be used as storage.

The possibilities, implementation and consequences of storage in the operation of the grid are not yet fully understood. To be able to use the opportunities that (distributed) electricity storage delivers as soon as possible, further research on this subject is necessary. Also, it is required that attention is paid to regulatory issues concerning storage. These will be further addressed in the next section.

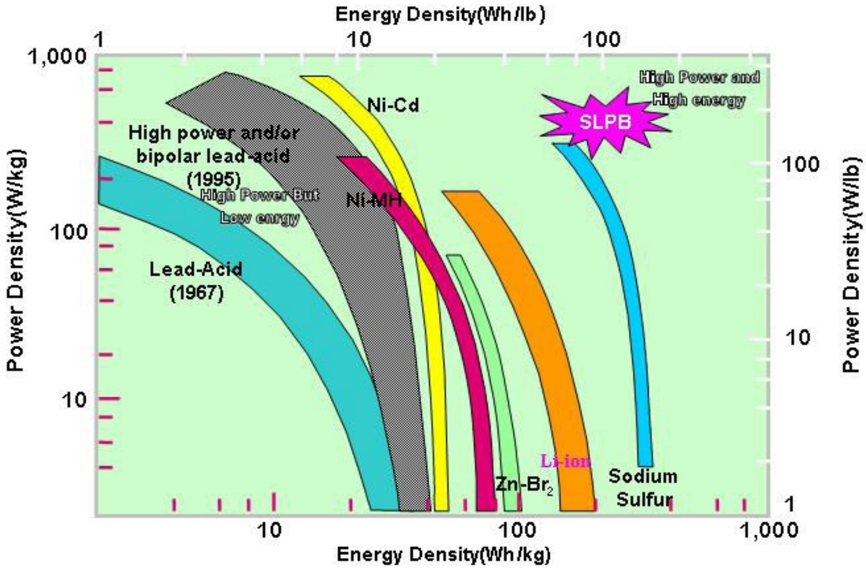

Figure 10.6: Characteristics of batteries (*Source*: Enexis 2009)

The role of regulatory frameworks and market mechanisms

The current regulation in the Netherlands emphasizes cost reduction and gives little attention to reliability and sustainability. This hampers innovation and implementation of new technologies in the grids. Large investments for innovation and also for replacement programmes are at this moment impeded by the regulation. Besides that, because of the monopolistic nature of dsos, they are not allowed to control generation or demand or to apply storage in the operation of the grids. These matters can constrain a successful implementation of the smart grid.

Although liberalization was expected to be stimulating innovation, the current institutional framework relevant to the sector of electricity grids in the Netherlands has some important barriers for innovation that need to be altered to fulfil the critical function of radical innovation (Jonker 2008). The liberalization has a strong focus on cost saving and efficiency, and the focus of the current regulation is short-term. Furthermore, investment levels are based on history and benchmarking between grid operators (Nillesen 2008).

As a consequence, the current regulation does not necessarily stimulate dsos to make the necessary or desirable investments. To support future investments and innovations the regulation of the energy sector needs to be altered. These investments include investments to guarantee the reliability and quality of the grid and the investments needed to facilitate the generation of sustainable energy. The investment level of these investments is unpredictable and depends on a lot of factors. Above that, driving forces for investments come from a local level. Municipalities, project developers, producers and other parties make technological choices for generating and consuming energy. These choices have a different impact on local grids and thus on the investments. The sort of investments will differ, therefore, between regions in the Netherlands and the investment level will increase (Suurmond 2009). Although the regulator in the Netherlands confirms that, to ensure public interest in the future, large investments are needed, and that a better investment climate is desirable to realize this, they want to investigate the alternatives further before making changes to the regulation (Energiekamer 2009), which could take too much time given the importance and urgency of the challenges ahead.

To address long-term values, local differences and in particular inherent dynamic and unpredictable nature of future developments, the regulation need to be adjusted. Suurmond (2009) argues that this new regulatory framework needs to address the following issues, which are less important in a stable period. First, prevent future sustainable options to be hampered in their development in an early stage because the investments in the infrastructure have not been sufficient (technological lock-in). Second, promote cooperation over the whole value chain to match the construction of the future infrastructure with distributed energy technologies. Third, deal with divergent and conflicting interests of different parties, because conflicting interests can be a huge barrier to enable large-scale changes in the sector. Therefore, the role of every actor should be considered and the question how these actors should be regulated need to be answered. The regulator should quantify long-term values, facilitate negotiation between dsos and market parties, define the public interest and make an indicative planning to make uncertainties explicit.

Besides the adjustment of the regulatory framework to change the investment climate for dsos, it is necessary to explore possible market mechanisms to support future developments. To successfully integrate new generation technologies and use the grid efficiently, the control of not time critical loads and storage by the grid operator should be made possible. The current regulation and market mechanisms restrict this in two ways.

The first is caused by the fact that grid capacity is a local phenomenon. To stimulate efficient use of the local grid local price differences may be introduced. However, these differences in network tariffs may politically and socially not be acceptable given the monopolistic nature of electricity distribution. Hence, adapting regulation in order to socialize the vast benefits brought about by smart grids is a crucial success factor for large-scale implementation.

Also, in new market mechanisms to treat demand side management and storage the roles of the distributor and supplier may be reviewed. In most countries with a restructured electricity sector, the grid is not allowed to impose any restrictions on market transactions and should unlimitedly facilitate the electricity market. This principle implies that grid operators are not allowed to use the inherent flexibility of not time critical loads (as, for example, heat pumps and electric vehicles) without financially compensating the owners. In many cases, taking into account transaction costs, it will turn out to be cheaper to extend the grids than to structurally compensate the owners. Therefore, regulation must be changed in such a sense that in case control actions by the grid operator do not in any way hamper the customer, no compensation by the grid operator should be required. This fundamental but rational change would pave the way for smart grids by giving new degrees of freedom to the system operator, which can only be utilized by smarting the grid and therefore would strongly support the transition to a sustainable energy supply.

International cooperation

The depletion of fossil fuels and the climate change as a consequence of burning these fuels are widely recognized as serious threats to economic prosperity and even international stability and world peace. Therefore, securing the supply of reliable and affordable energy and effecting a rapid transformation to a low-carbon, efficient and environmentally benign system of energy supply need to be addressed on a global level (International Energy Agency 2008). On an international level choices need to be made to set clear policies and make our energy supply sustainable. Social acceptance and suitable regulatory frameworks are very important to make the policies work. Choices will help to formulate and implement solutions. Although many solutions will be implemented on a local level, future developments we face are similar in other counties and the solutions will often be the same. This makes it important to share knowledge on an international level and support the development of new technologies by setting standards and cooperation between dsos, suppliers, other market parties and knowledge institutes. Cooperation over the whole value chain is a key enabler for a successful implementation of smart grids, paving the way towards a sustainable energy supply system (Kema 2008).

First, it is very important to make choices and define clear policies. The governments are responsible to deliver a policy for greener energy, greater energy efficiency and guard the availability of energy and quality of the energy supply system. They need to reveal the public interest and clarify this for the different parties as well as for civilians to gain social acceptance for their policies. The policies need to be discussed between the eu member states, while European laws, market mechanisms and regulation will influence national systems. The regulators face similar difficulties in the different countries in Europe. For example, the United Kingdom was the first country to start liberalizing the energy market and the national regulator Office of the Gas and Electricity Markets (Ofgem), was the first regulator to understand that the regulation hampered essential innovations in the grids. Now, Ofgem started to adjust the regulation to support investments for innovation. This is done by developing possible future network configurations. Subsequently, the scenarios are used to establish views on the scenarios' implication for the grids to be able to determine suitable regulation for future needs and determine new tariffs (Ofgem 2008). Sharing knowledge about projects like these can be useful for regulators in other countries and help them to adjust the regulatory frameworks within the needs for their own nation.

For dsos supporting the ability to make the right choices means that they will have to clarify the technological possibilities and impossibilities the grid has to deal with. It may also be useful for the dsos to jointly formulate the best choices and the vision from a dso's perspective as well as communicate with governments and regulators. Another role for the dsos is to start up pilot projects to better understand the opportunities and risks of new technologies.

Besides the needed social acceptance for policies, there is a growing need for dsos to cooperate and communicate with customers. Within the liberalized energy market and with more variability in the available energy sources customers have more choice and expect high quality, a high reliability of supply and efficiency. As a consequence, the customers have more influence and are more involved. Not only as consumers, but also as private individuals generating energy the customers of the electricity distribution system must understand the collective gain in the changes affecting them. This complicates the integration of generation and demand in the grid. Demand side management and controlling dg is for dsos seen as a solution to add flexibility to the grid and improve operation, but for customers this is perceived as a problem while it may harm their rights. Until now, customers are given an unconditional right on using grid capacity. This may need to be limited to introduce demand side management. Also, in case of exchanging data for optimal control systems privacy issues need to be regarded.

Smarting the grid for better control of the electricity flows in the grid enabling more efficient use and better integration of distributed, renewable sources and new demand side technologies requires exchange of data and information between the energy suppliers, the grid operators and the consumers of the electricity. This calls for good communication between these parties and agreements on the application and specifications of technologies should be made. It is the responsibility for manufacturers of these technologies to clarify the future product requirements in consultation with the grid operators and possible other users. Pilots initiated by grid operators can demonstrate new products and initial research and consultation in pilot projects can be provided by research institutes and universities. This accounts for all kinds of technologies, for the development of the desirable components for further automation of the grid and power electronics, but also for storage and end-user technologies like controllable electric vehicles. The electric vehicle is an example that shows that cooperation between all different actors is very important for the development and especially the adoption of new technologies in society. It is necessary to work together on an international level to set standards and conquer barriers that may hamper important steps towards a sustainable energy supply. Some technologies are still in an early development phase, like energy storage. Although developments so far gave a huge boost in the application of electricity storage, research activities in this field may still be increased. Other technologies are already mature enough for implementation, starting with the application in pilot projects. But for a successful development and a good selection of the best technologies it is very important that knowledge is shared and powers are bundled, on as well a national as an international level.

Summarizing, it is an established fact that cooperation with all different parties involved in the energy sector is an indisputable necessity to be able to adapt the energy supply system for future needs. Governments and regulators will need to determine the right policies, set the suitable frameworks, reveal the public interest and protect long-term values. The development of technologies can only be successful when dsos, market parties, research institutes and customers work together. Taking into account the benefits for and impacts on all parties, sharing knowledge and involving consumers are necessities to successfully deploy the smart grids that meet the needs of all and that support the public interest best.

Conclusion

In the current, ageing distribution systems very little automation is embedded and the ratio between used and available capacity is relatively low introducing a great potential to transfer extra energy with the existing capacity of the grid. New developments towards a more sustainable energy supply system require the support of dg, integration of more flexible demand and a more efficient use of grid. Also, due to liberalization of the energy sector and the connection of generation on the distribution level of the power system, there is no longer a strict separation between suppliers and consumers. As a consequence, it becomes more difficult to balance supply and demand. All this leads to the need to adapt the energy supply system and apply more efficient and flexible grid management. Additionally, developments in storage and the possibilities to control flexible loads provide possibilities to do this. This calls for a different approach of grid management.

The grids need to be adapted from a passive to a more active system in which storage, controllable loads and dg are incorporated. Active network management will ensure cost-effective development of an efficient and reliable electricity system that allows the integration of dg. With intelligent control embedded in the grids to incorporate electricity storage and controllable loads the operation of the grid can be optimized and maximum utilisation of all resources connected within them can be achieved.

The evolvement to these smart grids is not a one-time solution, but a long-term process towards a fundamental change affecting all actors. Governments and regulators need to determine the right policies, adapt the regulatory and market arrangements that no longer suffice, reveal the public interest and protect long-term values. Cooperation and knowledge sharing between dsos, market parties, research institutes and customers is needed for a successful development and integration of technologies. It is important to take into account the benefits for and impacts on all parties to develop the energy supply system that supports the public interest best. Cooperation between countries as well as between the different aspects over the whole value chain is of importance. It is a versatile theme that asks for a holistic approach, incorporating technical, market and regulatory aspects. Cooperation with all different parties involved in the energy sector on as well a national as international level is vital to successfully develop the smart grid and put it into in practice.

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