Bremer Energie Institut

Bremen Energy Working Papers

Paperseries No. 11

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Governing smart grids – the case for an independent system operator

November 2011

In Cooperation with Jacobs University Bremen

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Vorgeschlagene Zitierweise/ Suggested citing:
Autor, (Jahr), "Titel", Bremen Energy Working Papers No. #, Bremer Energie Institut.

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Governing smart grids - the case for an independent system operator

Nele Friedrichsen[†]

November 4, 2011

Abstract

The next years should bring about a rapid transformation of the electricity sector towards high levels of renewable generation. Smart grids are seen as the silver bullet responding to the challenge of integrating renewables, managing flexibility, and keeping the costs down in distribution networks. Network unbundling on the other hand is essential for competition in the liberalized electricity industry. It forces independence of the networks and thereby eliminates concern that incumbent integrated (network) firms discriminate against new entrants. With smart grids the unbundling questions become relevant for distribution networks because active control in smart grids entails discrimination potentials. However, smart grids exhibit coordination needs for system efficiency and unbundling eliminates firm-internal coordination. An independent system operator seems to be an appropriate compromise solution. It eliminates discrimination incentives and serves coordination needs, thereby striking a balance between both competition and efficiency goals.

Keywords: smart grid, unbundling, governance, coordination, independent system operator

JEL-classification: L43, L94, D23, L22, L51

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Financial assistance through the research council Next Generation Infrastructures within the project UNECOM and from the German Federal Ministry of Economics within the research project IRIN - Innovative Regulation for Intelligent Networks is gratefully acknowlegded. The author would also like to thank Gert Brunekreeft, Rolf Künneke, Roland Meyer, Christine Brandstätt and Jana Friedrichsen for valuable suggestions. Furthermore, the author acknowledges useful comments by participants of the 9th Conference on Applied Infrastructure Research, October 8-9, 2010 in Berlin, the 3rd Annual Conference on Competition and Regulation in Network Industries, November 19, 2010 in Brussels, the SIB Business Week Workshop on Research in Air Transport and other Network Industries, May 19-21, 2011 in Bremen, and the 13th Economics of Infrastructures Conference, May 26-27, 2011 in Delft. All remaining errors are the responsibility of the author.

1 Introduction

Climate and energy policy are shaping the future electricity system. The goal of a low carbon electricity system causes increasing shares of renewable energy sources (RES) and distributed generation (DG).[2] The growth of intermittent, decentralized generation puts distribution networks under stress. It overhauls the paradigm of top down energy flow with central controllable generation. This requires adaptations in system planning, management, and expansion. Growing demand or ageing assets are additional challenges in some regions (Veldman *et al.*, 2010). In the European Union distribution network operators expect massive network investment over the next years to accommodate these challenges (Veldman *et al.*, 2010; BDEW, 2011; Ofgem, 2010). Simultaneously they face increasing pressure to enhance energy efficiency on the demand side and in network operation.

Smart grids are considered to help electricity distribution network operators[3] avoid part of the network investment by enabling more intelligent and flexible network management (Veldman *et al.*, 2010, p. 297f). Voltage problems for example are a main problem of DG connection in (weak) distribution networks that can be addressed by targeted feed-in of reactive power, regulation of demand and/or generation, or automatic voltage management at the substation (cf. WIK *et al.*, 2006, p. 54).

Since smart grids facilitate efficient integration of DG and RES, they receive substantial financial and political support[4]. However, full benefits of smart grids can only be reaped if decentralized users and network coordinate. It is not yet clear how this can be achieved, and what the allocation of roles and responsibilities in smart grids will be. This article addresses the necessary degree of unbundling as one aspect of institutional organization of smart grids that is of particular importance.

'Network unbundling', the separation of generation and retail activities from the network business, has been introduced to guarantee non-discriminatory network access for third parties and to foster fair competition. For transmission networks, a big debate on unbundling found its preliminary end in 2009 with the

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[2] DG can but does not have to be RES. Large parts of DG are combined heat and power (CHP) plants fueled with natural gas.

[3] This article focuses on the European discussion of smart grids in distribution networks where smart grids are seen as a necessary tool to address the challenges of a low carbon electricity supply and integration of renewable energy sources (RES). In the US also the national transmission system plays an important role when talking about smart grids (see e.g. DoE, 2009). This is driven by an explicit investment need and reliability concerns that the system is facing (Coll-Mayor *et al.*, 2007, pp. 2456; 2461). Recently the discussion started to involve smart gas grids and the combination of different resources to smart poly grids or smart systems (see e.g. Hinterberger & Kleimaier, 2010).

[4] In the European Union this materializes in the renewable directive, the internal market directive, and the directive on energy end-use efficiency and energy services respectively Directive 2009/28/EC, Directive 2009/72/EC, and Directive 2006/32/EC. All these directives encourage intelligent networks or intelligent metering (EC, 2009a,b, 2006). Financial support within the Seventh Framework Programme for research and technological development (FP7) for research and development (R&D) in smart grids, microsystems & ICT, and Green Cars & electromobility amounts to roughly €1.5 billion. FP7 runs from 2007 to 2013. (Cordis, 2009)

adoption of the third legislative package for Europe's electricity and gas markets that contains measures to ensure more effective unbundling of transmission networks (EC, 2009c).[5]

Distribution networks are still only subject to legal unbundling. This might change in future. I argue that smart grids require a revisiting of the unbundling question for distribution networks. Two aspects are central: First, vertical integration of networks with downstream activities incurs discrimination potentials that an integrated incumbent could exploit to hinder competition. Second, separation inhibits firm-internal coordination. This can induce adverse effects on operational efficiency and hinder the coordination of network development and (distributed) generation. Clearly these aspects represent a trade-off. More organizational integration enables distribution network operators to actively manage and coordinate the complete system. At the same time discrimination becomes increasingly a problem in actively managed smart grids. In a recent communication the European Commission recognizes that smart grid technology gives DSOs "detailed information about consumers' consumption patterns" which could lead to competitive distortions. The commission diagnoses that the "regulatory setting will need to ensure that these risks are properly addressed" (EC, 2011, p. 10). The question is how to best strike a balance between competition goals and coordination needs.

The article investigates theoretical arguments in the debate on unbundling and smart grids in the framework of transaction cost economics. The main conclusion is that smart grids do require unbundling to prevent discrimination. However, they form complex systems that need coordination. Therefore, I argue that a compromise solution between vertical integration and ownership unbundling, an independent system operator (ISO), is a good governance model. The ISO is not suspect to discrimination incentives but would still enable system wide coordination. Hence, this solution consolidates both competition goals and coordination requirements while avoiding the difficulties of a forced ownership change.

The paper is organized as follows. Section 2 presents two opposing perspectives on unbundling: the competition policy perspective and the transaction cost economics perspective. Section 3 gives a brief introduction to smart grids. Section 4 analyses the institutional form for a smart grid in view of the pros and cons of unbundling. Section 5 concludes.

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[5] The third legislative package on the European internal market for energy consists of two Directives, concerning common rules for the internal market in electricity and gas, 2009/72/EC and 2009/73/EC respectively, and three Regulations, one establishing an Agency for the Cooperation of Energy Regulators, 713/2009, and two on conditions for access to the electricity and natural gas transmission networks, 714/2009 and 715/2009 respectively. They are published in EC (2009c).

2 Background: Vertical Integration and Unbundling

Electricity supply in most countries has traditionally been realized by vertically integrated undertakings in regional monopolies.[6] This has been changing since the end of the 20th century when countries around the world started restructuring their electricity sectors. Privatization and vertical unbundling were two main ingredients of reform (Joskow, 2008). Restructuring aimed to improve sector performance by relying more strongly on competitive forces in power generation and retail supply. The network as physical infrastructure essential to transport power to customers remained regulated because it constitutes a monopolistic bottleneck.[7] Vertical integration of networks with generation and retail is seen with suspicion because of possible anticompetitive effects. While unbundling certainly has positive effects for competition policy there is another side of the coin. Transaction cost economics draws attention to the possible negative effects of unbundling underlining positive effects from vertical integration. The following paragraphs describe the advantages and disadvantages of unbundling in turn.

2.1 Advantages of Unbundling: Competition Effects

Vertical integration between the networks and generation or retail can be motivated by anticompetitive behaviour (Perry, 1989). Integrated companies could possibly exploit their position in the network monopoly to hinder competition at the other stages and create or protect market power. Even under the assumption that regulation prevents direct price discrimination in the access charges, incumbents could engage in non-price discrimination or 'raising rivals' costs' (Beard *et al.*, 2001). In the case of electricity supply this can be hindering and delaying network connection or cross subsidies between network and competitive stages.[8] The European Commission identified vertical integration as a major obstacle to achieving the benefits of a competitive electricity market and subsequently introduced network unbundling to prevent such anticompetitive behaviour and create a level playing field for new entrants vis-a-vis incumbents (EC, 2007).

Furthermore, an integrated network firm may have insufficient incentives to invest in interconnector capacity. Assume a country A with low cost generation and a country B with high cost generation. The interconnection between A and B is congested. Assume further a vertically integrated utility in B. Expanding the interconnector enables generators from A to supply customers in B intensifying competition for B. Therefore the integrated company has incentives not to invest in interconnector capacity to protect its home market. This so-called

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[6] Joskow (2008) gives an overview of electricity sector reform. Detailed country studies are collected in Sioshansi & Pfaffenberger (2006).

[7] For an overview on the theory of monopolistic bottlenecks and the consideration of competitive versus regulated markets see Knieps (2006).

[8] The existence of cross subsidies in electricity network practice is disputed. The Dutch regulator did not find evidence for cross subsidization in Dutch network companies (NMa, 2007).

‘strategic investment withholding’ has been another significant argument for transmission unbundling because insufficient interconnection hinders the development of the European internal market for energy (Balmert & Brunekreeft, 2010; EC, 2007). For distribution networks, however, the argument is irrelevant because they are usually isolated subnetworks connected at singular points to higher voltage networks without any interregional linkages.

2.2 Disadvantages of Unbundling: Transaction Costs and Coordination

Anticompetitive motivations for vertical integration are the main argument in favour of unbundling to enhance competitiveness and in the end social welfare. Notably, there is another side of the coin. Transaction cost economics (TCE) describes integration as organizational choice to enhance efficiency (Coase, 1937; Williamson, 2000). TCE assumes that the ‘transaction costs’ of using the market mechanism, such as effort for information search, negotiation, or contracting, determine the make-or-buy decision. Vertical integration or more generally within-firm organization of transactions is chosen if this is more economical than market transactions. A forced unbundling would in this case sacrifice vertical economies of scope.

Indeed such integration economies are present in electricity supply because of complex interrelations across the system. Efficient management of the electricity supply system requires careful coordination across the vertical stages of the supply chain both in operation and with respect to investment decisions. This has been analysed in detail for transmission networks in the seminal work of Joskow & Schmalensee (1983) and confirmed empirically (see for example Nemoto & Goto, 2004; Kwoka, 2002; Kaserman & Mayo, 1991). Meyer (2011) provides a recent empirical and theoretical overview of vertical synergies at transmission level.

In smart distribution networks similar interactions can be expected because the generation feed-in in distribution networks is increasing. As a consequence, power flow in distribution networks is not anymore unidirectional top-down, but increasingly also bottom-up. This development triggers a change to more actively managed distribution networks, similar to the present management at transmission level.

This article analyses unbundling and smart grids from the perspective of transaction cost economics. More specifically it relates to the research on co-evolution of technology and institutions in infrastructures. This approach, also referred to as coherence theory, widens transaction cost economics by the integration of the technological dimension (Künneke *et al.*, 2010). Künneke *et al.* (2010) identify critical technical functions that determine demands on the organizational form. They argue that the degree to which institutional form and technological practice are coherent impacts system performance. Coherence theory posits that different organizational arrangements might be needed to fulfill the coordination needs of different technical functions in the electricity system. Furthermore, the necessary scope of control and speed of adjustment with respect to the critical technical functions are important characteristics to determine the organizational form (Künneke *et al.*, 2010, p. 503). Functions that exhibit a need for system level control and a high speed of adjustment call for direct central control. In cases that allow longer time for adjustments decentral coordination and guided planning can be sufficient.

In electricity networks the most obvious 'time'-critical technical function is system management: reliable operation of the power system requires a balancing of supply and demand at every point in time. A lack of coordination can cause operational problems and may in the end impair system reliability. Since the time period in which the balancing has to take place is very small with less than a second to react, market mechanisms are unsuited to ensure reliability, but a central coordinating entity is needed. For system development on the other hand, coordination can take longer time. Hence market coordination and guided planning may be sufficient.[9][10]

2.3 Status-Quo of European Policy on Unbundling

2.3.1 Transmission Unbundling

The European Commission proposed ownership unbundling for transmission network. However, no consensus on this strict option was found. The outcome is a political compromise represented in directive 2009/72/EC that leaves three options to comply with stricter unbundling requirements:

Full Ownership Unbundling prohibits joint ownership of network and generation or retail assets within one firm.

Full ownership unbundling is expected to completely eliminate any discrimination incentives and abilities of the network firm and thereby benefit competition. However, ownership unbundling eliminates firm-internal coordination along the vertical supply chain. External coordination is necessary to avoid adverse effects on system reliability and efficiency. Since ownership unbundling forces a divestiture of integrated firms, the legal acceptability has sometimes been questioned (e.g. Pielow *et al.*, 2009; Talus & Johnston, 2009).

Independent Transmission Operator (ITO) The ITO model is also known as Efficient and Effective Unbundling (EEU) or 'third way'. This option requires a strengthening of the current legal unbundling rules. It

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[9] On the European level, we observe a tendency for long term (central) planning for system development with the 10-year-network-development-plan (TYNDP), published by the European network of transmission system operators (ENTSO-E). At a national level, long term development statements published by network operators (Ofgem, 2007b,a) are elements that move in this direction. They can increase transparency and promote coordination of developments.

[10] Theoretically, also simple communicationcan enhance coordination: the network could ask generators about their plans to adapt its network expansion to the developments at the generation stage. Unfortunately simple information exchange might fail due to strategic behaviour (Brunekreeft & Friedrichsen, 2010).

allows companies to retain both network ownership and management, but it puts strong limitations on cross-involvement of employees to assure independence of the network (Brunekreeft, 2008; Wachovius, 2008; Schmidt-Preuss, 2009). ITOs are not considered further in this paper because, if applied strictly, they come near to an ISO concept. More likely though, they are an inferior solution since they might still leave room for discrimination due to inherent information asymmetries between the integrated firm and any controlling agency.

(Deep) Independent System Operator (ISO) An ISO requires that an independent entity takes over operational activities in the network. The network ownership can stay with the integrated or any other firm. The ISO is not allowed to be active in generation or retail businesses. The prefix *deep* indicates that the ISO is authorized to decide on network investments. This is necessary to address the problem of strategic investment withholding. Otherwise the network owner with generation affiliates could still protect its home market by not investing. However, the deep solution allocates investment decision and financing to different parties; the network owner has to carry out the desired investments or open the way to another investor. This split between decision maker and risk bearer might come with other problems (Balmert & Brunekreeft, 2010, pp. 34-35).

The ISO concept addresses discrimination concerns without requiring ownership changes. Importantly, because discrimination is not an issue anymore, an ISO can be left freedom to coordinate system actors from a central perspective, at least partially. This is not an argument against ownership unbundling, but only the claim, that it might not be required to go that far unless structural separation involves other benefits. This is important when judging whether the degree of separation required is proportionate.

2.3.2 Distribution Unbundling

Distribution networks are currently only subject to legal unbundling. This includes unbundling of accounts, operations and information. Similar to the ITO concept legal unbundling only encompasses administrative separation though in a less restrictive form. Eventually a discussion to strengthen the rules for distribution networks is likely to start for two reasons.

- First, European regulation has shown increasing rigor over time for transmission networks. In 1996 unbundling of accounts was introduced (Dir 96/92/EC). Legal unbundling, including informational and operational separation was added in 2003 (Dir 2003/54/EC). In 2009 the third legislative package mentioned above expanded the requirements even further (Dir 2009/72/EC).
- Secondly, recent developments with respect to smart grids and the immense development of DG make the unbundling question increasingly in-

teresting because of discrimination concerns and coordination needs.

3 Smart Grids

Smart grids is an umbrella term, which is used for several concepts including demand side management, generation management, targeted black outs instead of whole area failures, and smart metering (Granger Morgan *et al.*, 2009). In this article smart grids are referred to via their goal, improving network management and efficient integration of DG, RES, and demand side flexibility which are key challenges for today's distribution network operators. This is assumed to relax the need for network investment (Veldman *et al.*, 2010, p. 297f). As commonly understood, smart grids apply information and communication technology (ICT) to achieve this goal.

Many components of smart grids are already known from transmission networks where most equipment allows remote supervision and control. In contrast, distribution networks are largely still operated relying on local personnel. Advancing and transferring the technology from transmission to distribution networks is a central part of making the distribution grid smart. Furthermore, smart metering in combination with dynamic pricing is expected to mobilize the demand and generation side and thereby increase efficiency. One point which is not settled yet is the level of control in smart grids. The polar cases are central and decentral control.

Decentral control Smart grid tools can support conventional re-active system management. This can be improvements in the knowledge of the network operator on the system conditions in any, even remote locations of his network, or remote control in substations and distribution automation. Furthermore, flexible load and generation can be integrated via more dynamic price systems and innovative contractual solutions.

Load and generation control remain decentralized with the respective actors. Therefore such a decentralized approach to control needs to be complemented by a coordination mechanism. First, coordination is necessary to guarantee critical technical functions. Second, it is required to achieve system efficiency. Uncoordinated behaviour is unlikely to fully exploit the individual flexibility for system optimization because each actor acts in its own interest without taking into account the system perspective. This system perspective however is necessary to exploit the full potential of smart grids for improving system efficiency (WIK *et al.*, 2006, p. 140).

Central control Other smart grid concepts foresee a central, holistic system management. The overall aim of such a concept is to reduce network losses, defer investment or support reliability. These concepts typically include active control of generation and demand resources by the network or system operator which effectively entails a centralization of control rights. For resources that are not under the ownership of the operator the respective owners would need to transfer control rights to the network operator.

Anecdotal evidence suggests that the complication of the necessary arrangements in liberalized markets hinders direct control (Bertram, 2006). One possible reason is the disintegration of the supply chain. When network operation and supply are not under the same responsibility, the arrangements necessary for load control including a network focus become more complex. Interruptible contracts and ripple control for example are a common instrument to enhance system reliability or provide reserve services. They offer a financial compensation or rebated tariffs for participating customers. However, if supplier and network are separate entities and have diverging objectives, it is far from obvious how network concerns enter the supply contracts and who has the responsibility to send the control signal.[11]

4 Governance in Smart Grids: the Case for an ISO

The structures of actors and technology become increasingly decentralized by the growth of distributed generation and demand side flexibility. In future smart grids, demand and generation will be active components in system optimization. Even with efficient network expansion, congestion can occur in some instances on some lines. In those cases the system operator has to balance the system which requires, at least partially, central control. Furthermore, coordinated siting and local balancing of load and generation allows better use of existing capacity and enhances system efficiency by reducing network losses. Modern ICT and intelligent control technically enable and support the incorporation of decentralized resources into the management of smart distribution networks. Using these technological advances might require adaptations in the mode of organization. The desired governance model needs to strike a balance between coordination need and discrimination concerns in system operation and system development.

The most relevant point where coordination is indispensable is system operation. Clearly system operation requires certain central control to satisfy the need for real time coordinated actions in balancing. Furthermore, even with advanced market coordination, a system operator is needed to realize dispatch decisions that come out of market mechanisms. A central controller may also be beneficial to integrate small-scale flexibility potentials that are not economically accessible via market coordination. However, the central controller is naturally endowed with enormous power that is linked to the ability to discriminate.[12]

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[11] There may also be other motivations to discontinue ripple control: regulatory pressure to save cost can represent a disincentive for load control since cost for installation of the control equipment are one place to save fixed costs (Stevenson, 2004, p. 4). Furthermore, experience from New Zealand suggests that commercial suppliers abandoned ripple control which was widely used in monopoly times, to benefit from demand driven price spikes (Bertram, 2006, p. 204, footnote 2).

[12] While discrimination can be welcome in some cases such as favouring sustainable energy production over conventional generation, in general discrimination is considered undesirable as it may impede fair competition. Kruimer (2010) gives a detailed analysis of (non-) discrimination in the context of energy system operation.

Therefore the central system operator needs to be neutral.

Apart from the operational level, further benefits can be generated by coordination of network and generation investment because “piecemeal” connection is frequently less efficient than coordinated system planning[13] (Baldick & Kahn, 1993). Connection of DG can cause system benefits or cost increases, depending on local system conditions (cf. Ackermann, 2004, Ch. 5). Especially for increasing shares of DG a cost increase is likely Niesten (2010). Therefore, system efficiency mandates coordination of network and generation to exploit the trade-offs between network expansion, generator siting, and operational management (Strbac, 2008, p. 4422). In contrast to system operation, coordination of system development does not need to happen in real time. Hence, no central coordinator is needed. Planning might well be sufficient. Also with regard to network connection discrimination can be a problem when the network operator is integrated. However, it seems that this problem can be and is already adequately addressed with the existing rules on non-discriminatory network access. Possible discrimination can be revealed and punished more easily which makes it 1) easier to control and 2) less attractive in the first place.

Hence, the important question in smart grids relates to system operation: who decides which generators and/ or demand units to control to restore system balance? A governance structure is needed that balances discrimination concerns and coordination need. I suggest that an independent system operator can be the adequate middle way. The following paragraphs explain why. Drawing on the discussion of transmission network organization presented in section 2.3.1, three possible governance models are differentiated: full ownership unbundling, independent distribution operation, and independent system operation.

4.1 Full Ownership Unbundling

Separating the network completely from generation and retail creates an independent distribution network operator (DNO). The DNO would own and operate the networks and have no affiliations to any generators, retailers or customers. This most effectively addresses discrimination concerns. However, similar to the debate at transmission level, it is debatable whether such a measure would be proportionate. Furthermore, the exploitation of coordination benefits under ownership unbundling is not obvious. While vertically integrated firms could coordinate generation and network decisions firm-internally,[14] the decentralized structure of liberalized electricity markets carries the risk of network operators disregarding these benefits in favour of network investments (Piccolo & Siano, 2009). Furthermore, network users may lack incentives to take their impact on the system into account. Hence, an external coordination mechanism

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[13] Baldick & Kahn (1993) illustrate the investment interdependency with a three node network. They show that a lack of coordination may cause inefficiencies because network expansion critically depends on the development of generation.

[14] This is a simplifying assumption. Even within an integrated firm, problems of coordination among the different division and supply stages are frequently present. A whole strand of literature deals with agency problems in firms. For an overview see Miller (2005).

is needed.

The price is the standard coordination mechanism for decentral activities in economic theory. Applied to smart electricity grids, a market that could provide system coordination needs to unify all different actors, including the network operator. Generators, consumers and prosumers[15] typically control their energy consumption or production themselves.[16] Imagine a couple of electric vehicles that charge driven by low spot market prices. Without further coordination, they might charge all at the same time and cause local network congestion. Efficient prices would reflect this scarcity of network capacity and thereby signal network customers to reduce their demand. Hence, prices for electricity would differ across location and time depending on the network losses and local congestion. Equilibrium prices would then send signals such that individual behaviour yields system optimality. Importantly, control remains decentralized with individual actors in this case. At present, most retail customers receive flat, averaged tariffs that are neither differentiated by time nor by location. More refined pricing and metering (smart meters) would have to accompany future markets for smart grids if prices are supposed to coordinate customers.

There are three critical points to make on decentral coordination of electricity (distribution) systems.

1. The first problem of market pricing to assure optimal coordination is the assumption that prices reflect all relevant characteristics. Cost-reflectivity creates incentives for customers and generators to participate in system management. Several approaches to efficient network pricing exist (see e.g. Schweppe *et al.*, 1988; Hogan, 1992). The debate is very advanced at the transmission level (for an overview see Brunekreeft *et al.* (2005)) but only recently becoming a topic at the distribution level, too (cf. Li, 2007; Prica & Ilic, 2007; Pudjianto *et al.*, 2007; Brandstätt *et al.*, 2011). For some characteristics like network congestion cost and cost of losses, market coordination has been successfully realized in practice via nodal pricing.[17] However, it is debated whether prices are able to reflect all relevant system aspects. Nodal prices mainly send short run signals, signals for investment decision are considered to be insufficient (Brunekreeft *et al.*, 2005). Furthermore, the value of reliability and the trade-offs between network expansion and generator siting seem to be critical but difficult to reflect in prices (Brunekreeft *et al.*, 2005).

2. The second critique is motivated by transaction cost economics: some real world characteristics limit the efficiency and effectiveness of possible coordination via the free market. Theoretically, decentral coordination via

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[15] Prosumer refers to a customer who both consumers and produces electricity at its connection point.

[16] In future self-control will be assisted by automation devices. The user programmes the automation device to switch appliances on or off based on electricity prices.

[17] At transmission level, several markets around the world rely on nodal pricing, most prominently PJM in the US.

a market should be able to exploit the same optimization strategies as firm-internal control: actors could trade-off flexibility potentials in the market and transfer the necessary rights to a coordinator. Then the coordinator would regulate some demand or generation to reduce network costs if this is efficient. The network operator would buy this service of flexibility or the associated transfer of control rights in the market.

However, this equality of market outcome and firm-internal coordination is only true for a world with perfect information and costless transactions. In the real world with transaction costs the outcome of decentralized coordination may deviate from the centralized optimum for two reasons.

- First, prices or contracts are likely to not include all the relevant information as mentioned above. This implies that operators might be insufficiently informed about control potentials at the customer side and the customer's willingness to accept control interventions.
- Secondly, individual actors might benefit too little from being active in the market compared to paying standard tariffs. Transaction costs in the form of time spent, knowledge acquisition, and effort might be higher than expected benefits.

Hence, transaction costs are a barrier for efficient decentral coordination. With contracts and market transactions, it can be infeasible to exploit the same optimization strategies as under integration.[18]

Future developments are expected to reduce transaction cost of market participation. This includes for instance automation technology that assist users in reacting to prices and new market actors that aggregate smaller participants to larger units such as virtual power plants. Such tools are projected to enable near real-time coordination (Kok, 2010). Thereby technological developments together with market and pricing innovations increase chances for decentralized self-organization of electricity supply (Kiesling, 2009). Hence, in future the scope for market coordination in smart electricity systems might increase. Currently though, the relevant markets do not yet exist but are a topic for research and development (see e.g. the projects E-Energy in Germany or Gridwise in the US[19]).

3. Furthermore, and this is the third point, technical characteristics demand some degree of central control. Despite far reaching market coordination a system operator equipped with certain control rights is still necessary to oversee and ensure emergency system balancing (Künneke *et al.*, 2010,

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[18] This parallels the findings of Coase (1960). Assume a good that benefits different parties. Coase (1960) investigates the effect that the allocation of rights on that good has on the final outcome. Under standard economic assumptions including zero transaction costs the rights' allocation does not affect the final outcome. In a world with costs of market transactions, it does.

[19] see http://www.e-energy.de/ and http://www.gridwise.org or http://www.gridwiseac.org for further information.

> p. 499).[20] The components of an electricity system or specifically the smart grid are interdependent. System reliability is a critical technical function with a necessity for fast adjustments. Central coordination is therefore indispensable for technical system coordination in the balancing area. Hence, even with an increase of smaller decentral actors and decentral coordination facilitated by advanced automation and new markets, a party is needed that bears the responsibility for system stability, i.e. a system operator. This party will retain certain central control rights for emergencies and basic ancillary services.

Taken together I conclude that the price mechanism is not sufficient to address all coordination needs in smart grids even though the potential for decentral coordination and self-organization[21] increases in smart grids with advanced information, communication, and automation technology.

4.2 Legal Unbundling – Independent Distribution Operation

If system coordination via a central entity is still necessary over and above market coordination, the first intuition would be to leave this responsibility with the legally unbundled network operator. This corresponds to the ITO model for transmission, which is legal unbundling complemented with additional behavioural prescriptions to safeguard against discrimination concerns. This article argues that this will become unfavourable in smart grids. It might be unattractive to the network operators because of high transaction cost to guarantee non-discrimination. Importantly, the notion of legal unbundling used here does not stop with the separation of the network into a separate legal entity. It is understood explicitly to include informational and operational separation.

Apart from safeguarding reliable operation, sector organization has to guarantee non-discrimination and neutrality. The system operator balances generation and load at every point in time subject to the capabilities of the network. He may therefore control generation or load resources to manage congestion or restore system balance. Neutrality is a precondition for a network operator that takes such coordinating actions to avoid any discrimination. While traditionally the problem in distribution was minor, in smart grids discrimination can become a problem because the scope and necessity for control interventions increase. Along with the ability to control third party resources, comes the potential to use them to the own benefit and disadvantage of others. If the central controller is an integrated company that owns generation it could for example turn on/ off third party generation more frequently, which increases wear and

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[20] System balancing is currently a task of the transmission system operator. Whether or not with s mart grids some tasks shift to distribution system operators is still open.

[21] Recent research addresses bottom-up self-organization in infrastructures and decentralized coordination of electricity supply (see e.g. Kiesling, 2009; Egyedi *et al.*, 2007). Agent based systems are the technological grounds for decentralized coordination (see for example Kok, 2010).

tear, and run own generation at optimum.[22] Therefore, non-discrimination in control interventions and in the respective contract design is vitally important.

In integrated firms not every discrimination potential can be prevented by behavioural prescriptions and supervision. The integrated firm will always have an informational advantage over third parties. Therefore, the central controlling entity needs to be neutral and independent so as to avoid any *incentives* to discriminate. Today the total effects of possible discrimination are likely to be limited since generation in distribution networks is only a small percentage and active integration of demand is still rare, but the shares are likely to grow. Hence, smart grids reinforce the need for effective unbundling at distribution level.

Legal unbundling already aims to ensure neutrality of the network operator. But in smart grids, it might be impossible to guarantee this neutrality if the network operator still has affiliated retail and/ or generation activities. The high number and small size of actors and transactions makes it extremely difficult to prove neutrality in the choice of control actions. If neutrality cannot be guaranteed and tested with the status-quo, it can be advantageous to move to a truly neutral operator. Otherwise, the threat of discrimination can hinder smart grids because actors and investors are less willing to participate in innovative concepts that involve coordinated control.

Of course the law already prohibits discrimination and legal unbundling curbs the potential to discriminate. However, the burden of proof can be a significant obstacle for small actors in discrimination cases because they need to show that they have been discriminated. This is detrimental if it overly disadvantages the possibly damaged parties in comparison to the possibly discriminating actor. A measure to remedy discrimination concerns with legal unbundling can therefore be to allocate the burden of proof with the network operator. In Germany, for example, the network operator has to justify unequal treatment with regard to network access and proof that its behaviour has been non-discriminatory (Bundeskartellamt, 2001). The line of argument is that the network operator is better informed and generally suspected of discrimination especially when negating access to its network or charging unusually high prices. The European Commission proposed a similar approach in its white paper on damages actions for breach of the EC antitrust rules (Cook, 2008; EC, 2008). Applied to network operation, this could imply that network operators are under continued threat. If it is indeed difficult to prove discrimination or non-discrimination, they might find it favourable themselves to opt for an independent system operator structure to avoid unnecessarily high cost if customers claim damages from discrimination.

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[22] The same could be true for customers: preferential treatment of customers of the affiliated retailer in case of curtailments or control actions. However, stakes are small at the retail stage compared to generation.

4.3 Independent System Operation

An ISO allows centralized coordination while ensuring non-discrimination for all actors. At the same time it avoids complex behavioural and informational separation prescriptions. The ISO is the responsible party to physically manage the system implementing market outcomes as far as possible, give feed back on physical constraints, and assure balancing. The ISO model allows network owners to engage in the generation business. This can be a new and attractive business opportunity[23] but it could also enable efficiency gains from coordinated investment in lines and generation.[24] Furthermore, system operation can be combined with the information function in smart grids.

Obviously the information infrastructure is a vital component in smart grids. Especially decentralized approaches towards control reinforce the demand on information and communication across the system. This is likely to generate extensive data flow. These data are on the one hand price information flowing to consumers and thereby informing them about system conditions. On the other hand it is information about current status of generation, load, substations, other system components, or the system conditions such as voltage or frequency. In the simplest case diverse users could jointly use one common information infrastructure for diverse purposes: network information, demand side management, virtual power plants, and smart metering (WIK *et al.*, 2006, p. 121).

Importantly, such an information grid, similar to the electrical grid, needs to be operated independently with regulated, non-discriminatory access to information to prevent competitive distortions. A key point to contain the discrimination incentives is the neutrality of the information entity. Since this is also a key requirement for system operation, the idea lies near to combine both functions and give the information function to an independent distribution system operator. An ISO can bundle information handling with system operation which requires extensive and largely similar information. This combination extends the idea of Künneke & Fens (2009) who proposed a central independent agent for information processing. Such centralization re-simplifies the information streams that have diversified dramatically during restructuring. Künneke & Fens (2009) assumed ownership unbundling plus an independent information entity. An ISO solution further simplifies the structure by combining system operation and information tasks and avoids the duplication of information infrastructure. It also secures the access to the relevant data for the system operator which is important on reliability grounds.[25]

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[23] Traditionally, in Germany many municipal utilities did not own a lot of generation capacity but examples show that this might change. EWE (after takeover in 2009 including SWB), Stadtwerke München, and MVV, three of the bigger utilities after the ‘big four’, all invest in renewable energy projects, CHP, and smart grids, and position themselves as innovative, forward looking, and environmentally conscious companies (SWM, 2008; MVV, 2010; EWE, 2010).

[24] With this line of argument, unbundling regulation in New Zealand was loosened for distribution network operators (MED, 2006).

[25] Furthermore, information handling needs to fulfill requirements on data privacy and se-

Obviously, an important precondition for a functional ISO solution is that it has the correct incentives to optimize the system and behave neutral towards all participants. The ISO can for example be created as club solution or as completely independent entity (Brunekreeft *et al.*, 2007). Details are likely to matter when creating such entities which is an important topic for future research.

The club solution for example is known from the US in the service areas of PJM and New England-ISO (Brunekreeft *et al.*, 2007). The club consists of all different stakeholders: network owner, generators, traders, and customers. They elect a board of independent representatives; hence their impact is only indirect. However, such a concept could conflict with current EU legislation that prohibits significant cross-involvement in network and generation (respectively retail) activities. Hence, the participation of these actors in board elections may be problematic.

Standards for data format, information handling, and transfer protocols are another important requirement to assure easy and system wide exchange.[26] It is self-evident, that the process of standard setting bears large potentials to distort competition and hence needs to be neutral. The European Union has recognized the importance of standardization and pushes for their development and implementation (EC, 2011, p. 6).

5 Conclusions

Smarter network and system management improve the integration of intermittent renewable generation and flexible demand. Smart grids are therefore considered essential for the rapid decarbonization of the electricity system needed to fight climate change.

Smart grids develop their full potential of advanced system management if they integrate the whole supply chain. Importantly, in a liberalized and unbundled market no actor has an inherent interest to optimize the whole system. Theoretically, an adequate price system could set incentives such that the system is optimized based on decentral decisions. However, this might be difficult in practice, because of transaction costs and infeasibilities to implement full cost-reflectivity. More importantly, in electricity certain critical technical functions such as system balancing require central control even if large parts of system coordination can be realized in a market. Therefore, a central coordinating operator is needed.

The problem of decentralization does not uniquely lay in unbundling, but rather in sector liberalization and the increasing competition which is beneficial. Hence, the argument cannot be to reverse unbundling as this does not solve the problem.[27] Rather, smart grids reinforce the need for unbundling because of

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curity (for more information see e.g. McDaniel & Smith (2009)).

[26] Standards also benefits competition in the markets related to metering and information software and hardware as the product and services become more homogeneous.

[27] Strbac (2002) even argues that DG inevitably leads to unbundling and a changing role of

discrimination concerns. A governance structure is needed to balance both discrimination concerns and coordination need.

Tapping the full potential of smart grids is considered to require some delegation of control for efficient system management. Capturing network benefits of demand side management e.g. requires allocating control to the network operator. This speaks in favour of central control approaches because differentiated retail tariffs alone are not suited to induce the desired effects as long as they do not incorporate a network component. However, central control concepts incur discrimination potential and therefore increase the need for effective unbundling. The network in its enabling function for DG and competition in generation and supply should therefore be operated independently.

Given these characteristics of smart grids, independent system operation seems to be the most adequate unbundling concept for distribution networks. The question how to address interconnector investments, which is a significant concern of ISOs at transmission level, is irrelevant in distribution. Therefore, the argument against ISOs, the necessity of the problematic deep ISO solution, falls away and incumbent network firms could even retain investment authority. No ownership unbundling is necessary to achieve the goals of unbundling. Furthermore, an independent distribution system operator can perfectly be combined with the information function that is central to smart grids. Hence, the ISO simultaneously addresses discrimination concerns and coordination requirements and could fulfill the challenge of bringing more active management to distribution networks.

Importantly, the governance structure of the ISO is another important issue which should be addressed in further research. The key of an ISO clearly is the independence of network operation, hence the immediate question is: how is the ISO owned and controlled? But it is not yet sufficiently clear how an ISO for smart grids should optimally be structured and what its tasks should be. An ISO can for example be created as a club solution representing all different stakeholders or as completely independent entity (Brunekreeft *et al.*, 2007). Critically, such a concept needs to fit with EU requirements that limit cross-involvement in network and generation (respectively retail) activities.

References

Ackermann, Thomas. 2004. *Distributed Resources in a Re-Regulated Market Environment.* Ph.D. thesis, KTH, Stockholm.

Baldick, Ross, & Kahn, Edward. 1993. Network Costs and the Regulation of Wholesale Competition in Electric Power. *Journal of Regulatory Economics*, **5**(4), 367–384.

Balmert, David, & Brunekreeft, Gert. 2010. Deep ISOs and Network Investment. *Competition and Regulation in Network Industries*, **1**, 27–49.

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the network operator.

BDEW. 2011. *Abschätzung des Ausbaubedarfs in deutschen Verteilungsnetzen aufgrund von Photovoltaik- und Windeinspeisungen bis 2020. March 30, 2011.*

Beard, T. Randolph, Kaserman, David L., & Mayo, John W. 2001. Regulation, Vertical Integration and Sabotage. *The Journal of Industrial Economics*, **49**(3), pp. 319–333.

Bertram, Geoff. 2006. Electricity Market Reform: An International Perspective. Elsevier, Oxford.

Brandstätt, Christine, Brunekreeft, Gert, & Friedrichsen, Nele. 2011. Locational Signals to Reduce Network Investments in Smart Distribution Grids: What Works and What Not? *Utilities Policy*, **in press**.

Brunekreeft, Gert. 2008. Eigentumsentflechtung, deep-ISO, der dritte Weg – wohin führt die Reise der Europäischen Energiemärkte. *Zeitschrift für Energiewirtschaft*, **3**, 33–42.

Brunekreeft, Gert, & Friedrichsen, Nele. 2010. *Vertical Unbundling, the Coordination of Investment, and Network Pricing.* Bremen Energy Working Paper No. 03, Jacobs University Bremen/ Bremer Energie Institut.

Brunekreeft, Gert, Neuhoff, Karsten, & Newbery, David. 2005. Electricity Transmission: An Overview of the Current Debate. *Utilities Policy*, **13**(2), 73–93.

Brunekreeft, Gert, Balmert, David, & Gabriel, Jürgen. 2007. Independent System Operators - ein Überblick. *Bremer Energie Institut.*

Bundeskartellamt. 2001. *Bericht der Arbeitsgruppe Netznutzung Strom der Kartellbehörden des Bundes und der Länder über 1. die Reichweite der kartellrechtlichen Eingriffsnormen für die Überprüfung der Höhe der Entgelte für die Nutzung der Stromnetze 2. die kartellrechtliche Relevanz von den Netzzugang behindernden Verhaltensweisen der Stromnetzbetreiber.* Tech. rept. Bundeskartellamt - Federal Cartel Office.

Coase, Ronald H. 1937. The Nature of the Firm. *Economica*, **4**(16), 386–405.

Coase, Ronald H. 1960. The Problem of Social Cost. *The Journal of Law and Economics*, **3**, 1–44.

Coll-Mayor, Debora, Paget, Mia, & Lightner, Eric. 2007. Future Intelligent Power Grids: Analysis of the Vision in the European Union and the United States. *Energy Policy*, **35**(4), 2453–2465.

Cook, Christopher J. 2008. Private Enforcement of EU Competition Law in Member State Courts: Experience to Date and the Path Ahead. *Competition Policy International*, **4**(2).

Cordis. 2009. http://cordis.europa.eu/fp7/energy/open-topics_en.htmlopen-topics-table.

DoE. 2009. *Smart Grid System Report*. Tech. rept. United States Department of Energy Office.

EC. 2006. *Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC*. Tech. rept. European Commission.

EC. 2007. *Report on Energy Sector Inquiry SEC(2006)1724, 10 January 2007*. Tech. rept. European Commission, DG Competition.

EC. 2008. *White Paper on Damages Actions for Breach of the EC Antitrust Rules*. Tech. rept. European Commission.

EC. 2009a. *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*. Tech. rept. European Commission.

EC. 2009b. *Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC*. Tech. rept. European Commission.

EC. 2009c. Legislation: Acts Adopted under the EC Treaty/Euratom Treaty whose Publication is Obligatory. *Official Journal of the European Union*, **52**, 1–136.

EC. 2011. *Smart Grids: from innovation to deployment, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, SEC(2011) 463 final*. Tech. rept. European Commission.

Egyedi, Tineke M., Vrancken, Jos L.M., & Ubacht, Jolien. 2007. Inverse Infrastrucutres: Coordination in Self-Organizing Systems. *Pages 23–35 of: 5th International Conference on Standardization and Innovation in Information Technology (SIIT 2007). University of Calgary, Canada, P. Feng, D. Meeking & R. Hawkins (eds.).*

EWE. 2010. *Information on the corporate website.* http://www.ewe.com/konzern/profil.php; http://www.ewe.com/konzern/energie.php. last access 14.06.2010.

Granger Morgan, M., Apt, Jay, Lave, Lester B., Ilic, Marija D., Sirbu, Marvin, & Peha, Jon M. 2009. The Many Meanings of Smart Grid. *EPP Policy Brief, August.*

Hinterberger, Robert, & Kleimaier, Martin. 2010. Die intelligenten Gasnetze der Zukunft: Herausforderung und Chance für die Gaswirtschaft. *DVGW Energie & Wasser Praxis*, **6**, 32–37.

Hogan, William W. 1992. Contract Networks for Electric Power Transmission. *Journal of Regulatory Economics*, **4**(3), 211–242.

Joskow, Paul. 2008. Lessons Learned From Electricity Market Liberalization. *The Energy Journal, Special Issue. The Future of Electricity: Papers in Honor of David Newbery.*, 9–42.

Joskow, Paul, & Schmalensee, Richard. 1983. *Markets for Power: An Analysis of Electric Utility Deregulation.* MIT Press.

Kaserman, David L., & Mayo, John W. 1991. The Measurement of Vertical Economies and the Efficient Structure of the Electric Utility Industry. *The Journal of Industrial Economics*, **39**(5), 483–502.

Kiesling, L. Lynne. 2009. *Deregulation, Innovation and Market Liberalization – Electricity Regulation in a Continually Evolving Environment.* Routledge Studies in Business Organizations and Networks.

Knieps, Günter. 2006. Electricity Market Reform: An International Perspective. Elsevier, Oxford.

Kok, Koen. 2010. Multi-Agent Coordination in the Electricity Grid - from Concept towards Market Introduction. *In: 9th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2010), May, 10-14, 2010, Toronto, Canada, van der Hoek, Kaminka, Lespérance, Luck & Sen (eds.).*

Kruimer, Hannah. 2010. Non-discriminatory Energy System Operation: What Does It Mean? *Competition and Regulation in Network Industries*, **12**(3), 260–286.

Künneke, Rolf W., & Fens, Theo. 2009. Towards an Information Architecture in Unbundled Energy Distribution Networks. *In: Unecom Workshop Brussels.*

Künneke, Rolf W., Groenewegen, John, & Ménard, Claude. 2010. Aligning modes of organization with technology: Critical transactions in the reform of infrastructures. *Journal of Economic Behavior & Organization*, **75**, 494–505.

Kwoka, John E. 2002. Vertical Economies in Electric Power: Evidence on Integration and Its Alternatives. *International Journal of Industrial Organization*, **20**, 653–671.

Li, Furong. 2007. The Benefit of a Long-run Incremental Pricing Methodology to Future Network Development. *In: IEEE Power Engineering Society General Meeting, 24-28 June 2007, Tampa, Florida USA.*

McDaniel, Patrick, & Smith, Sean W. 2009. Security and Privacy Challenges in the Smart Grid. *Security & Privacy, IEEE*, **3**, 75–77.

MED. 2006 (April). *Investment in Electricity Generation by Lines Companies*. Ministry of Economic Development New Zealand.

Meyer, Roland. 2011. *Vertical Economies of Scope in Electricity Supply – Analysing the Costs of Ownership Unbundling*. Ph.D. thesis, Jacobs University, School of Humanities and Social Sciences.

Miller, Gary. 2005. Solutions to Principal-Agent Problems in Firms. *Pages 349–370 of:* Ménard, Claude, & Shirley, Mary (eds), *Handbook of New Institutional Economics*. Springer US. 10.1007/0-387-25092-1_15.

MVV. 2010. *Strategy*. http://www.mvv-investor.de/de/wir-ueber-uns/konzern/strategie.php. Information in the investor relations section of the website. last access: 17.06.2010.

Nemoto, Jiro, & Goto, Mika. 2004. Technological Externalities and Economies of Vertical Integration in the Electric Utility Industry. *International Journal of Industrial Organization*, **22**(1), 67–81.

Niesten, Eva. 2010. Network Investments and the Integration of Distributed Generation: Regulatory Recommendations for the Dutch Electricity Industry. *Energy Policy*, **38**, 4355–4362.

NMa. 2007. *Onderzoeksrapport inzake de interne verrekeningsprijzen van energiebedrijven,*. Tech. rept. Nma, Den Haag.

Ofgem. 2007a. *Decision on the Long Term Development Statements (LTDs) for Electricity Distribution Networks - Decision Letter*. Tech. rept. Office of Gas and Electricity Markets.

Ofgem. 2007b. *Form of Long Term Development Statement*. Tech. rept. Office of Gas and Electricity Markets.

Ofgem. 2010. *Press Release 26 July 2010: Ofgem Reengineers Network Price Controls to Meet £32 billion Low Carbon Investment Challenge*.

Perry, Martin K. 1989. Vertical Integration: Determinants and Effects. *Chap. 4, pages 183–255 of:* Schmalensee, Richard, & Willig, Robert (eds), *Handbook of Industrial Organization*. Handbook of Industrial Organization, vol. 1. Elsevier.

Piccolo, Antonio, & Siano, Pierluigi. 2009. Evaluating the Impact of Network Investment Deferral on Distributed Generation Expansion. *Power Systems, IEEE Transactions on*, **24**(3), 1559–1567.

Pielow, Johann-Christian, Brunekreeft, Gert, & Ehlers, Eckart. 2009. Legal and Economic Aspects of Ownership Unbundling in the EU. *Journal of World Energy Law & Business*, **2**(2), 96–116.

Prica, M., & Ilic, M.D. 2007. Optimal Distribution Service Pricing for Investment Planning. *Pages 1–7 of: IEEE Power Engineering Society General Meeting, 2007.* Citeseer.

Pudjianto, D., Ramsay, C., & Strbac, G. 2007. Virtual Power Plant and System Integration of Distributed Energy Resources. *IET Renewable Power Generation*, **1**(1), 10–16. M3: Article.

Schmidt-Preuss, Matthias. 2009. OU - ISO - ITO: Die Unbundling-Optionen des 3. EU-Liberalisierungspakets. *Energiewirtschafltiche Tagesfragen*, **59**(9), 82–88.

Schweppe, Fred C, Tabors, Richard D, Caramanis, Michael C, & Bohn, Roger E. 1988. *Spot Pricing of Electricity.* Kluwer Academic Publishers, Norwell, MA.

Sioshansi, Fereidoon P., & Pfaffenberger, Wolfgang. 2006. Electricity Market Reform: An International Perspective. Elsevier, Oxford.

Stevenson, Toby. 2004. *Mass Market Load Control - Its Use and Its Potential Use. Report prepared for the Energy Efficiency and Conservation Authority New Zealand.*

Strbac, Goran. 2002. Impact of Dispersed Generation on Distribution Systems: A European Perspective. *In: IEEE Power Engineering Society Winter Meeting, 2002*, vol. 1.

Strbac, Goran. 2008. Demand Side Management: Benefits and Challenges. *Energy Policy*, **36**(12), 4419–4426.

SWM. 2008. *Energiekonzept 2030 der Stadtwerke München GmbH.*

Talus, Kim, & Johnston, Angus. 2009. Comment on Pielow, Brunekreeft and Ehlers on 'Ownership Unbundling'. *Journal of World Energy Law & Business*, **2**(2), 149–154.

Veldman, Else, Geldtmeijer, Danny A.M., Knigge, Joris D., & Slootweg, J.G.(Han). 2010. Smart Grids Put into Practice: Technological and Regulatory Aspects. *Competition and Regulation in Network Industries*, **3**, 287–306.

Wachovius, Martin. 2008. *Ownership Unbundling.* Frankfurt: VWEW Energieverlag GmbH.

WIK, Fraunhofer ISI, & Fraunhofer ISE. 2006. *Potenziale der Informations- und Kommunikations-Technologien zur Optimierung der Energieversorgung und des Energieverbrauchs (eEnergy).* Tech. rept. Studie für das Bundesministerium für Wirtschaft und Technologie (BMWi).

Williamson, Oliver E. 2000. The New Institutional Economics: Taking Stock, Looking Ahead. *Journal of Economic Literature*, **38**(3), 595–613.