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The role of transmission investment in the coordination between generation and transmission in the liberalised power systems

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Abstract

This paper examines how transmission coordinates with generation to the long term in a liberalised power system. To ensure non-discriminatory access to transmission network in a liberalised power system, it was needed to break the former vertical integration between generation and transmission, which creates new challenges to coordinate newly unbundled activities. To have a better understanding of this challenge, we rely on a modular construction of an ideal Transmission System Operator (TSO) as a benchmark to study the mechanisms implemented in practice by real TSOs to coordinate with generation. As generation and transmission are now unbundled, a new reflexion is required to operate efficiently their coordination in a new market-friendly way. In the paper, we highlight the role of the governance structure of transmission activities to realise this coordination. We then show that in a logic of complementarity, this governance structure influences the options that Transmission System Operators can implement to manage effectively power flows. Although locational signals are necessary to guide the installation of new power plants, we demonstrate that the governance structure is the key element to explain the investment in network as the only effective method of long-term coordination between generation and transmission in liberalised power market.

Keywords: coordination between generation and transmission investments; locational signals; governance structure of the network.

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Introduction

In liberalised power systems, to ensure non-discriminatory access to transmission network, it was needed to unbundle vertically competitive generation and the natural monopoly of transmission network. Unbundling activities previously integrated in a vertical and horizontal monopoly creates problems of coordination between generation and transmission investments. We show that transmission investment is the mechanism that will effectively realise this new coordination to the long term in a liberalised power system.

Facing this situation, Lévêque (2003) has shown that a centralised authority should send locational signals to generators to replace the traditional coordination. This centralised authority is called the Transmission System Operator (TSO). Therefore, we expect that the TSOs implement the best existing locational signals that should lead to efficient coordination between generation and transmission investments. But we will see that the study of real TSOs shows that those who implement the more locational signals are not those who experience the best coordination with generation. How to explain this paradox? How to reconcile the theoretical expected results and the practice of the TSOs?

To answer this question, in the first section, we propose and build an ideal TSO organisation which combines efficiently the most efficient option to perform TSO tasks of coordination between generation and transmission. We will use this ideal TSO as a benchmark for the study of coordination between generation and transmission of real TSOs. In the second section, we show that the incentive structure of the ideal TSO is difficult to achieve in practice because the governance of electricity transmission assets influences the implementation of power flow management. Finally, in the third section, we apply this modular and organisational framework to compare two emblematic TSOs, 1° Pennsylvania, Maryland and New Jersey (PJM), and 2° National Grid. Then we will see what the central mechanism to coordinate generation and transmission of electricity is transmission investment.

1- Ideal organisation of a TSO

To manage power flows, the Transmission System Operators realise three main tasks that range from very short term (a few minutes to several hours) to the very long term (5 to 20 years) (Brunekreeft *et al*., 2005). These three missions are: i) the management of short run power flow externality on the transmission network; ii) the development of transport capacity, and iii) coordination with neighbouring interconnected systems. To study the multiplicity of real grid operators, we have shown in Rious *et al*. (2008) the relevance of a modular analysis framework *à la* Clark and Baldwin (2000) and Wilson (2002) to classify the existing empirical diversity of TSOs. Here we focus on two first missions, the short run management of power flow externality and the development of transmission network. And we will refer to the third mission of coordination more sporadically.

If we choose the optimal option for each of these two missions, an ideal TSO can be defined. It is a combination of "nodal pricing" and, under a benevolent regulation, of the minimisation of the total cost of network (that is to say, to minimise the sum of the congestion cost and the investment cost of the network). We will detail these two points and see why nodal pricing and long-term development of the transmission network are the building blocks of the optimal organisation of an ideal TSO.

First, the optimal short run management of power flow externalities is obtained with the system of nodal pricing of energy. Schweppe *et al*. (1988) show that an efficient power dispatch can be achieved through a system of nodal pricing of electricity whose clearing is constrained by the externalities associated with congestion of powerlines. This method has

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incentive virtues superior to those of the two other well-known power flow management schemes, zonal pricing[3] and redispatch[4].[5] Thus nodal pricing determines a price of energy for each node of the network. These prices indicate the nodes where it is preferable to produce or consume one more megawatt taking into account the constraints of network capacity.

Figure 1 illustrates nodal pricing on a simple two-node congested network. There is only generation connected to the first node S and its cost is low. To the second node D, there is a quantity Q of inelastic load and also generation whose cost is high. These two nodes are linked by a single powerline SD whose transmission capacity is K. If we ignore the limited capacity of powerline when clearing the market, generation to node S is sufficient to supply load (to node D). The equilibrium price is unique and is P_E. This equilibrium induces a flow on line SD greater than the available transmission capacity K, that is to say $K < Q$. As a consequence, this equilibrium is not technically feasible.

To incentivise generation to the nodes S and D to take into account congestion on the line SD, with nodal pricing, the generator at node S is paid a price P_S below the equilibrium price without congestion P_E and the generator at node D is paid P_D a price higher than P_E. In this case, the difference in value between the nodal prices reflects the social value of network externalities. This difference creates a surplus for the TSO called “congestion rent”. And the constraints of network capacity limit the maximisation of social welfare by a quantity called “congestion cost”. The congestion rent is represented on Figure 1 by the grey rectangle and the congestion cost by the dark grey trapezoid.

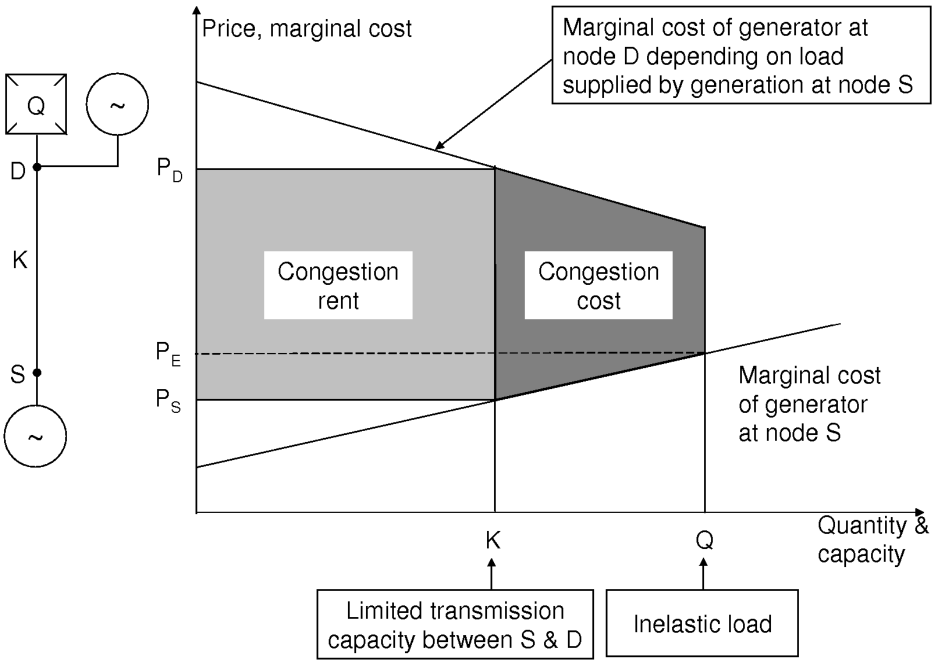

Figure 1 Graphical representation of nodal pricing on a congested two-node network

[3] Zonal pricing is similar to nodal pricing but only the most important network constraints are internalized in the pricing system of electricity market. The other minor constraints are managed by redispatch. This simplification from thousands of nodes to few zones is very sensitive to errors and gaming by generators.

[4] When congestions are managed by redispatch, they are not internalized in the electricity market. The TSO manages congestion after the market clearing by modulating production of the adequate power stations. Redispatch thus does not emit any locational signal, except for the modulated power stations.

[5] Nodal pricing is also a central scheme to ease the coordination between neighboring areas (Cadwalader *et al.* 1999).

The second mechanism of coordination between generation and transmission is the long-term development of the power transmission grid. In theory, the management of power flow externalities can inform the TSO and the users of the network on the constraints related to the current state of operation of the network.[6] But to the long run, the TSO should also make efficient network investments to eliminate all the constraints on the grid that are economically excessive. If one considers by simplification that the TSO is benevolent and efficient, it must invest in order to reduce the social costs caused by the externalities of use of the network and so, in an equivalent way, to maximise social welfare.

Considering our definition of the ideal TSO, the observation of the modes of organisations of real TSOs reflects a large variety of combination of suboptimal management schemes of power flows. This variety can be explained beyond the technical constraints of power flow management by the different characteristics of the governance structures of the transmission grid.

2- Complementarities between the governance structure and the management of electricity flows

In the liberalised power system, the TSO can take different organisational forms or governance structures, according to whether he owns the property rights of the network he manages, and according to the form of regulation that is applied to this monopoly. The governance structure of the network modifies the incentives that the TSO can perceive from the management of power flows. In this section, first of all, we define the governance structure of the network by presenting its main components. Then, we show that the governance structure of the network influences the options that the TSO implements to manage power flows.

2- a) The governance and the incentive regulation of the network

The way the transmission grid is unbundled constitutes the ground of the governance structure of the network because it determines the degree of incentives that can be introduced into the regulation of this monopoly. Unbundling the transmission grid from competitive activities like generation or supply is currently considered essential. This vertical unbundling is of two degrees of intensity. The first level always includes the unbundling of short run system operation. Indeed, the withdrawal of system operation from incumbents is rather easy to impose in a process of liberalisation because this activity represents a relatively small volume of investment and employment. To the contrary, the second degree of unbundling for ownership of the power grid depends on the possibility of forcing the incumbents to cede their network assets. This level of vertical unbundling is more difficult to produce at the time of competitive reforms. Indeed a pure generator faces competitive pressures and uncertainty from electricity markets, while the network assets are a source of regulated revenue that is guaranteed and recurring. This secured source of revenue is then very interesting and attractive for a generator in electricity markets where the companies are also judged on their financial performances.[7]

The choices of the level of network unbundling can also be influenced by the interactions so called "border effects" between interconnected power systems. If ownership

[6] This is true considering not only the short run locational signals but also the long run locational signals. But we do not consider the long run locational signals in our analysis because it complicates our analysis framework without modifying the conclusions (see footnote 12).

[7] Moreover, ownership of the network can make it possible for the generators to protect strategically their generation portfolios in the development plans of the network.

and operation of a grid on a continental scale are strongly fragmented between a lot of distinct TSOs, the loop flows between these TSOs create many border effects that are difficult to deal with and that can reach critical values for the reliability of the system. Then, operation and ownership unbundling of the network in each of the TSO's zone may not be sufficient to internalise the "border effects" and solve the associated problems. A remedy is then to remove the "System Operation" part from incumbents and to recompose this function on a wider geographical area including several electric zones, under the operational authority of a new Independent System Operator (ISO). The horizontal integration of system operation on wide zones then allows internalising the border effects between the previous zones of the incumbents (Costello, 2001; PJM, 2004b).

One can now distinguish two main families of TSOs in terms of degree of unbundling: the "heavy" TSO and the "light" TSO. A "heavy TSO" owns the network infrastructures that he operates. A "light TSO" does not own the network infrastructures that he operates. These modalities of grid unbundling are thus important to understand not only the efficiency of the governance of the transmission network but also its regulation as a monopoly.

In the case of a "heavy" TSO, the regulator can impose an incentive regulation on the controllable costs of the network to set the income of this monopoly. Indeed, the potential financial risks of an incentive regulation are acceptable for a "heavy GRT" in terms of assets, equity and revenues. To the contrary, it is difficult for a regulator to incentivise strongly a "light TSO" because of its weak financial standing (few assets, little equity, low revenue). That is why the "light TSOs" are usually non-for-profit organisations, partly self-regulated by the market participants in its zone (Barker *et al*., 1997).[8]

2- b) The governance of the network and the management of power flows are complementary

A TSO does not have the same incentives to manage and develop its network depending on the combination between its governance structure and its method to manage short-term externalities. Depending on the implemented method, the management of externality can generate rent or cost for the TSO. Nodal pricing effectively allows an efficient dispatching of generation taking into account the network constraints. But congestion rent arising from this method gives a counter-incentive signal to the TSO for its own investment decisions. Indeed, nodal pricing can incentivise a TSO maximising its profit to make congestion last more than needed (Pérez-Arriaga *et al*., 1995). A TSO that internalises power flow externalities with nodal pricing should then be subject to a more demanding regulation to ensure that the maximisation of the TSO's profit is in line with the maximisation of social welfare.

Inversely, the method called "redispatch" is considered inefficient to internalise the power flow externalities because the TSO then deals with congestion out of the day-ahead electricity market. In this case, no short-run locational signal is transmitted to the users of the network who cannot then make efficient use of the transmission capacity. But this method has the advantage that the TSO directly bears the congestion cost arising from system operation. Consequently, the TSO can here maximise its profit by comparing the social cost of short term congestions with the long-term cost of investment and maintenance of the grid and thus naturally maximises social welfare.

The governance structure of the network and the design of the modules of power flow management must then be seen like a global interacting system. The theoretical perfection

[8] One will notice that the good functioning of this principle of self-regulation is efficient only under the assumption that there is no risk of collusion or capture of the TSO by a single group of interest (Boyce and Hallis, 2005).

would be to combine the options of the ideal TSO with a perimeter of heavy TSO, unbundled from generation and regulated with a strong and incentivising regulator. However, as we have just shown it, the complementarities between the governance structure and the modules of power flow management will generally lead to sub-optimal choices in the design of these modules. Compromises must then be realised between the control of the costs of the network and the design of the modules of power flow management.

The study of two worldwide references TSOs (PJM & National Grid) will show in the following section that their structure of governance influences the choice of the mode of coordination between generation and transmission. Thus some TSOs favour internalisation of externality by scarcity pricing with given network capacity, while others act directly on the cause of externality by investing and increasing the transmission capacity.

3- The comparison of two TSOs of reference: PJM and *National Grid*

The objective of this section is twofold. First, we study the consequences of the complementarities on reference TSOs to explain their non optimal choices to manage flows of electricity. We will proceed in two stages. First of all, we will compare the options of power flow management implemented by each TSO with those of the ideal TSO. Then, we will show how the structure of governance of the network constrains the implementation of these options. We show finally that the structure of governance can correct the failure of some sub-optimal options of coordination and then reconcile the expected theoretical results and the concrete organisation of the TSOs.

From this comparison, the second objective of this section is to show that the effects of complementarities brought by the governance of the network alternatively focus on the choice between "*internalise externality of use of the network related to congestion*" or "*to increase the capacity of the network to treat the cause of congestion*". Then we will show that it seems very difficult to carry out these two tasks jointly.

3- a) Comparison of real TSOs to the ideal TSO

Now we will use our construction of ideal TSO as a point of comparison for the study of real TSOs. The first, PJM, is a light TSO structured as a non-for-profit organisation that operates in the North-East of the United States. PJM is recognised as a worldwide model because it uses the nodal pricing system which enabled him to extend its area of responsibility over a wide part for the North-East of the United States and to become thus the TSO that manages the highest peak load in the world (Joskow, 2006). In spite of the implementation of the best method of internalisation, the congestion cost of this zone strongly increased until 2006. In fact, before April 2004, PJM didn't take into account the possibility to reduce congestion cost in the planning of network investments on its zone. The network investments were made only for technical reasons of reliability.

The second worldwide reference model is National Grid because it is a heavy TSO, owner of the network he operates in England and Wales[9]. He is unbundled from generation. He operates, maintains and develops the network of England and Wales, in one of the oldest electricity markets. National Grid is a private company, quoted on the stock exchange, but regulated by the British regulator of energy, the OFGEM[10] (Joskow, 2006). This TSO is often

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[9] We limit our analysis to the period during the UK Pool and then the NETA (New Electricity Trading Arrangement) before the extension of the British market to Scotland and the implementation of the BETTA (British Electricity Trading and Transmission Arrangements – for an analysis of the BETTA, see Prandini, 2007)

[10] *Office of Gas and Electricity Markets*

quoted as an example for its efficiency in the management of the network within the framework of a liberalised power system (Rossignoli *et al*. 2005). While at the same time National Grid operates its system with redispatch and this option of congestion management does not internalise the externalities of use of the network. But the practical modalities of regulation applied to this monopolist for its system operation and the development of its network push it to invest in order to minimise congestion cost. Its congestion and investment costs have then be considerably reduced.

We note that these two TSOs do not apply the optimal combination of coordination mechanisms of the ideal TSO. And this, although they are both recognised at the international scales for the management of their network. In addition, the trend of congestion cost of TSOs is not coherent with the locational signals used by each one of these TSOs. Indeed, it is paradoxical that PJM sees congestion increased whereas its locational signals are very incentive. In the same way, it is paradoxical that National Grid has a good control of congestion, whereas its locational signals are theoretically weaker. In table 1, we summarise the comparison of these two TSOs, PJM and National Grid, with the ideal TSO, as well as the "unexpected and paradoxical" evolution of their congestion costs compared to the implemented congestion management schemes.

Table 1 : Ideal TSO, PJM and National Grid: the puzzle of congestion cost evolution

	Ideal TSO	**PJM**	**NGC**
Congestion management	+ Nodal pricing	+ Nodal pricing	- Redispatch
Investment	+ Social welfare maximisation	- Decrease of congestion cost not considered	+ Arbitrage between congestion and investment costs
Evolution of Congestion		↗	↘

Sources: Joskow (2006) and Rossignoli *et al*. (2005).

3- b) Governance of the network and consequences on the options of congestion management

The governance structure of the network that completes our initial framework of analysis makes it possible to explain the options implemented by the TSOs and their performances to coordinate generation and transmission of electricity. In particular, the type of network unbundling is central because it determines the most suitable regulation that can be applied to the TSO.

In the case of PJM, the grid remains the property of incumbent companies. The structure of "light TSO" of PJM has the advantage that it can be easily extended to integrate new zones in its market. This extension is all the more efficient as it is carried out thanks to nodal pricing of energy. The use of this method proves to be obligatory in the case of a light TSO like PJM because, by nature, PJM is insensitive to the congestion cost or the congestion rent resulting from the short run signals. Nevertheless, nodal pricing did not prevent a recrudescence of congestion on the zone of PJM.

The increase of congestion revealed in fact an insufficient coordination between generation and transmission within PJM. This problem ended up by drawing attention of the federal regulator of energy, the FERC (PJM, 2004b; Joskow, 2005). Thus, it is only under the pressure of the FERC that PJM defined the concept of "*Economic Planned Transmission Facilities*" (Joskow, 2006). Without the constraint of the regulator, PJM would probably not have taken this initiative because its statute of light TSO does not incentivise him to do it.

Indeed, the heart of its activity is the short-term management of grid and it is thus the extension of this activity of system operation which guides the development of PJM.

Conversely, when the TSO owns the network like National Grid, the development of the infrastructure is its core activity. Network ownership then makes it possible to impose him an incentive regulation. Then, making him bear even partly the congestion cost arising from redispatch incentivises him to develop the network efficiently. Indeed, thanks to the structure of governance of heavy TSO of National Grid, an incentive regulation allows to control the congestion cost and, to a lesser extent, the investment costs of the network. This incentive regulation allows to compensate for the theoretical failures of redispatch related to the absence of internalisation of externality. The regulation of system operation and of network ownership proposes to National Grid an arbitrage between the costs of system operation in the short and medium term and the investment costs of the network (Joskow, 2006). In this framework, the incentive regulation of system operation prompts National Grid to arbitrate between the congestion cost and transmission investments of small sizes (with short periods of return on investment); while the long run budget constraint incentivises National Grid to arbitrate between the investments of small size and the investments of bigger size, the latter being able to be less expensive thanks to the economies of scale that characterise power grid.

3- c) Governance of the network and coordination between generation and transmission

Our analysis makes it possible to show that, to deal with congestion, light TSOs and heavy TSOs choose basically different methods. The light TSO like PJM primarily focuses on the internalisation of congestion in a price system, while the heavy TSO as National Grid concentrates more on the development of the network. The governance structure of the network influences coordination between generation and transmission. Depending on its form, the governance incentivises the TSO to focus more either on internalisation of congestion (with given transmission capacity) or on the development of the network (in order to treat the cause of these congestions). In practice, the governance structure of the network makes it difficult to reconcile efficiently and simultaneously these two approaches of treatment of externalities.

Considering the performances of PJM and National Grid, we note that the module of network investment holds a central place in coordination between generation and transmission. Even if the system of PJM is best equipped in locational signals, the evolution of congestion cost on its zone shows that the investments in network were insufficient. Then coordination between the investments in generation and transmission was not satisfactory. Conversely, National Grid is more concerned with the long run coordination with generation. That can be easily understood since he owns the network and prefers to develop it to eliminate congestion.[11]

But considering the trend of congestion cost, the strategy of developing the network is more efficient. Of course, the locational signals are necessary to incentivise the location of power plants. But the generators have other constraints of location to settle their new power stations that are stronger than locational pricing incentives[12]. For generation investment, the primary energy source must be easily accessible. Besides, for the thermal power plants (with gas, coal or nuclear power), a river with an important water flow is also necessary. Lastly, the generators must find lands that fit with these criteria at a reasonable price. These constraints

[11] This is also true when the locational signals are ineffective.

[12] The last forecasts of connection by National Grid (2005 & 2007) support this rationale and show that the network cost and locational signals (whatever short run or long run) are secondary in the location of power plants and that the other constraints are more important to the generators for locating their plants.

for the generators lead to durable congestions for which the only solution is to develop the network.

The network investment then holds a central role in long-term coordination between generation and transmission, and this for two reasons. Firstly, the structure of governance of the network can result in setting up little or no coordination signals. Secondly, the coordination signals when implemented do not guarantee that the cause of congestion, related to the lack of capacity of the network, is treated.

Conclusion

We have shown that the complementarities between the governance structure of the network and the modules of management of power flows influence coordination between generation and transmission of electricity and allow to reconcile the expected theoretical results and practices in two manners. First of all, the governance structure of the network defines the degree of unbundling of the TSO from the rest of the electric system, which modifies the incentives that he can perceive in the various options of power flow management of flows. Then, depending on the governance structure, only the sub-optimal schemes might be applied, in particular when the optimal options are counter-incentive for the TSO in the configuration of its governance. But the structure of governance can also correct some failures of these sub-optimal methods. The conclusions of our analysis are thus more moderate than those of other studies (Boucher and Smeers, 2002; Ehrenmann and Smeers, 2005). Because they show that it is still useful to study the effects of these options on coordination between generation and transmission. Then, the study of PJM and NGC in terms of complementarity showed that the module of investment of the network has more influence on coordination between generation and transmission than internalisation of externalities.

Internalisation of the externalities of use of the network is admittedly needed to effectively coordinate the production and the short-term and long-term transmission electricity. But, since the long term location of generators generates durable congestions on the network, only the development of transmission capacity brings a satisfactory coordination of these two activities. The module of investment of the network is thus the heart of coordination between generation and transmission of electricity. The complementarities show that the investment in network can be the only effective process of coordination between generation and transmission.

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