Electricity infrastructure governance has been subjected to substantial changes in the recent past and is expected to be prone to more changes in the near and farther future. Liberalisation affected the entire energy sector with, as a main result, the unbundling of transport from production/delivery. In most cases of unbundling in the electricity sector this concerns transmission networks; yet, in fewer cases it concerns both the transmission and distribution networks, such as in the case of The Netherlands. The liberalisation thus induced changes in the governance structure of the electricity sector by introducing commercial functions for market-based competition. These commercial functions now exist next to the established technical functions that provide essential infrastructure services for bringing electric power to end customers. In this respect the transport function that the electricity infrastructure fulfils did not alter substantially: the institutional structure was and remains regulated and the network still serves as a conduct for electricity from a few large scale electricity generation units to many end customers. At this point we state that liberalisation and associated unbundling induced more transactions for the operation of electricity network infrastructures to facilitate commercial functions, but in essence did not substantially change the technical functions and their operation. The above reasoning is valid for both the high voltage transmission networks and the lower voltage distribution networks.

**Observations of developments**

The increased awareness of environmental impact did lead to improved sustainability considerations by the society at large. The disappointing results from the Copenhagen conference last December 2009 only amplified these considerations, and it is increasingly observed that society realises that measures have to be implemented at an end-use customer level, meaning essentially at local level bottom up, and that national and supra-national top down efforts (such as Copenhagen) only at best can be seen as facilitating and are not considered initiating and guiding (Commission 2009). In addition to this environmental awareness, another social phenomenon has been observed; that of autonomy, largely caused by the availability of abundant information, primarily via the Internet. People seem to more and more value autonomy, resulting in self-determination and autarky, not only in general but also in case of essential societal services such as energy. Another observation is that technology developments, largely based on fundamental physics, seem to follow their own dynamics, certainly affected but essentially not hindered by economic, institutional and social evolution.

The combination of sustainability considerations, end customer autarky wishes and technology developments did lead to the rise of decentral energy resources (DERs) such as decentral electricity generation, local heat (and cold, replacing airconditioning units) generation by means of heat pumps, and decentral electricity and heat storage (Ackermann, Andersson et al. 2001; Kari Alanne 2004). The storage capability is seen as an additional aspect of two recent developments: the entrance of electric cars as the car batteries can be seen as a storage device, and the increasing use of heat pumps possibly combined with micro combined heat and power systems that will require heat storage for flexible dynamic operation (Watson, Sauter et al. 2008). Decentral heat generation by heat pumps requires less energy in comparison with heating by burning natural gas and results in less carbon dioxide (CO₂) emissions, but will substantially increase the amount of electricity used and will thereby increase the load on the electricity infrastructure. Furthermore, the use of electric cars will also considerably increase the load on distribution networks. Decentral electricity generation, in this context solar PV systems and micro-CHP systems, and the storage capacity of electric cars will therefore affect the transport function of electricity distribution networks. Traditionally distribution networks serve as one-directional conduct of electricity from large centrally placed electricity power plants to...
the end customer. The entrance of DERs not only leads to more load on the distribution network infrastructure but also leads to feed in of electricity into the distribution networks, this bi-directionality is known energy value chain reversal. The hitherto consumer can thereby swiftly change into a small-scale producer; and it is in this context the term prosumer has been coined.

Therefore, the entrance of DERs will change the electricity distribution network governance from elementary one-directional distribution of electricity to a distribution system operator, a DSO (M. J. N. van Werven 2009). The distribution network as such will start to show characteristics of transmission networks that also allow bi-directional transport of electricity. From a technical point of view the operation of the distribution networks will more and more resemble that of transmission networks. As a result this will require similar control intelligence as currently in use by transmission networks. This means that technical functions, such as balancing, currently mainly operated by transmission system operators, will now involve distribution system operators as well. Consequently the balancing function may not only operate at transmission level but also at distribution level, and this may even lead to localised area balancing also known as islanding, which is basically forbidden in the current network governance structure in many countries for safety reasons. The resemblance of the operation of distribution networks to that of transmission networks brings about that transmission network intelligence, founded on information and communication technology (ICT), will have to be implemented into these distribution networks, leading to so-called smart grids (McDonald 2008). The chain reversal, that is, bi-directional electricity flow, will lead to more transactions and will thereby affect both technical functions (for example balancing) and commercial functions (for example financial settlement). Not only will the complexity of distribution network management change substantially, its scale will also change: next to several large electricity feed in points, many small-scale electricity generation and storage units will have to be incorporated in the daily operation of the electricity system. Thus, we postulate that the governance structure of electricity distribution networks will have to be adapted in order to facilitate the aforementioned developments concerning DERs, which in turn respond to the increasing societal need for a more sustainable energy provision.

Change in governance of distribution networks

Fortunately, the need for a change in governance structure may well be synchronised with other, more asset management related activities concerning distribution networks. In the near future many parts of the current electricity distribution networks, not only in The Netherlands, but in wider Europe, may need to be renewed and/or reinforced. The main reason for this is that the majority of the distribution network assets are approaching their technical end of life. If the aforementioned is considered in the light of increasing electricity use by heat pumps and electric cars, and feed in by solar PV and micro CHPs, several solutions can be envisaged. Traditional solutions encompass reinforcement of the electricity infrastructure; hence thicker cables with higher power capacity. Another approach may, however, be a more intelligent use of the current distribution network capacities for instance by spreading usage in time (peak shaving) and making use of storage capacity in electric cars, intelligently combined with employment of production capacity in micro-CHP systems (Solar PV systems cannot be dynamically controlled). A ‘back of the envelope’ calculation supports this: an average electric car has an energy capacity of some 20–30 kWh. Suppose that 10 kWh of each car is available for peak shaving. For a million cars (some 8 million cars in The Netherlands) this amounts to an electricity production capacity of 10 GW during one hour, or 5 GW during 2 hours. Note that 10 GW represents 50 percent of the total Dutch electricity production capacity for one hour. Similar reasoning can be followed in the case of micro CHP systems. For example, suppose that in The Netherlands one million households (of the 7.5 million) will install a 1 kW micro CHP, this then represents 1 GW capacity; comprising roughly 10 percent of the total energy production capacity. These DERs somehow need to be included in the critical technical functions as for instance the balancing mechanism. Concerning commercial functions; the one million prosumers (owing both an electric car and a micro CHP) will need to be settled financially most probably leading to new market roles and settlement mechanisms.

As a result we can conclude that the entrance of DERs induces chain reversal and will therefore require a different mode of operation leading to a change in the governance of distribution networks. Combined with the planned renewal this in fact may lead to the next generation electricity infrastructures at distribution level. As electricity transport functions are in many cases regulated this will inevitably lead to a change in regulation of distribution networks and the associated institutional arrangements. For instance, the regulation, often vested in codes describing rules and principles, may have to be adapted in order to make feed in of electricity possible at end customer level. From the perspective of technical functions this will not only pose demands on the quality of the electricity fed back into the network (for example voltage fluctuation, power factors, harmonics, etc.) but also concerns balancing issues. Hitherto, the balancing is being carried out on
a transmission level by the transmission system operator (TSO) and in essence concerns an aggregation of the expected usages by all end customers to be met by planned production capacity of all power plants on a daily basis. This mechanism becomes substantially more complicated when DERs are included; a very large amount of DERs will have to be incorporated in this balancing mechanism. Given the amount of information that has to be processed it may well prove to be difficult and thereby costly to collect all expected production and usage data of all end customers on a daily basis. As a consequence this then could imply that the balancing mechanism may have to change and perhaps even to be redesigned. One can envisage balancing on a more localised level and even islanding operation. We thus conclude that the current governance model for electricity distribution networks may not suffice and will have to be adapted substantially in order to facilitate DERs.

This expected change in governance structure brings along a set of questions to be answered. How will the current roles of institutions change? This concerns the roles of the current players in the energy sector: end customers, producers (including prosumers), distribution network companies (they may have to convert into DSOs): , various new market parties such as aggregators brokers (that will take care of functions that end customers will or cannot fulfil themselves), and also the government (which regulatory measures are required?). How to realise an adapted governance model: a central or decentral mode of organisation? It may well be that an extended set of institutional arrangements will be required. The adapted governance model may also bring about the need for redefining market rules, which in turn will affect both technical and commercial functions. Technical functions will probably have to be redefined partially, for instance the aforementioned balancing certainly will have to be adapted. As the entrance of DERs is unprecedented, experiments and pilots coupled to thorough scientific evaluation may shine light on this. It is however clear that the governance structure of distribution networks will face a paradigm shift. Of all actors in the energy value chain the distribution network sector will face the majority of these changes.

Evidently, ICT will play a major role in this as the entire energy value chain in essence runs on adequate and timely information. Benefits may be achieved by looking at the architectural approach for ICT as this is already successfully applied in other businesses. It may therefore be necessary to devise a sector architecture approach, to be applied to the electricity value chain in which the required information flows can be formulated (Rene Kamphuis 2008). As these information flows support both technical and commercial functions, and these functions are prone to adaptation, the architectural approach may also serve to help define and implement the transition in governance structure.

It is also clear that the smart meter is one of the boundary conditions for the implementation of DERs and the realisation of smart grids. Note, however, that smart meter implementation is not the only boundary condition. Other requirements may be derived from the current mode of operation as applied in electricity transmission networks. These functions, and new ones, may cascade down into the distribution networks in order to support the transition into smart grids: localised balancing, islanding, routing of power, dynamic control of networks sections etc. These new functions at distribution network level may bring the need to assess the current role of the distribution network operator. For instance in The Netherlands no commercial activities are allowed for distribution network operators under the present regulation. Perhaps the redefined role of distribution network operators may require commercial contracts with end customers. From a regulatory perspective the distribution network operators presently solely take care of the transport function and asset management, and basically all other contracts and commercial functions are managed by the energy supplier, including billing for transport. A new governance structure for distribution networks may perhaps entail commercial contracts on usage and feedback of electricity in so called ‘time of use’ contracts. This may even prove to be essential when mechanisms as local balancing and islanding come in view, implying a change in the current institutional arrangements, for instance adaption of regulation and may not be in line with the present regulatory model.

Finally, it may well be that electricity distribution networks have to be integrated in some fashion with gas and heat distribution networks; in essence these networks all transport energy that is expressed in the same basic physical unit, the kWh.

Conclusion

The energy utility sector is facing a transformation from a centralised, producer-controlled network to one that is partly centralised and partly decentralised with a higher involvement of the end customer. The entrance of DERs will require adaptation of the governance of distribution networks and may be considered to be paradigm shift. The grounds for this paradigm shift is found in the societal need for a more sustainable energy provision under the conditions of market based competition. This encompasses better demand/supply alignment via a more efficient energy market, well-considered investments in distribution networks for renewal, and efficient use of current distribution networks. Hence we conclude that a number of ques-
tions will have to be addressed and answered. These answers will impact the governance structure of distribution networks and it is foreseeable that institutional, technical and economic arrangements will alter substantially.

References