The integration of Wind Power into competitive electricity Markets:

The case of transmission grid connection charges

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Given the new unbundled structure of the electricity industry and the introduction of different forms of competition, new challenges for the development of renewable energy have to be solved. Renewable energy and particularly wind power exerts constraints that have an impact on the reliability of the electricity system. A key issue concerning the integration of wind power into competitive electricity markets is the connection charges to the grid. Wind power units are generally located in remote areas. The cost for their connection could be very high, and so creates an entry market barrier if the wind generator has to bear the total cost of connection. Different approaches concerning the cost allocation exist (i) the deep approach, (ii) the shallow approach and (iii) a hybrid model. The aim of this paper is to assess each of these connection pricing policies in regard of the integration of wind power. We show that to support wind power development, a shallow cost approach seems better because it lowers the entry barriers even if it does not provide the good incentives in term of efficiency. An optimal solution could be the hybrid model but it is an innovative approach that has not yet provided results concerning the development of wind power. In order to shed the light on this issue, three cases are examined: the Denmark and its shallow connection pricing policy, PJM and its strict application of deep connection costs, and England and Wales as an example of hybrid model.

Introduction

For about 15 years, the electricity sector has known a drastic move from a traditional vertically integrated organisational form to a completely new unbundled structure. In most countries the sector was deregulated in order to introduce competition, improve the efficiency and to prevent the inefficient effects of the former monopoly (over-investments). The electricity reform has set different faces depending on the former structure of the sector, the available resources of the country and other different factors like policy or public acceptance. In parallel to this new face of the industry, new cleaner technologies have been developed due

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to the climate change issues. Among these new technologies wind power is likely the most attractive solution. However the development of wind energy faces some difficulties: the variability and unpredictability of wind make wind power non-dispatchable; the wind farms locate far from the load centre and impose new constraints for the grid management due to the distance and the technical characteristics of wind turbines, the cost of generation from a wind turbine is higher than the cost of generation from a conventional unit even if this cost tends to decrease thanks to innovation and improvements of wind turbine design. Nevertheless these constraints have to be integrated to new unbundled market originally designed for conventional generators.

The liberalisation of the electric sector has not changed the physical constraints of electricity which govern a reliable transmission network operation. The network must satisfy the physical laws concerning the frequency, voltage and stability. It must be well coordinated with the interconnected networks (Denmark is interconnected with Norway, Sweden and Germany). Furthermore the network has to provide operating reserves to respond to uncertain demand and supply (variability of wind) and meet the requirement of balancing both. Nonetheless the liberalisation of the sector has changed the organisation of the power sector and has involved new tools for the management of the grid keeping in mind that the new market has to be competitive. The introduction of new technologies adds a new variable to be managed by the network operator.

Considering the constraints of wind power integration the issue of transmission access and pricing seems to be one of the key factors of the development of wind power into a competitive electricity market. The wind farms are typically located in remote areas and the cost of connecting these wind farms could be high and particularly if the connection to the grid of wind farms involve reinforcements and upgrades of the transmission or/and distribution grids. The rules applied to the connection have to be in conformity with the competition requirements. Depending on the share of theses costs born by the wind producer, the integration of wind power can be either facilitate or worsen. That is why the choice between different rules of transmission connection pricing is a key factor for a generator.

The aim of this paper is to assess the different possible ways of transmission connection pricing and their impact on the integration of wind power into competitive electricity markets. The outline of this article is organised as follows. The section 1 gives an overview on the transmission pricing principles by answering this question: who has to bear the cost of the connection and to what extent? The section 2 presents three case studies of transmission grid management: the case of Denmark which applies a strict shallow cost approach, PJM which represents the case of deep connection charges and then the United-Kingdom, particularly the case of England & Wales which tends to adopt a hybrid approach.

I. Allocation of Transmission Connection charges

This segment of transmission network contains two main approaches: the deep cost basis and the shallow cost basis. The deep cost analysis means that the producer has the burden of all the costs for connecting and improving the grid. The shallow cost approach allocates just the cost of connecting to the grid, whereas the other costs (improvement, upgrading) are socialised through the use of system charges. Hybrid models exist that try to keep advantages from both methods. The connection charge has to be differentiated from the Use of System charge. The first concerns only the connection to the transmission or distribution grid; it serves to recover the costs involved in providing the assets which afford connection of a user to the transmission system; this cost could be paid once at the beginning of the operation or paid each year of the life time of the assets. The second concerns only the use of transmission grid; it covers the costs of providing and maintaining transmission assets and balanced system. It could include: infrastructure costs, operation and maintenance, system operation costs, administrative costs, losses, ancillary services, congestion management and other costs depending on the choice of rules. For our purpose we will focus on connection costs and just have a look on use of system charges if connection charges are socialised through network users (case of shallow connection charges).

Each of these policies – deep, shallow or hybrid - impacts the development of wind power. They could be seen as mechanisms required improving the efficiency of renewable energy support policy. In this section we will provide an assessment of each policy in regard of the wind energy development.

A. Deep Cost Approach

1. Definition

The deep cost approach consists of charging the producer for all the costs incurring for the connection to the grid. It means that the producer has to pay for the grid connection and for the necessary investment in the grid. The connection of a generator somewhere on the network could involve a loss of system reliability. At the beginning of a generator project, the network operator realizes a feasibility study in order to assess the impact of this potential new connection and the new potential injection of electricity into the grid. It is quite possible to assess a loss of system reliability. To restore this reliability parameter, investments have to be made. When applying a “deep connection approach” both grid connection and network reinforcement charges are born by the generator responsible for the loss of reliability. The connection charges do not imply only the cost of the lines but also the cost of all facilities necessary to the connection of the turbine. It is especially the case of renewable energies: [ILEX, 2OO2] explains that “an embedded generator connection under a ‘deep’ connection policy, to the low voltage network may be required to pay for any reinforcement higher up the system. This would not include any 11kV/LV transformer costs but also any work in the 11kV circuits. In addition, should there be a need to replace 33 kV or 132 kV switchgear as a result of excessive fault level; this cost would also fall to the embedded generator”.

2. Properties of the deep connection approach

a) From the point of view of the stakeholders

The choice of rules concerning the allocation of transmission connection charges involves three stakeholders: first, it concerns the generator and/or the investor of the project; second it concerns the network operator and then it concerns the regulatory authority since it is the regulatory authority that influences the rules choice.

(1) *Generator/Investor*

First of all the application of deep connection charge implies that the generator pays a relatively upfront payment for connection to reflect all the costs of connection. This investment tends to be quite high and would increase the amount of the project. The generation developers would face a high initial capital costs and so these costs would have a significant impact on the financial viability of generation project and may even prevent the building of the generator. This is particularly a problem in the case of wind power since a wind power plant is capital-intensive.

The deep connection policy allows existing generators to not be affected by the connection of a new one. Any new connection demand is treated in isolation comparatively to the system. Once a generator is connected to the grid, it is not concerned by the connection of competitors. In a competitive environment it seems totally normal to not be affected by the connection of a new generator. An existing generator would disagree to share the cost of a competitor connection since this latter is a new competitor.

For the case of wind power, the deep cost approach can be contentious. Generally, the wind power plant or wind power farms are located away from the load centre. More the wind power plants are located far from the load centre, higher are the costs because the transmission lines have to be either reinforced or built. The cost of connection seems to be higher for a wind power and could affect the viability of the project. Even if the project is made, this kind of allocation of the costs won't reduce the cost of energy transportation for a wind power plant. Depending on the rules applied to the use of system charge, the location of a generator on the network could increase de facto the amount of use of system charge if they are charged on the basis of the energy originating from the transmission network. This involves a kind of competition distortion.

Nevertheless the problem due to location of wind power plant is not so different from any conventional generator. In fact, few generation technologies are totally free to choose their locations. The principal difficulty of a wind power plant comes from the fact that a wind farm is located far from load centre mostly on the coastal county whereas a conventional generator could be built near a load centre even if it is not possible to choose optimally the location. The choice of location for a wind farm is locked in whereas the choice of location for a conventional generator is more flexible.

(2) Network Operator (Distribution and Transmission Operators)

From the Network Operator (NO), the deep connection policy will have an impact on the use of system charges. There is a direct link between connection charges and use of system charges: more the connection charge are born by the generator, less the use of system charge is important. If the connection charges should not be born by the generator, the charges will be passed through the use of system charges ("shallow cost approach"). A deep connection results in minimum connection expenditures by the NO.

The deep connection charge represents a low risk approach for the NO. All the cost are paid at the outset and the NO is not exposed to the perceived risks associated with the possibility of assets which may subsequently become stranded if embedded generators fail to operate for the duration of the intended connection asset life [ILEX, 2002].

b) Incentives and Effects

The deep connection policy involves various characteristics which can be seen as an externality: the deep connection approach has consequences on the well-functioning of the network. By "externality" we mean that the deep connection charge impacts a third party and not only the stakeholders.

(1) Incentives

The deep cost approach has the benefit of apportioning as much of the "blame" for cost as possible. The generator pays all the costs of network due to its connection. The deep interconnection basis seems to be "cost reflective" since the generator pays the overall costs relating to its connection to the grid. The cost-reflectiveness involves a better efficiency of the network by preventing over-investments of lines.

Furthermore it brings a locational signal which tends to improve the location of generators on the network. The locational signal brings an incentive to locate where it is the least costly. A generator will settle down where the costs of network are the lowest possible that is where the generator project won't impact the reliability of the network even if it delivers the maximum capacity. New generators can reduce their investment costs by selecting a location where the network improvement requirements are low rather than high. These costs may play an important role for a generation location. This incentive of location tends to improve the efficiency of network design. Unifying both parameters (the cost-reflectiveness and the locational signal) the design of the network would be the most efficient possible. As much as by paying an upfront capital the generator would have a liable behaviour ensuring the rationality of the generator.

(2) Negative effects

However it is very difficult to allocate grid investment costs. The main reason is that the improvements of transmission lines as well as the building of a new line do not benefit to the sole connected generator but these improvements tend to improve the electric system as a whole and the reliability of the network. But the physical laws of electricity – Kirchoff's laws - avoid knowing exactly which flows impact negatively the network since it is very difficult to trace the electricity flows. From this point of view the transmission network tends to be a public good. The reliability of the network concerns all the users of the network: suppliers, end-users, generators. If the reinforcement of a new line improves the reliability of the system as a whole, it tends to be charged to all users since every one takes benefits from this upgrades.

Some countries or areas still manage the system in providing access to the wholesale market through deep connection charges. This is the case in PJM (Pennsylvania – New-Jersey – Maryland) where a new generator has to bear all the costs concerning its connection and all the necessary charges for upgrades and improvements in order to restore the reliability constraints [Joskow, 2004].

The deep cost approach creates difficulties for the development of wind power generator and can be a barrier to new entry into the market for generation. This is particularly the case when wind generator is the first to connect to the grid. Due to its connection, it would have to support all the costs of connection, whereas the second would not be impact the network since it is reinforced by the first generator. This is the issue of first mover.

If a wind power plant project forecasts high cost for connection, this can be dissuasive.[BWEA, 2003] in its response to Ofgem's Preliminary consultation considers that "deep connection charges are not consistent with the principles of equity and transparency" and supports Ofgem's proposal to move to 'shallow' connection charge. If generators pay the overall costs of connection, the overrunning costs would be passed through the energy price to the consumer. If the consumer may choose his supplier, his choice will depend on the price of energy. Generators located in remote areas will be impacted since any consumer would choose it. Conversely if generators pay only the cost due to the network connection point, this will not impact the energy price. The consumer will choose his supplier without taking into account the supplier location on the network. In order to manage the increased share of renewable source into the generation mix, some countries decided to change the connection charge. Before 2002 the French producers pay connection cost plus all the reinforcement cost on medium-voltage and high-voltage network. Aware of the potential difficulties created for renewable energies by this deep cost approach, the French government changed the rule. After November 2002, the producers pay all the cost for connection and reinforcement up to (and including) the substation to the higher voltage (except higher voltage bus) [RTE, 2003]. This kind of change gives the possibility to share cost with other producers.

B. Shallow Cost Approach

The shallow cost approach is quite different. We will explain in the next section the characteristics of the shallow connection approach. Different methods are possible to allocate shallow connection policy [ILEX, 2002].

1. Definition

The shallow connection policy allows producer to pay only the charge of connecting to the grid while the necessary investment costs are included in use of system charges. This part of the connection facilities is called 'shallow assets' [ILEX, 2002]: they are defined as the items of connection equipment up to the point of common coupling – that is for the 'sole user' assets only. In many cases, this may only cover the switchgear and cable connecting the generator (in that case wind power generator) to the nearest point on the network (for wind power, it concerns particularly the distribution system).

The necessary investments for improving and upgrading the grid are shared out among all producers. Different rules could be applied concerning the methodology for sharing the cost of network reinforcement:

- Shallow connection policy with all requirement costs paid by load customers: The generator would not pay for use of system charge but the load customers would continue to pay them. This means that the share of cost charged to the generator is zero, and the cost is entirely born by the load. In certain articles, this means that G=0 and L=100
- Shallow connection basis with all reinforcement costs shared by all parties: the costs of reinforcement are shared among both customers and generators.
- Shallowish connection charges: this option introduces the concept of "shallowish" connection where some, but not all, of any upstream reinforcement costs are included in the connection charge. In this configuration, the issue concerning the allocation between generation and demand is the same as in the shallow connection charge. That's why I have decided to not discuss about this method, and to take care of the first two methodologies.

2. Properties of the shallow connection policy

a) From the stakeholders' point of view

(1) *Generator*

From the generator point of view, this option is the most favourable particularly if the reinforcement costs are shared by the load customers. This policy encourages the development of the renewable energies since they don't have to pay the reinforcement costs. The viability of a project only relies on the cost of generator, no further costs are added. A wind power plant project will be more attractive if the cost of reinforcement is born by the load. In fact, applying a shallow connection policy could be seen as an incentive to develop renewable energy, and particularly wind power. It is a strong signal send by the regulatory authority in accordance with the energy policy of the country concerned.

This approach, conversely to the deep connection one, allocates similar costs for connection whatever the generation technology chosen. Concerning the aim of the electricity reform, it allows generators to compete in a fair and equitable way. Any generator will be impacted by its location on the network. The consumer will choose his supplier without taking into account of the location. Even a generator located in remote areas could be chosen, since its energy price does not reflect the overrunning costs due to its location on the network. The load customers should choose his supplier independently of his location. In such a scheme there is no competition distortion due to the location on the network. This feature is particularly important in the case of wind power which is located in windy remote areas. Even if the costs of reinforcement are shared among both generation and load, it encourages the development of wind power. Nevertheless although the costs of reinforcement are shared among generators and load, it is always the load which will pay ultimately the cost of these reinforcements since the share of the generation cost will be reflected in an increase of price for the load.

(2) *Network Operator*

By applying the shallow connection approach, the Network Operator would receive only a relatively low charge income associated with the connection. [Ilex, 2002] explains that "the assets associated with making new connections whose costs are not recovered from connected plants at the time of connection, will become part of the general distribution system. These costs will be added to the regulatory asset base (RAB) and will be recovered from the general demand customer base, through the use of system charges over the lifetime of the asset (40 years). This unrecovered connection expenditure represents the network operator’s new business expenditure”. We can say that under this kind of connection approach, the business capital expenditure of the network operator would increase significantly. If the connection of a generator, for example a wind power plant, implies others investments from the network operator like additional administration, design and construction costs, this will increase the business capital expenditure of the grid operator. It could be expanded that the network operator does not favour a shallow connection approach even if this policy could bring him a part of independency.

b) Incentives and effets

(1) Incentives

Conversely to the deep connection approach the shallow cost approach proves to be easier to apply and does not represent method a barrier to new entry into the market for generation. The difficulty of allocate the charge to a generator disappears, and the costs incurred by the network operator are easily passed through the use of system charges either on the load or the load and the generation. This facilitates the work of the network operation, because it is very difficult due to the physical laws to allocate the cost of reinforcements of the system to the generator which causes the problem. Furthermore, with the shallow connection policy, the costs of system reliability are shared among all users or a group of users (in the case of costs of reinforcement paid by the load). The network is de facto seen as a public good, where the reliability of the system has to be taken in account by all users. From this point of view, the shallow connection policy is less contentious than the deep one.

The most famous advantage of the shallow connection policy concerns the development of renewable energies. If the costs of reinforcement of the network due to the integration of a wind power plant are socialized, it could be interpreted as strong support from the regulatory authority in accordance with the government objectives. The additional costs of network reinforcements if paid by the wind generator prevent the development of wind energy since the viability of the project get worse since a wind power plant project is capital-intensive. In fact the shallow connection approach sends a political signal whereas it does not send a locational signal.

(2) Negative Effects

The shallow cost approach is not cost-reflective [Joskow, 2004]. The integration of the reinforcement costs into the use of system charges blurs the frontiers between all the components of the charges unless the network operator adopts a transparent methodology. This policy does not allow the generators to behave rationally since they only pay the cost of connection to the network. This problem accompanies the possibility of over-investment since it is not cost-reflective. Furthermore, no locational signals are sent. In that case the network could be designed differently from the optimal design. Any incentive exists to favour the location on the network. So the network operator has to manage a system that is not efficient in that way. By doing this it could be possible to attain a situation where there is an over-investment on the network.

In a competitive electricity market it is very difficult to apply shallow cost. The main question is why should a producer share the cost of a transmission reinforcement made hundred of kilometres away to accommodate a new and competitive generator? In a competitive context it seems to be quite contentious.

C. Hybrid Models

Some hybrid models emerge depending on the rules added in the deep or shallow connecting cost. The hybrid model deals with the lack of locational signal of the shallow connection pricing policy. The idea is to keep a so-called shallow cost approach but in introducing a locational signal. [Groenhuije, 2004] explained, for example, the approach of shallow cost method plus incentive. In this approach a generator pays for connection to the grid plus an extra-fee depending on location. It provides benefits of the deep cost basis while avoiding the cost induced by investment and improvement of the network. The main difficulty in that case is to well determine the extra-fee which is the work of the network operator (or the regulatory authority depending on the architecture of the electricity market). Another method of hybrid model concerns the introduction of “exit and entry charges”. These new charges would provide one way of financing the reinforcement of the grid as well as other costs that are incurred [Mitchell, 2002]. The entry charges could take the form of a single capacity payment or an annual charge that could be positive or negative. These capacity charges would include a locational signal to ensure that there is an economic incentive to be located in location that could help the reinforcement of the network. [Mitchell, 2002] defines the exit costs as “Exit charges would cover distribution network costs not covered by shallow connection charges and capacity-based entry charges. These costs include payments for the difference between deep and shallow connection costs, the transport of electricity across the network, the operation and maintenance of the network and the provision of capacity to meet peak demand”. The author notices that the elements covering the difference between deep and shallow costs could be socialised across all demand consumers.

The choice for a hybrid model relies on the possibility of smoothing the effects of shallow connection pricing in avoiding a deep connection pricing. In this kind of connection pricing, a generator still pays the cost of connection to the grid, but not the cost of reinforcement. From the point of view of the network operator, a hybrid model allow to have a locational signal and so allow first to configure as well as possible a reliable network and secondly to have the most efficient use of the network. It lessens the cost of network maintenance for the network operator which deals with the reinforcement costs that could be socialised across consumers. From the generator’s point of view, it is quite beneficial, since the generator does not bear the cost of strengthening and enlargement of the network. The additional charge will be less than the cost of deep connection pricing policy but provide a good locational signal. Conversely to the deep cost approach, a generator located in remote areas won’t be penalised by its location of the network. That tends to improve the competition between renewable energies and conventional generation. From the regulatory point of view, this kind of policy is easy to apply and tends to improve the renewable target of regulatory policy. Nevertheless this new kind of policy seems to be quite innovative. Any experience is old enough to assess the benefits of this policy in regard to the integration on renewable energies.

The choice between deep or shallow cost is not easy to do. Nevertheless the transmission connection charge is not a new feature; all generators whatever the chosen technology have to pay for connecting to the grid. The main difference concerns the political mail that could be sent through the connection charge policy. Knowing that the most critical feature concerning the wind power integration into the network concerns the allocation of cost of the connection, a political support to development of wind power should consider a least-cost option for the wind generator. As the wind power plant is sensitive to the cost, the best option for supporting the wind power in regard of the generator is to apply a shallow connection policy. With a deep connection policy, the generator has to pay both costs of connection and network reinforcement. The table 1.Connection Approach Summary summarizes the connection pricing approach.

Table 1. Connection approaches summary

	Deep Connection	*Shallow Connection*	*Hybrid Connection*
Generator	High upfront payment impacting the financial project	Low connection costs	Low connection costs plus an annual charge
Network Operator	Low risk approach Low business expenditure	Increase of the business expenditure Riskier approach (stranded assets)	Medium business expenditures Recovery of some reinforcement expenditures through different charges
Performances	Cost reflective: efficiency of network use Locational signal In accordance with competition: liability of each stakeholder	Easy to apply Mutualisation of reinforcement costs Network seen as a common facility Do not represent a market barrier for renewable technologies	Easy to apply but need to well assess the overrunning charge Mutualisation of some features of the reinforcement costs Locational signal (even if lower than deep approach)
Problems	Difficult to apply First mover disadvantage Reinforcement benefits to other network users Entry Market Barrier for small-scale units and renewable units	At variance with the notion of competition Any locational signal and no cost-reflective: problem of inefficiency of the network	Less cost-reflective than deep policy Assessment of the added charge

To conclude, the best connection policy to develop and incentive wind power plant projects is the shallow connection policy. In the next section, the case of Denmark will shed in light the case of shallow connection pricing; the PJM case will illustrate the case of deep connection charges and England & Wales will be a hybrid model. To analyse the connection pricing policy and assess the link between integration of wind power and transmission connection cost policy, we have to analyse three features (i) the context and particularly the institutional environment, (ii) the transmission connection policy and (iii) the link between wind power and connection pricing.

II. Empirical Analysis: the cases of Denmark, PJM and England & Wales

The choice between deep or shallow connection policies could be interpreted as a strong support to the development of renewable energies. In order to shed in light this assumption, we are going to consider three different cases. Denmark is one of the famous countries for its renewable energy policy. Wind power energy represents about 20 % on average of the total electricity consumption. The connection policy is based on a shallow approach. The case of PJM is totally different. The choice has been made for a deep connection bases. On PJM market, wind power only represents 0.21% of generating electricity capacity. The UK case is quite different from both Denmark and PJM since it applies a kind of shallow cost which could be interpreted like a deep one. We have to notice here that the difference between transmission grid operator and distribution grid operator is not clearly announced; particularly the rules applied for the grid connection concern both of them. Even if the connection of wind turbines has to be done with the distribution grid, the rules concern transmission and distribution grid. That'

A. Denmark Case Study

1. Context

Denmark was one of the first countries to apply energy policy in order to boom the development of renewable energies. Its electricity supply industry has gone through several drastic changes in its fuel choice in the last three decades. In 1973 the power industry was heavily dependent upon oil which accounts for more than 64% of its output. The oil crises following by government's efforts had already led in 80's to substantial replacement of oil by coal. In 1990, the share of coal in power generation was more than 85 %. Coal has been replaced by natural gas during 90's due to the high level of greenhouse gas. In parallel to these changes, wind power has been strong supported and the share of wind energy in the Danish system is the highest in the world: in 2003 it represented 15 % of the electricity consumption. More than 80 % of the turbines are owned by individual farmers or wind energy cooperatives. Some 150 000 Danish families own wind turbines or shares in wind cooperative [IEA, 2002]. Between 1993 and 2000 the development of wind energy was particularly rapid: installed wind capacity quintupled. This development is the result of vigorous government support.

The electricity reform took place in 1999 by the amendment of the Electricity Supply Act in order to introduce competition in Denmark while ensuring that the electricity industry would fulfil the obligations of the Danish government and in particular those relating to protection of environment. The Electricity Supply Act contains obligations concerning CHP and renewable which are:

- An obligation for electricity enterprises to purchase electricity from small-scale CHP and renewable at a fixed prices. The final consumers are obliged to purchase their proportional part of this electricity thus covering the costs for the electricity companies
- An obligation to purchase electricity from other CHP to the extent that the electricity cannot be sold at cost-covering prices. Final consumers are subsequently obliged to purchase their proportional part of this electricity
- An obligation for all consumers to buy renewable energy certificates as a way of giving a financial support to producers of electricity of renewable energy sources.

2. Transmission connection pricing

a) Transmission organisational structure

Denmark has more than 166 750 km of high-voltage lines, of which 6 000 km are 400 and 132 kV. The Danish transmission system is operated by two separate grid companies, Eltra (Western Denmark) and Elkraft (Eastern Denmark). They were formed as a consequence of the Electricity Supply Act. Both Eltra and Elkraft benefit from a natural monopoly position as owners and operators of public infrastructure facilities. Their systems are not directly interconnected but both are connected to the Nordic market and to Germany. Eltra is jointly owned by 48 western Danish grid companies which, in turn, are owned by local authorities or consumer cooperatives. Elkraft is split into two companies: Elkraft Transmission which is the owner and operator of high-voltage transmission grid in the eastern Denmark. It operates the interconnections with Germany and Sweden. Elkraft System is the system operator. Both companies are owned by 10 eastern Danish grid companies, which are owned by local authorities and consumer cooperatives. Both are impacted by the ever-increasing share of renewable energy, and particularly by local electricity production from wind turbines and local CHP. Even if the wind power plants are connected to the low-voltage grid, Eltra and Elkraft have to reinforce their network as a consequence of the wind power share increase. Eltra and Elkraft are responsible for (1) safe running and maintenance of the primary grid, (2) maintaining the physical balance in the system and creating equal conditions for all balance responsible market players, (3) cooperation between neighbouring system operator, (4) handling priority production including prioritised wind turbine and (5) making up and settling of market players.

b) Connection policy

Denmark has adopted a shallow connection policy. Both Eltra and Elkraft have a similar connection policy since this policy is done in the Electricity Supply Act. The rules of law of connection of wind turbines are given in section 68 of the Danish Electricity Act and are amplified in Executive Order N°331 of 8 May 2003 on connection of wind turbines to a grid.

The basic principles of connection policy are based on a Point Of Connection Tariffs. Each grid user pays a transmission tariff depending on the point of connection. The transmission tariff in each point of connection is calculated relative to a defined fictitious “market place” in the grid. The seller has to pay for electricity being transported into the market place whereas the customer pays for transport out of the market place. The grid users face only one tariff: the one from the central, regional or local grid transmission levels. All costs related to higher voltage grid levels are passed to other grid users [Rothwell, et.all, 2003]

In Denmark there is a special connection policy for wind turbines. In fact all small-scale productions have a prioritised access to the network so that the distribution companies are obliged to connect them. The costs are paid only to the nearest 10 kV connection point even though there is a need for larger reinforcement or for another connection point. Concerning the connection costs relative to the connection of a wind turbine on the network, the legislative basis edicts:

- The owner of the wind turbine shall bear the cost of the grid connection up to the grid connection point indicated by the grid company: (1) installation of wind turbine, (2) the low-voltage connection, (3) establishment of a local wind turbine transformer including a meter, for billing purposes, (4) service line to the grid, (5) connection to the grid including phase compensation (although not for reactive power consumed by the wind turbine)
- The owner of the grid shall bear the other following costs: (1) the grid company’s costs for dealing with the application for grid connection, (2) maintenance of the grid company’s meter, reading of the meter and billing of electricity, (3) calibration and replacement of the grid company’s meter and (4) the owner’s own meter with associated telecommunication
- The grid company (the network operator) shall bear the cost of: (1) enlargement and strengthening of the grid, (2) grid losses from the meter on the grid to which consumers or other producers than wind turbines are not connected and (3) phase compensation for reactive power not consumed by the wind turbine.

This is basically a shallow cost approach. The generator bears only the cost for connecting to the grid whatever the transmission level; the costs of reinforcement are born by the grid company which dispatches them on the use of system charge. The components of the grid tariff in Eltra area are (i) a grid tariff for consumption, (ii) a system tariff, (iii) a Public Service Obligation Tariff, (iv) a Prioritised Production tariff and (v) a grid tariff for generation. We focus here on the connection tariff and we do not discuss the relevance of use of system charge.

Elkraft has similar tariffs but has decided to split the Public Service Obligation Tariff into two different one: PSO 1 covers the cost of minimum capacity, R&D, supervision while PSO 2 covers the costs relating to the surcharge on non-prioritised generation.

In fact the costs due to the connection of wind turbines are socialised through the Public Service Obligation Tariffs. The following box explained the component of the Public Service Obligation tariff.

Principles for PSO Tariff

The PSO tariff covers the expenses for public service obligations (security of supply and environmentally friendly electricity) except for those covered by the tariff of Purchase Obligation Production.

Security of supply

- Ensure sufficient production capacity
- Maintain fuel emergency stores

Environmentally Friendly electricity

- Pay subsidies to the environmentally friendly electricity production of the power stations
- Pay subsidies and balance remuneration to wind turbines that are excluded from the purchase obligation
- Research and development into efficient use of energy
- Environmental research relating to offshore wind turbines
- Grid connection of wind turbines and local CHP units
- Grid connection of offshore turbines

The costs of carrying out the public service obligations are distributed proportionately on all consumers in Western Denmark. The costs of subsidies and balance remuneration to the Renewable Energy Electricity production of power stations and wind turbines that are no subject to the purchase obligation must be equalised between Eastern and Western Denmark.

The PSO tariff is paid on the basis of gross consumption. However major electricity consumers and auto producers subject to net settlement are exempt from paying part of the cost relating to subsidies for utility-owned Renewable Energy units and wind turbines that are not subject to the purchase obligation:

The discount is given for the part of consumption that exceeds 100 GWh

Auto producers subject to net settlement get a similar discount for their auto-production

Cost relating to subsidies for utility-owned RE units and wind turbines that are not subject to the purchase obligation have been divided into separate accounts with their own excess revenue/deficit

Source: Eltra Annual Report 2003

The costs associated with grid connection of wind turbines and local units (CHP) at low voltage levels have to be spread evenly across all consumers. They amounted to DKK 74 million – XX- those concerning the connection of wind turbines are about DKK 66 million [Eltra, 2003]. The major part of the reinforcement and enlargement costs due to wind power are in fine passed through the final consumer since it has to pay them by the grid transmission tariffs. [ETSO, 2003] realised a benchmarking on the transmission pricing in Europe. The tariffs analysed covered all the transmission charges (infrastructure, loss compensation, congestion, cost of supply of system services and other costs). Concerning the sharing of network operator costs among customers in Denmark it concludes that the load supports about 95 % of network operator costs. Even if it concerns all costs of network operator, it shows very well that Denmark applies a shallow connection policy.

3. Impacts on wind power

Denmark has applied a shallow connection policy. This approach tends to strength our conclusion concerning the support to development of renewable energies. Denmark is the most famous country concerning the development of wind power turbines. Even if the growth of wind power is not only affected by the connection pricing policy, it seems possible to conclude that applying a shallow connection cost aims at supporting the development of renewable units. The wind capacity in Denmark is about 3400 MW at the end of 2004 [Danish Energy Authority, 2004]. The wind power units produce less than 20 % of total Danish consumption. Even if the choice between deep or shallow is not considered to be a support from renewable energy policy, it could be interpreted as a mechanism whose aim is to reinforce the renewable energy policy. The connection pricing policy is a feature of the set of mechanisms developed in parallel to the strong support of regulatory authority to develop the wind power. In order to help the growth of wind power plants regulatory authorities have to choose a shallow connection charges even if it is too difficult to isolate only a feature to explain the development of wind energy. Nevertheless the shallow cost does not provide locational signals for the efficient use of the network. From this point of view we can conclude that Denmark made the choice of better integrating renewable energies rather than use more efficiently the network. Denmark faced two different approaches: the first concerning the development of cleaner energy technologies and the second considering the efficient use of the network in the case of Internal Energy Market. By applying a shallow cost approach Danish regulatory authorities have decided to strong support the development of wind turbines and less taking care of the efficiency of the electricity network.

B. The PJM Case

PJM is an independent system operator covering a large area: Pennsylvania, New Jersey, Maryland, Delaware, Washington D.C and a part of Virginia. Its geographic footprint has been expanding for a couple of years integrating transmission owners portions of West Virginia, Ohio, Kentucky, Indiana and Illinois [PJM, 2004]

1. Context

PJM entered the electricity liberalisation era as a multi-state power pool which centrally dispatched the generating facilities for vertically integrate utilities in Pennsylvania, New-Jersey, Maryland, Delaware and Washington D.C. In 1998 it was restructured to turn cost-based power pool into a set of bid-based wholesale spot power market and supporting institutions, including transmission pricing and investment protocols. PJM is now an Independent System Operator and has been qualified as an RTO by FERC pursuant to Order 2000. This order contained a new set of regulations designed to ease the voluntary creation of large Regional Transmission Organization to resolve the problems of balkanised control of transmission networks [Joskow, 2004].

PJM is structured as a for-profit company though it operates de facto as a non-for profit organisation. PJM is not a market participant; it does not own generation, transmission grid and distribution assets; it is not engaged in wholesale or retail marketing [PJM, 2003]. PJM is responsible for system operation reliability and for applying reliability rules and criteria.

The owners of transmission networks are all vertically integrated utilities that also own generating capacity or distribution companies. They continue to have transmission operating functions, including transmission maintenance, outage restoration and investment responsibilities but all are subject to various agreements with PJM. Furthermore, PJM manages a regional transmission investment planning process and can designate transmission responsibilities to specific transmission owners. PJM operates voluntary day-ahead and real-time (adjustment or balancing) bid-based markets for energy and ancillary services. Market participants submit bids and offers to the day-ahead and real-time markets. Participation in the day-ahead and real-time markets is voluntary since generators, loads and intermediaries may submit their own day-ahead schedules for energy and ancillary services to the RTO and can use bilateral arrangements to stay in balance in real time. Bilateral schedules are still liable for congestion and loss charges. PJM is not a state but a multi-state power pool. Each state participating in PJM market has developed a renewable energy policy and has to apply the legislation concerning the Renewable Portfolio Supply. We take into account the renewable energy policy as a whole and do not explain deeply the mechanisms of renewable energy policy. This will be done in a next article concerning the role of institutional environment.

2. Transmission connection pricing

PJM manages an open access tariff that requires the transmission owners in PJM to offer transmission services at non-discriminatory cost-based prices. This tariff establishes prices for various categories of transmission service available to third party transmission users. Particularly PJM specifies the interconnection rules and obligations for generators, merchant transmission owners and regulated transmission owners [Joskow 2004]. PJM provides various types of transmission services. Here we shall see only those concerning the connection to the grid.

PJM first provide a so-called "Firm Network Integration Service". This service is designed to make it possible for any Load-Serving-Entities – distribution companies or competitive retail suppliers which face the responsibility for supplying retail consumers – to integrate flexibly any generating plants it owns and power supply arrangements it makes with third parties with its retail loads [PJM, 2004]. Each LSE purchasing network integration service pays a transmission access charge based on their proportional peak demand on the network in each "transmission area" in which power is delivered to a distribution network to serve their load. A transmission zone is the geographic zone served by each transmission owner. The transmission access charge is FERC regulated and equal to the average total cost of capital investments (depreciation, interest, return on equity, taxes) plus the operating costs of the existing transmission assets included on the network. Additional charges may be assessed to cover network enhancements necessary to provide the service consistent with reliability rules. The charges are remitted to transmission owners to cover their regulated costs of service. Depending of the transmission zone on the PJM network, prices for this service are in the range of \$15 - \$25/Kw-year. This service could be interpreted as a use of system charge. By paying these access charges LSE receives financial transmission right or Auction Revenue Rights. However this does not concern our purpose. For more information see [Joskow, 2004]

PJM provides a Firm-point-o-point transmission service to support exports, imports, intra-PJM transaction and extra-transactions (with interconnected control area). The pricing arrangement is the same as Firm Network Integration Service. It provides a non-firm point to point transmission service which is a variant fo the firm point to point transmission service. The generator owning a non-firm point to point transmission service is curtailed first if there is a congestion indicated on the network based on day-ahead schedule. All these services are quite important for the integration of wind power, but it should be the topic of a next paper.

What's about the transmission price charged to generator? In fact generators are not required to pay a separate transmission service charge to use PJM Network. Generators must pay for the cost of interconnection facilities and network upgrades required to restore reliability. If the engineering study required in case of new installation of power plant indicates that reliability parameters are in danger, the expected costs of network investment required to reinforce the network reliability would be charged to the proposed generator. However it could be possible to share the costs with other generators that benefit from the reinforcement of this part of the network but the allocation mechanism seems to be very complex. Engineering studies are performed to determine the reliability level incurred by the generation of a new power plant somewhere on the network. PJM effectively has a deep connection pricing policy.

3. Impact of wind power

As seen in section 1, the application of deep connection pricing policy is quite contentious for a wind power plant. If the developer has to bear all the costs related to its connection on the network - the interconnection pricing and the enlargement and strengthening network costs - it creates a real market entry barrier, since the viability of a wind power plant project deteriorates.

Nevertheless, it is very complex to isolate only a feature in the study of integration of wind power. We cannot say that the deep connection pricing policy prevent the development of wind power, because wind power is not only affected by the question of connection pricing policy but also by the global management of wind power into the market. Nonetheless, we shed on light one of features allowing a smooth development of wind power. Concerning wind power on PJM network, it is easy to see that wind power represents only 0.21% of the generating electricity capacity [IEA, 2004]. The wind power capacity accounts about 305 MW whereas the PJM system accounts more than 144 000 MW of generating capacity.

The choice for a deep connection pricing policy tends to show that PJM has decided to not strong support the development of renewable energies even if it has to comply with the Renewable Portfolio Standard. Conversely to Denmark where the development of renewable energies is written into the laws and where the regulatory authorities in accordance with the government has been providing for 20 years a strong support to the growth of renewable energy capacity, PJM applied rules which allow to obtain an efficient network because of the strong locational signal it sends. The PJM network tends to be more efficient: it identifies transmission investment needs thanks to a strong regional planning process and network monitoring and it prices transmission service in order to provide very useful locational incentives. The difference between Denmark and PJM set down in the political objective they want to achieve: Denmark has launched a high level of renewable energy capacity on its system; PJM has got a very strong network, which continues to grow and provides locational signal.

C. England and Wales: an hybrid approach

1. Context

In 1990 the electricity sector in England and Wales was privatized and restructured to create competitive wholesale and retail market. The former state-owned generation and transmission company, the CEGB that historically had provided wholesale power to distribution entities (Area Boards) and large industrial customers in England and Wales was broken into three generating companies and a single regulated transmission company: NGC. NGC owns the high-voltage transmission network (400 kV and 275 kV facilities) and maintains the network. NGC is responsible for investment in the network to meet reliability obligations. NGC has standard principles that are (1) operating the network in an efficient economical and coordinated manner and (2) offering services based on a non-discriminatory terms and conditions.

From 1990 and 2001 the wholesale power market was organised like a pool, a bid-based pool which determined the economic dispatch and associated uniform market clearing prices for energy [Staropoli, 2002]. From March 2001, the New Electricity Trading Arrangement (NETA) was introduced. In fact, NETA replaced the mandatory pool with a new wholesale market design structured to encourage generators and load to enter into bilateral contracts and to minimize the transactions formerly made in the centrally pool. With NETA, NGC is responsible for balancing the system using offers to buy and sell increases and decreases in real time generation supplies mediated through a balancing market. NGC responsibilities concern real time balancing of demand and supply, management of network and other constraints of the network.

Concerning the renewable energy policy of United-Kingdom the government set in its Energy White Paper goals for energy policy in order to tackle the threat of climate change by reducing greenhouse gas emissions. The 2003 Energy White Paper “Our Energy Future – Creating a low carbon economy” set the target that by 2010, 10% of electricity should come from renewable sources. Various mechanisms were applied in order to support the development of renewable energy such as the Renewables Obligation which is the main mechanism for supporting renewable energy and which requires suppliers to source annually increasing percentage of their sales from renewables, or such the Non-Fossil Fuel Obligation which was before the introduction of Renewables Obligation a mechanism which provided premium payments for renewable generated electricity over a fixed priced with contracts being awarded to individual generator. The UK government has shown an ambitious target by the Energy White Paper.

2. Transmission connection pricing

The connection charges enable NGC to recover with a reasonable rate of return the costs involved in providing the assets which afford connection to the transmission system. [NGC, 2004] specifies that “the connection charges relate to the costs of assets installed solely for and only capable of use by an individual user”. The connection assets are defined as “those assets solely required to connect an individual user to the transmission network which are not and would not normally be used by any other connected party” [NGC, 2004]. NGC defined those single user assets as:

- For Double Busbar type connections are those single user assets connecting the user’s assets and the first NGC owned substation up to and including the Double Busbar Bay
- For teed or mesh connection are those single user assets from the user assets up to but not including the high-voltage disconnector.

[NGC, 2004] adds that “where customer choice influences the application of standard rules to the connection boundary, affected assets will be classed as connection assets”. In fact, two types of assets are defined by NGC: connection assets which refer to the connection required to connect solely an individual user and infrastructure assets, which refer to the transmission assets whose reinforcement or building would benefit to multi network users. Concerning the connection assets, their costs are borne by the individual user whereas the infrastructure costs are shared among network users. For more details concerning the determination of the connection cost, please refer to *Statement of the Connection charging Methodology*, NGC, 2004. From this analyse, we may say that NGC applies a shallow connection pricing policy. The individual generator will only pay the connection assets required to solely connect it to the grid; all costs relating to reinforcement or enlargement of the transmission grid would be shared among network users through the Transmission Network Use of System (TNUoS) charges.

TNUoS charges reflect the cost of installing, operating and maintaining the transmission system. The split of TNUoS between generator and load was adjusted in 2004 to approximately 27% to generator and 73 % to load. To apply the TNUoS various areas were implemented in order to issue a locational signal: there are 15 TNUoS generation zones and 12 TNUoS demand areas. The general level of charges are set to allow NGC to recover its cost-of-service based revenue requirement or budget constraint as adjusted through the incentive regulation mechanism. The structure of TNUoS charges provides for price variations by location on the network based upon scaled differences in the incremental costs of injecting or receiving electricity at different locations as specified in the Investment Cost Related Pricing Methodology. Generators pay significantly higher transmission service costs in the North of England than in the South because there is congestion from North to South and deep transmission network reinforcements are more likely to be required to accommodate new generation added at various locations in the North but not in the south. Similarly load in the south pays more than the load in the North because transmission enhancements to increase capacity from constrained generation export areas benefits customer in the south more than those in the north. The cost of Transmission Network Use of System Generation Charges (£/Kw) for the year 2005 is shown below.

Tableau 1. Cost of Transmission Network Use of System Generation Charges per generation area in 2005

Generation Zone	Zone Area	Generation Tariff (£/kW)
1	Northern	9.009237
2	Humberside	5.767201
3	North West	6.222266
4	Pennines & North Wales	4.121912
5	Dinorwig	10.715347
6	Anglesey	7.011370
7	East Anglia	2.889748
8	West Midlands	2.032089
9	South Wales & Gloucs	-2.150590
10	Oxon and Bucks	0.004330
11	Estuary	1.733641
12	Central and SW London	-6.604821
13	South Coast	-1.507146
14	Wessex	-3.829097
15	Peninsula	-6.836065

Source: NGC, 2004

As the TNUoS charges vary by location, it send a locational signal. In fact, this variation defined the long run marginal cost of a change on generation (or demand) at a particular point on the network. To conclude, this use of system pricing is both a shallow connection pricing since a generator would pay only the cost of connection assets required to its sole connection and a deep connection pricing policy since the reinforcement costs are de facto integrated into the Transmission Network Use of System charges and that these charges vary by location depending on the long run marginal cost of a change on generation on the network..

3. Impact of wind power

As the wind power forecasts are greater in the North than in the South, a wind power plant will pay a higher TNUoS. The wind power is indeed completely insensitive from the locational signal sent by the transmission pricing. Nevertheless the objectives of renewable energy policy drawn by the White Paper show a true motivation to develop renewable energies. Presently in England and Wales all generators who are directly connected to the transmission system are liable for TNUoS. Nonetheless, concerning the distribution connected generation, NGC makes a broad distinction between distribution-connected generators that are deemed to be sufficiently large to impact on the transmission system and those that do not. The former are charged TNUoS charge on the same basis as directly-connected generators. The latter are not liable for use of system charges. NGC determines liability for charges for distribution-connected generators on the basis of size. If a generator has export capacity not greater than 100 MW then it is not liable for TNUoS charges. So if a wind power plant has export capacity not greater than 100 MW then the wind generator won’t be charged for TNUoS charges.

Promoting the White Paper objectives therefore requires a package of measures: some of them like the Renewable Obligation would have the effect of redistribution income between classes of market participants. In parallel to these measures, new configurations have to be rethought. NGC must apply a charging methodology that encourages transmission assets to be built and charged for in the most efficient way. This will ensure that the necessary costs of upgrading the transmission network to accommodate the expected growth in renewables are minimised. It will be a requirement of European legislation to have a cost-reflective and non-discriminatory charging methodology in place. It is quite difficult to apply a transmission connection charging methodology which has to facilitate the development of renewable energies and to be efficient and cost-reflective in order to ensure investments. In fact, the wind power is quite few developed in England and Wales even if all date found concerned the United-Kingdom as a whole. Nonetheless, the wind power capacity represents less than 1% of total generating capacity [BWEA, 2003]. Even if the transmission pricing policy is both a deep and a shallow approach, the development of wind power remains quite slow. Aware of this problem, DTI and OFGEM have consulted on transmission charging in the context of Government's policy objectives for growth of renewables. The objective is to modify the transmission pricing policy in order to sustain the development of renewable energies keeping always in mind that the transmission pricing policy must provide good incentives for investments so that they have to be cost-reflective, efficient and send a locational signal. Presently this consultation concludes to two new mechanisms in order to support the renewable development while respecting the European legislation: the first deals with lower charges for all renewable generators and the second concerns lower charges for renewable generators located in peripheral areas.

We can conclude that the hybrid model of England & Wales does not bring sufficient signal to further develop the growth of renewable energies. Conversely to Denmark the growth of wind power plant in England and Wales remains quite slow. Even if the development of wind power does not depend solely on the transmission connection pricing, we can see that Denmark which has a shallow transmission pricing policy is one of the leader country for wind power capacity development. The England & Wales with an hybrid model (shallow-deep one) fails to support strongly the development of wind turbines. The consultation of DTI./Ofgem shows that the charging methodology remains a barrier to a smooth growth of wind power.

Conclusion

To conclude we have shown that different connection pricing policies exist. The deep connection pricing approach obliges the generator to pay all the connection costs plus the cost related to the enlargement and strengthening of the network. This deep connection pricing approach is cost-reflective and provides a good locational signal, commonly required for an efficient and reliable transmission grid. The shallow connection pricing policy means that the generator pays only the cost of connection assets, which are the features for connecting the grid; all reinforcement costs being shared among networks users. This approach does not provide a locational signal and is less cost-reflective. The hybrid model tends to take advantages from the two previous policies: offering a shallow connection approach in providing a locational signal through a capacity charge. Concerning the wind power connection, it seems that the shallow connection pricing policy or a hybrid one have to be favoured: all reinforcement costs being shared among users the viability of wind power project is improved and the connection pricing does not constitute a market entry barrier as the deep connection policy does.

Three case studies have been analysed in order to assess the choice in term of renewable energy policy. We have seen that Denmark, which is the leader in the wind power development - wind power represents 20% of total Danish consumption in average - has applied a shallow connection pricing policy. A wind generator only pays for connecting to the grid; all reinforcement costs are shared among network users, particularly on load, by the Public Service Obligation Tariff which is a component of the use-of-system charge. Denmark in parallel has a strong renewable energy policy and has been supporting wind development for more than 20 years. Conversely to Denmark, the case study of PJM shed in light the deep connection pricing policy: on PJM grid, a generator has to pay all costs related to its connection: the cost of connection itself and all reinforcement costs due to the connection. These costs are required to restore the reliability parameters of the network. In fact, the wind power is few developed: wind power capacity represented only 0.21 % of the total generating capacity in PJM in 2003. The last case study shows a hybrid model: England and Wales have developed a shallow-deep connection pricing policy. The connection charges are "shallow" but through the use of system charges, which vary by location, a deep connection pricing is introduced. A generator in the North of England & Wales will pay higher transmission network use of system generation charges since congestions exist between North and South. As highest wind energy forecasts are located in the north of the country, wind power would be more penalised by this shallow-deep interconnection pricing policy. But this new model has been applied for one year and we are not able to assess the results on the development of wind power.

In conclusion, shallow connection pricing methodology has been favoured by countries which tend to develop quickly renewable energy. This connection policy accompanies commonly a strong renewable energy policy and a strong support from the government and regulatory authority. Deep connection pricing policy has some advantages for the configuration of the network thanks to the locational signal. We can conclude that the choice between a shallow or deep connection pricing approach depends on the parameter preferred by the regulatory authorities: more the challenge concerns the renewable energy policy, more the connection policy will draw nearer to 'shallow' policy. More the challenge concerns a reliable efficient network; more the choice will conduce to a deep connection policy. To go further in this direction, the next questions should concern the role of each of regulatory institutions in correlation with the choice of transmission connection pricing policy.

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