Opening the Electricity Market to Renewable Energy —Making Better Use of the Grid

by Karsten Neuhoff

Opening the electricity market to renewable energy sources would create flexibility for the further integration of renewable energy, leading to considerably lower costs and emissions. This requires the electricity markets to be reorganized in three ways.

Firstly, most trading, and therefore production decision-making, is completed at least one day prior to electricity production. But it must be possible to make adjustments on shorter timescales, in order to effectively utilize wind forecasts, which are only relatively accurate a few hours ahead of production.

Secondly, demand for operating reserve to stabilize the grid varies with the uncertainty of forecasts for wind and other generation. Most power plants can offer operating reserve, but only together with electricity. At present, however, operating reserve is traded separately from electricity, often in long-term contracts. And thirdly, network operators generally compensate market participants for grid constraints. But with around 200 GWs of new wind and solar capacity being built by 2020, grid expansion must be combined with transparent, market-based congestion management.

The introduction of an independent system operator offering an integrated platform for short-term power trading using a pricing system that internalises network constraints (»nodal pricing«) could meet these conditions, allowing further openings of the power market for renewable electrical energy. Experience in the US and simulations for Europe show that international transmission capacity is up to 30% better utilized, congestion management alone yielding annual savings of 1 - 2 billion euros.

The deregulated electricity market was designed with conventional power generation in mind, but the requirements are changing with the rise of renewable energy.

Wind and solar energy production is dependent on weather conditions, which cannot be accurately predicted. It must thus be possible to coordinate with other power plants‘ production on short notice, i.e. up to only a few hours prior to delivery. The shorter time horizon is accompanied by a spatial challenge stemming from the fact that wind and solar power plants are connected to a network already being used by conventional power plants. Transmission capacity must now be flexibly allocated and expanded where production is concentrated.

In planning for the evolution of the electricity market, both the temporal and the spatial dimensions must be simultaneously taken into account. European national action plans for renewable energy envisage 200 GW of additional wind and solar capacity by the year 2020. It is not economically, environmentally or politically viable to expand networks to such an extent that transmission constraints never occur. Instead, what is important is to efficiently expand the grid while simultaneously implementing effective congestion management.

Integration of renewable energy poses new challenges

Energy production using coal, nuclear fuel and gas can be planned over the long term. Most output is traded no later than at the auction on the day before production; which has proven an appropriate practice in the past. The situation is different with wind power, however, as weather and wind forecasts are rather imprecise. Taking Spain as an example, Figure 1 shows that forecasts are considerably more accurate up to four hours ahead of real time. While forecasting has generally improved, inaccuracies cannot be eliminated, even in Germany[1].

Wind turbine operators and their representatives thus would like to trade power a few hours prior to production, but the previous day's central electricity auction is already over.

If wind forecasts indicate lower wind power generation versus the day-ahead forecasts, conventional power plants need to increase their own production accordingly. This considered, there are three reasons why in today's market the most suitable, cost-effective power plants are not always used.

- *Fragmentation*: In most cases, production only has to be adjusted for a few hours at a time to meet demand. Power plants need to be able to start up or increase production in exactly that period. But in the bilateral intraday market, plants with the right location and availability are relatively hard to find.
- *Participation*: Not all conventional power plants able to supply surplus electricity have a trading department that is open 24 hours a day.
- *Transparency*: Electricity prices in short-term bilateral trading are difficult for small suppliers and competition regulators to monitor, as prices in bilateral trading include a variety of costs not limited to fuel costs, but also a margin covering fixed costs and costs for power plant start-up and adjustments.

Reduction of power plant overcapacity and rising demand for flexible production are increasing the opportunities and incentives for participants to exercise market power. In the bilateral intraday market, it is however difficult to verify whether a power plant has offered all options for producing on short notice or adjusting production while offering a 'fair' price for the output.

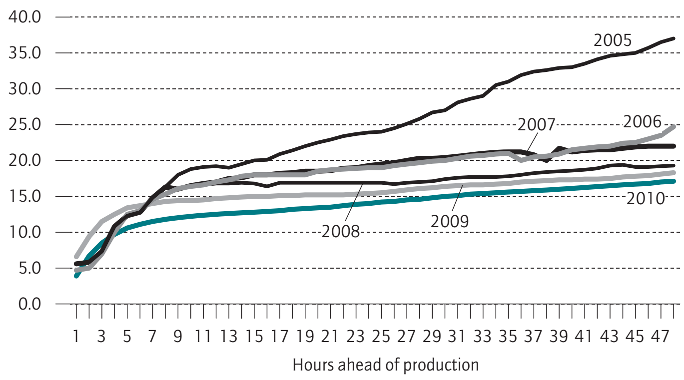
In the past, most renewable electricity in Germany has been produced in accordance with the German Renewable Energy Sources Act (EEG), and thus was marketed by transmission network operators –until 2008 all expected wind output was sold in the day-ahead power exchange, and since 2009 in short-term intraday trading as well. This has increased liquidity in intraday trading[2].

The next step proposed for the EEG by the German government is to offer renewable electricity producers the option to receive a variable market premium instead of fixed compensation when they market their own power[3]. This premium charge is to be passed on to the consumer, and gives plant operators a business incentive to effectively market their electricity. However, the optional premium model does not solve the fundamental problems with short-term trading (fragmentation, participation and transparency) or grid problems: they are only partially alleviated.

Figure 1

Average wind forecast error for Spain

In percent



Source: Based on data from Red Eléctrica de España, SA, error calculation for 2009/2010 adjusted, thus no direct comparability.

Just a few hours ahead of production, the wind forecasting error rate falls below 10%.

The key role of the independent system operator

Platform for short-term energy trading

In most deregulated electricity markets in the US, an independent system operator (ISO) has been introduced who conducts the central auction on the day prior to electricity delivery. Specific power plant characteristics may also be stated (such as plant start-up duration and cost, minimum and maximum electricity production and adjustment period).

The auction outcome corresponds initially with previous-day electricity European exchange trading. However, the ISO retains the supply parameters for the remaining hours until delivery. The auction outcome is upda-

1 Dena Grid Study II – Integration of renewable energy into the German electricity network in the period from 2015-2020 with a view to 2025), Berlin 2010.

2 Weber, C. (2010): Adequate intraday market design to enable the integration of wind energy into the European power systems. Energy Policy no. 7, 3155–3163.

3 German government (2011): Report on Renewable Energy Sources Act, Federal Government draft, Version 03.05.2011.

ted to reflect any short-term changes in production and demand. All supply offers can still be included (participation) and specific power plant characteristics taken into account (fragmentation). Transparency is created by separately listing the cost components of offers and the operational requirements, and the ISO conducts the auction according to a clearly defined algorithm. Market participants benefit from this approach, as they are paid for all adjustments versus the previous day's auction outcome, while electricity consumers benefit from the algorithm's day-ahead and intraday optimization across the entire power system that lowers costs[4].

Combined trading of energy and operating reserve

Separate marketplaces were introduced in Germany upon deregulation of the electricity sector. Electricity supply firms buy electricity from power plants to meet their own customers' demand, and transmission network operators pay power plants for providing operating reserve (Box 1). This reserve power is utilized to balance out real-time fluctuations in production and demand.

In the past, power plants have sold energy and operating reserve separately and to different groups of buyers. This worked as long as it was possible to plan and coordinate coal, gas and nuclear energy production over the long term. If it is known which power plants are producing what amount of electricity, it is clear who is able to provide operating reserve. A wind farm can only do this when the wind is blowing. Therefore, it cannot sell operating reserve over a long-term period.

With electricity production from wind and sun increasing, conventional power plants must adjust their production to the supply situation on a more short-term basis, making the power system less predictable. Providing operating reserve thus becomes more complicated. If, on the other hand, electricity and operating reserve can be traded together on a short-term basis, all technologies can play a role in providing system services, thus reducing costs and emissions[5].

Optimal provision of operational reserve

The volume of operational reserve required is not fixed but depends on the current state of the system. For example when wind speeds are high, the probability that local wind speeds exceed the limit of wind turbines and they are shut down increases. Operating reserve can only be efficiently provided when the amount is determined on short notice based on information about the status of all power stations[6].

Box 1

Operating reserve

Operating reserve is utilized to ensure that electric power supply always precisely matches electricity demand. It is used to balance out the effects of short-term power plant failures, fluctuations in demand and load or wind forecasting inaccuracies. There are three types of operating reserve, reflecting the technical capabilities of traditional technologies:

- Primary operating reserve is available within 30 seconds for a period of 15 minutes. It can be produced by all major thermal power plants by exploiting the inertia in a steam cycle and temporarily heightened steam production.
- Secondary operating reserve is available within five minutes, for a minimum period of 60 minutes. It is provided by starting up rapid output generation plant such as pumped storage power stations and gas turbines, or by increasing the output of power plants already running at below capacity.
- Tertiary operating reserve is available within 15 minutes. The longer warning time allows including different types of power plants and power buyers, usually by notifying industrial firms by telephone.

Many renewable energy sources and demand side response can provide operating reserve both rapidly and over an extended period of time. However, they have to restrict their supply of operating reserve to categories/rules defined for conventional power plants. This reduces the amount they are able to supply to the power system, and for which they are paid (if not covered by the EEG).

Additionally, bids by transmission network operators for primary and secondary operating reserve apply for a whole month. This prevents wind energy from participating, as it will not be able to provide operating reserve when there is no wind.

4 Muesgens, F., Neuhoff, K. (2002): Modelling Dynamic Constraints in Electricity Markets and the Costs of Uncertain Wind Output, EPRG Working Paper Series 0514; TradeWind (2009): Integrating Wind. Project report for the trade-wind study coordinated by the European Wind Energy Association 2009.

5 Smeers, Y. (2008): Study on the general design of electricity market mechanisms close to real time. Study for the Commission for Electricity and Gas Regulation (CREG).

6 EWIS (2010): European Wind Integration Study – Towards a successful integration of wind power into European Electricity Grids. ENTSO-E Premises, March 2010.

Transmission network operators, however, only have limited information on the status, the operational schedule of power plants and on neighbouring networks. Accordingly, it is difficult for them to optimize their provision of operating reserve.

Defining new categories of operating reserve

The ability to market new energy and system services is essential in opening the market to new technologies. Wind turbines, battery storage and demand management have completely different reaction times and operating periods compared to »traditional« types of operating reserve. However, they still have to serve the rigid auction formats matching traditional categories.

The integrated auction mechanism for energy and operating reserve used by ISOs allows the flexible formulation of specific technical options. In turn, this allows new technologies to be contracted and remunerated according to technological ability, boosting the incentives for innovation and investment.

Enhancing competition in trade

ISOs play a clearly defined role in providing a platform for day-ahead and intraday energy trading, but are not involved in longer-term energy trading. This allows for competition among trading platforms to host trades of longer-term energy products.

To implement market coupling between countries, one power exchange from each country is linked to the international clearing mechanism. This power exchange thus becomes the preferred place for short-term trading. The price on the power exchange is usually taken as a reference value for trading of derivatives, thus creating an incentive to also trade derivatives on the same platform and reducing competition with other trading platforms.

European markets too inflexible in the short term

The discussion up to now has shown some of the challenges in integrating renewable energy that have resulted from the current market design. An ISO may lend flexibility to a platform for short-term trade in energy and operating reserve. This becomes apparent by comparing selected countries according to the following criteria:

- Efficient use of power plants: Would this optimize production across power plants towards an efficient provision of energy and system services?
- Demand adjustment in operating reserve: Would operating reserve energy storage be adjusted for system requirement?
- Power plant flexibility: Can power plants trade energy in flexibly defined blocks of several hours (fragmentation)? The past saw predefined blocks of hours formed for trading in day and base load. Wind power does not follow these rigid structures.
- International market integration: Can energy and operating reserve be sourced from other countries on short-notice, and is the market compatible with congestion management?
- Transparency: Is there enough transparency for effective market supervision? This is especially important in short-term markets as they are predestined for exercising market domination for three reasons: First, the number of market participants is small - often only a few power plants offer the necessary flexibility and are in a suitable operating mode at appropriate locations. Second, production in hydro-electric power and conventional power plants changes with the production from wind and solar power. This will reduce the share of power output that already is committed based on long-term contracts, and increases the importance of short-term trading. Without coverage of output by long-term contracts, the most important mechanism in reducing incentives to exercise market power breaks. Third, the cost structures of the power stations bids are difficult to determine as they can reflect stand-by, start-up, and adjustment costs and can include the scarcity value.

A functional market that fulfils these criteria ensures fair power prices for final customers and reduces the costs of integrating wind and solar power, while promoting market opportunities for small suppliers that cannot optimize within the portfolios provided by power plants.

Qualitative evaluation in Figure 2 shows that the current electricity market does not provide the flexibility required for effectively integrating renewable energy. Fulfilling individual criteria is not enough – an integrated solution is required. The market model with an ISO, as introduced in most of the liberalized US markets, fulfils these new requirements. The comparison assumes that the ISO – as is the case in US examples – provides the platform for the short-term energy market.

Three factors explain the good results that this model shows. First, the ISO carries unequivocal responsibility for the system. Second, an independent system operator has all of the major information on the system and holds the responsibility for implementing efficient and safe system operation. The ISO uses a uniform auction

Figure 2

Market comparison for operating reserve and short-term energy trading

	Dispatch adjusted during day	Balancing requirements during day	Flexible use of conventional power stations	International integration of markets	Effective monitoring of market power
UK system	◔	◔	◔		◔
German system	◑		◔	◔	◔
Nordpool	◑	◑ (grey)	◔	◑	◔
Spanish system	●	◑	●		◑
ISO with nodal pricing	●	●	●	◕	●

Source: Borggrefe, F., Neuhoff, K. (2011): Balancing and Intraday Market Design: Options for Wind Integration, www.climatepolicyinitiative.org.

The European markets do not do justice to requirements with regard to integrating renewable energy.

platform that takes every bid from market players to find an ideal market solution across the system. Third, the clearing algorithm in the auction platform represents the technical reality of the electricity system. Most US regions with liberalized electricity markets have since switched to this market model combining an ISO with nodal pricing after its introduction in the integrated electricity markets of Pennsylvania, New Jersey and Maryland (PJM) in 1998.

Network congestion gaining relevance in the electricity market

Up to now, electricity has been traded on a nationwide wholesale basis at a uniform electricity price in Germany. This uniform price zone may turn out to be a serious challenge to the energy revolution. Producers and traders may freely choose where to supply electricity to the grid and where to draw electricity from the grid. This leads to situations where the planned electricity transmission is greater than the transmission capacity of the grid. Intervention is required from the network operator in order to ensure network stability. The operator pays the power plants contributing to the grid overload to reduce electricity production and conversely, pays power plants in other regions to replace the electricity (known as redispatching).

There are historical reasons for the congestion management we have today. European electricity markets were liberalized at the end of the twentieth century, when the electricity companies were vertically integrated. Simple, clear rules were necessary to give competition and new market entrants a chance. As it was difficult for third parties to verify calculations of costs and commercial available transmission capacity of vertically integrated electricity companies, regulators created uniform price zones and rules for international electricity transfers. Constraints within countries were not explicitly represented in the market design. Instead, the dominant companies were required to resolve constraints within their own supply areas. These companies owned almost all of the power plants that both contributed to constraints and were necessary to resolve them, and were thus in a good position to carry out the task.

Unbundling of electricity generation, transmission and distribution has reduced the ability of network operators to resolve constraints by adjusting production in their own power plants. Also more players – including renewable energy – contribute to grid constraints, and have to be included in congestion management. This requires transparent congestion management to solve conflicts between technologies (e.g. feed-in priority according to the German Renewable Energy Sources Act), as well as a credible basis for decisions on extending the network. However, the most important aspect is effective usage of grid capacity for increased inclusion of renewable energy and a secure European electricity supply.

Faced with increasing congestion on the network, costs to resolve transmission constraints and mitigate any risks to grid stability rise with uncoordinated congestion management7. Producers and traders can report their schedules to the network operators up to a quarter of an hour before real time. This gives the network operator a very limited time window to recognize and remedy any possible constraints. To make matters worse, the number of power plants located at suitable grid nodes and are in a position to react within the necessary timeframe is limited. For this reason, transmission system operators retain the right to refuse short-term changes in schedule8. However, this poses a challenge for short-term bilateral energy trade if agreed energy transfers can subsequently not be executed.

However, the alternative of subjecting the transmission system operator to the obligation to carry out all transactions is equally unsatisfactory. As soon as congestion is expected, even small producers in regions of an

7 Improved coordination would not have prevented the reasons for previous blackouts, but would probably have prevented their broad spread (USA and Italy 2003, UCTE 2006. Bialek , J. W. (2007): Why has it happened again? Comparison between the 2006 UCTE blackout and the blackouts of 2003. IEEE PowerTech Conference, Lausanne.

8 Tennet (2011): Bilanzkreisvertrag zwischen TenneT TSO GmbH und BKV (Area supply regulation contract between Tenne T TSO GmbH and BKV), www.tennettso.de, May 4 2011.

export constrained area within a price zone would profit from first selling additional production, and then being paid by the transmission system operator for reducing production. In the autumn of 1998, this caused a failure on the British gas market[9], and was one of the most important factors in the failure of the Californian electricity market in the years 2000/2001. Both cases were triggered by increases in congestion levels.

Increasing constraints in Germany

In the past few years, increased electricity production from wind turbines has increased demands on the German grid. The situation began with a relatively well-developed national grid. The German grid had long since been up to the demands put to it, and the network operators contributed to improved grid capacity utilization with overhead cable monitoring. The years 2009 and 2010 saw two particular events which reduced electricity transmission from northern to southern Germany.

Reduced precipitation led to a reduction of hydro-electric power in Norway, with power imported also from Northern Germany to make up the difference. In addition, two nuclear power plants in northern Germany were out of action for servicing. Even if it is unclear what impact accelerated departure from nuclear energy will have on electricity transmission in Germany, one thing remains certain – investment in wind power in northern Germany will take a disproportionate share of future investment. In general, transmission constraints in Germany will likely undergo a sharp increase. This calls for extension to the grid while introducing appropriate congestion management to use the existing capacity efficiently.

Uniform wholesale price untenable in Germany

An argument that is often raised is that extending the grid to a sufficient extent will be enough to retain the uniform price zone. However, other transmission networks are not placed under such expectations. Capacity on rail, road and in the air usually falls short of demand at peak times. Flight prices, railway contingency ticketing and longer periods spent in traffic congestion often encourage travellers to alter their route or time of travel. In contrast, in the current power market design electricity producers are rewarded for congestion occurring on the network as the transmission system operators – and therefore also the end customer – subsequently pay the producer for adjusting production to resolve these constraints.

Introducing market based congestion management

Initial experience with market-based congestion management on the international electricity markets has been positive in Europe. First, auctions were introduced for transmission capacity between individual countries. Only those that purchase transmission capacity can register for electricity trades between countries. Separate auctions for transmission rights and energy have not yielded an efficient market result – even after years of operation. Therefore electricity markets have been increasingly coupled directly to one another – market players submit their bids for electricity production at their national electricity exchanges. A common algorithm determines the market price in individual countries, and uses the transmission capacity available between the countries to balance out price differences as far as possible. Common optimization across several price zones is referred to as market coupling.

Norway and Sweden often experience transmission constraints between hydro-electric plants in the north and demand in the south. Several price zones have been introduced within the countries for this reason. However, defining price zones within a country proved difficult, even with the simple structure of the Scandinavian supply network[10].

In technical terms, the price zones should be formed in such a way that transmission constraints occur between the zones, where they are solved by market means, rather than by redispatching within a zone. However, the congested lines can change after grid extensions, or with the connection of new power plants or added demand. In each instance new price zones would have to be defined. This is unsettling for investors and dealers, as they have no way of telling whether their trading partner will remain within the same price zone or not. Possible changes in price zones also make it difficult for an ISO (in this case, Nord Pool), to conclude long-term transmission agreements with market players between price zones. This is a challenge to long-term contracting and thus also for investment in generation capacity.

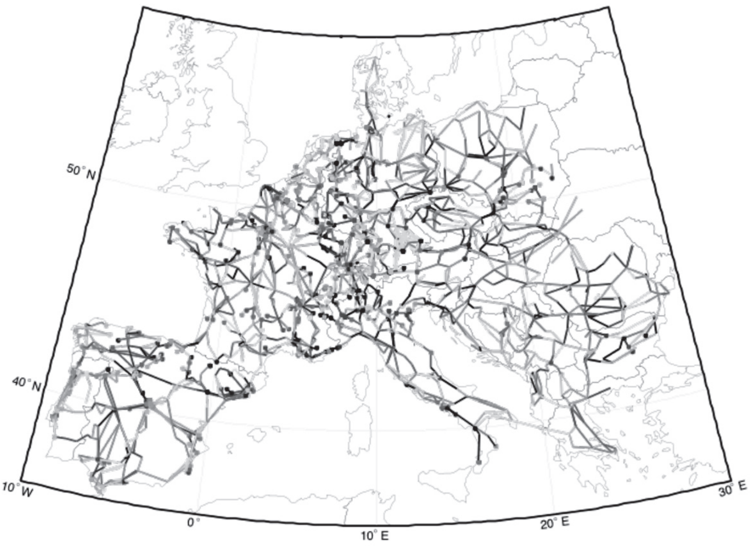
Defining price zones in Europe's continental electricity network is even more difficult. Figure 3 shows how tightly meshed the transmission network is. The simulation represents electricity production in a randomized

9 McDaniel, T., Neuhoff, K. (2003): Auctions to gas transmission access: The British experience. In: M. C. 50W Janssen (Publ.): Auctions and Beauty Contests: A policy perspective. Cambridge.

10 Bjorndal, M., Jörnsten, J. (2007): Benefits from Coordinating Congestion Management – the Nordic Power Market. Energy Policy, 35 (3), 1978–1991.

Figure 3

Line loads – simulation for Europe with 12.5% wind power



Dark lines = heavy load, light lines = less load.

Source: Neuhoff K, and J. Barquin, J. Bialek, R. Boyd, C. Dent, F. Echavarren, T. Grau, C. von Hirschhausen, B. Hobbs, F. Kunz, C. Nabe, G. Papaefthymiou, C. Weber, H. Weigt (2011): Renewable Electric Energy Integration: Quantifying the Value of Design of Markets for International Transmission Capacity, CPI Report. www.climatepolicyinitiative.org.

wind situation assuming extended wind power. The darker lines represent heavier line load. Effective congestion management would prevent overload on individual lines. Many of the constraints have turned out to be within, and not between EU countries[11]. This speaks in favour of introducing price zones within national borders as well.

However, constraints do not only move with new investments, but also with changes in wind or demand situation, as the Scandinavian experience shows. National price zones need to be divided into smaller price zones, but defining them in such a way as to keep them stable is a difficult task. This matches the US experience after liberalizing the integrated electricity markets in Pennsylvania, New Jersey and Maryland (PJM). First, congestion management was only introduced for transmission lines that had often been subject to constraints. However, ever-increasing numbers of lines had to be included since the electricity transmission flow and therefore constraints often changed[12]. This resulted in excessive complexity in trading and operation. For this reason, the market system was transferred to a system of nodal prices as shown in Box 2.

Box 2

Keyword: nodal prices

Nodal prices are used for market-based congestion management. They may be regarded as an extension of market coupling. In today's market coupling systems, electricity auctions take place the day before for each price zone – such as the EEX in Germany and the APX in the Netherlands. The transmission system operators inform the exchanges taking part in the common auction program as to how much transmission capacity will be available between the price zones. The auction mechanism automatically plans for this in order to transfer electricity from price zones with low prices to price zones with higher prices. This leads to a convergence in price, often resulting in a single uniform price.

The more transmission constraints exist in the system, the smaller the price zones become for a uniform price to be applied to. Nodal pricing involves defining an individual price for each network node, typically connection points to the high-voltage network. If there are no constraints, neighbouring prices will still converge.

Usually, an independent system operator (ISO) will be ordered to implement the nodal prices. The ISO may take thermal, voltage and other technical network limitations into account in the auction mechanism. This makes effective and safe network utilization possible. In addition to the financially binding auction price from the previous day, the ISO also conducts several auctions during the course of the current day. This allows optimization across the whole system if forecasts for production and demand should change.

The ISO, usually a not-for-profit body, acts according to clearly defined algorithms and procedures, and can therefore act in the interest of the community without commercial involvement. The ISO only offers a platform for short-term trading, and publishes reference prices. Any longer-term trading will only take place bilaterally or at auctions.

11 EWIS (2010): European Wind Integration Study – Towards a successful integration of wind power into European Electricity Grids. ENTSO-E Premises, March 2010.

12 Hogan, W. (2000): Flowgate Rights and Wrongs. Harvard University.

Nodal pricing is a market-based system of congestion management[13]. Up to now, electricity was only traded in one price zone under market coupling. Transmission system operators inform the electricity exchanges on the amount of transmission capacity available between national price zones. The common auction mechanism in the exchanges uses this information to plan transfers from low-price price zones to high-price price zones, thus also adjusting prices at the same time. Given sufficient free transmission capacity, this will result in a uniform electricity price. The more transmission constraints exist in the system, the smaller the price zones become that a uniform price can be applied to according to the Norwegian model. Nodal pricing involves always defining an individual price for each network node for this reason. If there are no binding constraints, prices in neighbouring nodes will converge.

In the European RE-Shaping Project, several European research organizations have simulated the European electricity system in order to quantify the effect of nodal pricing on the European market. First, the project involved modelling the electricity market with further development of zonal pricing, and the result was compared against a nodal pricing situation. Improvement in network utilization enables an increase of up to 30% in power to be transmitted between different regions. This matches the experience reported in the US on introducing nodal pricing[14]. The simulation results also show that effective network utilization would save annual fuel costs and emission rights by one to two billion euros[15].

Financial transmission rights key to introducing market-based congestion management

Clear definition and allocation of ownership rights are important for economic efficiency. Difficulties arise where ownership rights have been awarded more than once. This will be the case as long as market players are able to lay claim to customary rights to transmission rights unlimited by time or scope. One pragmatic solution could be for financial transmission contracts to be offered instead (Box 3).

Box 3

Keyword: financial transmission rights

Financial transmission rights remunerate the owner for price differences between two zones or nodes in the network. This allows longer-term electricity trading, such as where Power Plant at Node A sells electricity to a customer at Node B at a set price for one year. The power plant would sell electricity from Node A to buy it for the customer from Node B on a daily basis in the auction. The possible price difference – therefore the risk – would be secured by payments from the financial transmission rights.

If the sales price at Node A should fall short of the production costs of the power plant on a certain day, the power plant operator would be given the option of not producing any electricity. This would mean additional profit at the level of difference between the price at Node A and the power generation costs saved. Nodal pricing thus creates an incentive for flexible electricity production while financial transmission rights additionally secure long-term agreements and investments.

Introducing financial transmission rights was a central factor in the success of congestion management on the liberalized US electricity markets; physical transmission rights and other claims on the network were converted into financial transmission rights. This created legal security and acceptance. Financial transmission rights exist for time periods of up to thirty years in the US which protects investments against possible changes in network structure or utilization. A liquid market for financial transmission rights at periods of several years has established itself, which completes the picture in energy trading.

A pragmatic solution using nodal pricing was also found for household electricity supplies in most states. The whole state determines and applies a unified electricity price for households.

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14 Mansur, E. T., White, M. W. (2009): Market organization and efficiency in electricity markets. http://bpp.wharton.upenn.edu/mawhite/.

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