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Effects of Large Amount of Wind Power Capacity

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Adequacy and transmission interconnection in regional electricity markets: effects of large amount of wind power capacity

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***Abstract*--The power system adequacy has public good features that cannot be entirely solved by electricity market. Regulatory intervention is then necessary and old methods to assess adequacy have been used to help regulators to fix this market failure. In regional electricity markets, transmission interconnections play an important role in contributing to adequacy. This paper presents a simple model to study how the transmission capacity contributes to adequacy and focuses on the particular case with large amount of wind power. First results indicate that increasing interconnection capacity between systems improves adequacy up to a certain level; then further increases do not procure any adequacy improvements. This effect depends upon the amount of wind power intalled in each zone. Furthermore, besides adequacy improvement, increasing transmission capacity under asymmetrical amounts of intalled wind power could create several externalities concerns.**

I. Introduction

The European Commission (EC) identifies the reliability of electricity supply as one of the three major goals in the liberalisation of electricity markets, next to the price competitiveness and the development of renewable energy. However, the progressive reduction of capacity margins and the recent experiences of blackouts question the fulfilling of this goal. Electricity is a staple commodity and therefore, interruptions are hardly acceptable politically and socially [1].

Generation adequacy is the long term component of reliability of electricity supply [2]. It is an impure public good that presents characteristics of non-exclusivity, because all producers' investment decisions in competition and any variation of the demand affect the electricity supply at the collective level. Public authorities must, therefore, ensure that the market rules and the definition of the roles and responsibilities of the participants in the market, contribute to obtain an optimal level of capacity adequacy. Different approaches have been adopted in the world to ensure a sufficient level of adequacy:"energy-only" design, capacity payments, public strategic reserves, capacity requirement placed on suppliers with secondary markets, etc. In the last years research has been concentrated on the design of these different generation adequacy mechanisms [3]-[5].

However this topic has been generally treated from a national point of view despite the goals settled by the EC regarding the integration of the European electricity market. Considering interactions in regional electricity markets is particularly important due to two factors. Firstly, each country

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is normally governed by its own adequacy mechanisms (including no mechanism at all)[1] which try to give incentives according to the level of adequacy that public authorities estimated in the behave of national consumers. Secondly, the type and size of the adequacy problem in each system could be very different depending upon the type of technology, the parterns of consumptions, etc. This second point is particularly important in Europe given the high promotion for the development of renewable (intermittent) energy. In particular, introducing a large amount of wind power may strengthen the adequacy problem. Increasing interconnection capacity under these conditions could introduce asymmetric effects and produce externalities concerns.

The aim of this paper is twofold. Firstly, this paper studies how interconnections improve adequacy and can reduce generation capacity requirements. Secondly, it studies the externalities concerns that could arise when adequacy problem in each system is more or less acute due to a large amount of wind power installed capacity. Our research is based upon an adequacy model representing two zones linked by a transmission interconnection.

The paper is organized as follows. Section II briefly explains the adequacy problem, the role of transmission interconnection and the effects of large increase of wind power capacity. In Section III the model and the stylized system are presented. In Section IV the results of simulations are shown and discussed. Finally Section V concludes.

II. The Adequacy Problem and the Role of Transmission Interconnection

Generation Adequacy is a property of a system representing the level of risk of failure in the long run. Transmission interconnection capacity helps zones to reach the desired level of generation adequacy. The promotion ofrenewables (intermittent) technologies (mostly wind power) change the adequacy problem; it may also affect the way adequacy and interconnection interact.

A. The adequacy before and after the liberalisation

Before the liberalisation of electricity market, the reliability of electricity supply was managed by a vertically integrated utility and controlled by public authorities. Decisions regarding new investments were determined by the capacity expansion plan. Expansion plan is determined by the margin that assess if there is enough production capacity to meet the expected peak load. Said margin is obtained by adding new production units so as to respect an adequacy criterion. This latter is determined on the basis of an accepted risk of failure. As demand and available capacity are not exactly known in advance, the risk of failure is never eliminated, as there is always a probability that the demand is greater than the instantaneously available capacity [6].

After the liberalization of the electricity industry, the new organization suggested a transformation of the planning system management. Thus, the provision of generation reserves in deregulated systems depends not only on institutional dispositions and regulatory instruments chosen but also on the degree of coordination among market participants. This new industrial organization supposes that the market receives a signal of consumers' willingness to pay their electricity. This signal would replace the implicit security criteria used in the former industrial organization. However, to accomplish this hypothesis, this signal should be made explicit by consumers to suppliers and by suppliers to producers via the market. It would require profound changes in metering technology, as well as new forms of electricity contracting between suppliers and consumers. Until then, the market cannot know (because it cannot implement it in a credible way) consumers' willingness to pay for their electricity. Consequently, the market today cannot infer what investments in production capacity must be made in order to satisfy consumers' demand for generation adequacy [7].

These constraints in the new industrial organization have led some regulators (or TSO) to use the old adequacy criteria. In some countries, these criteria have a strictly informative character, while in other countries; they are used as inputs of the market design implemented by regulators. In this latter case, it is very important to use an adequacy assessment methodology that allows to represent the physical requirements of the system the more realistically as possible [8]. In the next paragraph some approaches to assess adequacy are presented.

B. The adequacy assessment in electricity systems

There are no simple rules to determine the optimal level of risk of failure. A trade-off between the increasing investment costs for new capacity and the reduction in failure cost for consumers would in theory determine the risk of failure. The difficulty with this approach remains on the inability to determine the economic benefits of increasing the adequacy due to the lack of knowledge about consumers' true willingness to pay for electricity in scarcity periods. Therefore the value of adequacy is set by public authorities but results of this rule may not be perfectly accurate.

Once the adequacy criterion is known, different methods which are more or less rigorous can be used to assess capacity adequacy. On one side there are deterministic methods that use typical adequacy criterion, such as generation margins equal to a fixed percentage of the peak demand and operating margins sufficient to cope the most likely contingency. One of the limitations of these methods is that they do not take into account the stochastic nature of supply and demand. Indeed, randomly events as uncertainty in customer demand, forced outages of generating units, intermittent production have an impact on the adequacy assessment. The probabilistic methods, on the other hand, provide a more meaningful and realistic information about the random events that affect supply and demand [9]. Two criteria are particularly used : the Loss of Load Probability (LOLP), defined as the probability over some period of time that the power system will fail to provide uninterrupted service to customers and, the Loss of Energy Expectation (LOEE), defined as the expected amount of energy not served over some time frame. As we will see in the next section probabilistic methods are very useful to deal with adequacy problems.

[1] It is important to note that sometimes Public Authorities do not define any criterion of adequacy or generation dimension considering that the « market » would solve the adequacy problem (see [7] for more details).

C. The impacts of interconnections on generation adequacy

The historical role of interconnections is to ensure the system reliability by pooling the production capacity on a larger scale. The constitution of the regional electricity markets (such as the European Internal Electricity Market and the Regional Transmission Organization as PJM in the US, etc.), assigned two additional roles to interconnections: arbitraging between markets and increasing the level of competition. In this new context, considering the role of interconnections in the capacity adequacy is necessary. Several reasons explain this fact:

Firstly, the interconnections can increase the security margin of a system through the production and consumption patterns of the neighbouring systems. Indeed, the complementarities between production and demand structures may make it profitable to develop a regional vision of generation adequacy and security of electricity supply. Thus, regional approach allows each country to reduce its capacity margin requirement. Accordingly, there is savings in investment and operating costs in each interconnected country. Secondly, despite the benefits of interconnection in terms of adequacy, dysfunctions may be exported from one country to another through interconnections, as shown by recent blackouts (September 2003 in Italy and November 2006 in Germany). Finally, the lack of harmonization between power systems in terms of adequacy criteria and market designs could lead to a situation where consumers of a country feel to pay for adequacy providing consumers in the neighbouring countries. In others terms, thanks to interconnection some consumers may benefit from a risk-adverse generation adequacy criteria in a neighbouring power system and have a relatively high level of security of supply without incurring the corresponding investment costs. This free-riding behaviour which ultimately can lead to a general decrease in the level of adequacy of interconnected system. This is the traditional free-riding and public goods financing problem [10].

D. The impact of large amount of renewable generation on generation adequacy

The impacts of large-scale development of wind power on the capacity adequacy can be analyzed, in general, from two aspects: intermittence and capacity margin in one side and regional effects in the other side.

The first aspect concerns the character of the intermittent supply of primary energy, in this case the wind. This intermittence, reflected in the variance of the wind production, is largely superior to the conventional production units (e.g. in France, wind power standard deviation is 1.2 GW and expected generation average is 1.4 GW while corresponding values for the thermal generation are 2 GW for standard deviation and 75 GW for expected average available capacity repectively [11]). If it isn't taken into account in investment's decisions, such unavailability produces an increased risk of supply failure which increases with the installed capacity of wind power. To ensure a constant level of risk in the long term, new conventional generation units must be installed as a backup.

The second aspect concerns the wind power development at regional level. The interaction of systems leads to take into account impacts of large-scale development of wind energy. In fact there is a lack of harmonisation between countries concerning the mechanisms of support schemes for electricity generation from renewable sources (e.g. feed-in tarif; green certificates, etc.). Differences in the effectiveness in support mechanisms have been translated in different amount of installed wind power by country (e.g. countries that have adopted a successful scheme wiill have more installed capacity of wind power than others that have adopted other ineffective schemes). This lack of harmonization between schemes leads to asymmetries between systems that negatively affect the adequacy of the regional system. This asymetrical development can be conceptualized through the "risk-averse" adequacy criterion of a country with regard to the other. Thus, a country with a priority strategy for the development of wind power as compared to conventional technologies could be assimilated to behaviour of low risk aversion adequacy criterion if this renewable priority is made without adaptation of the adequacy criterion. This behaviour may lead to, a free-riding behaviour from countries that have a higher risk-aversion.

III. THE MODELLING ADEQUACY

In this section a simplified model is developed to study the adequacy problem and the value of interconnection capacity. The lost of load probability and the "requirement in generation capacity" (at a level of risk) are computed for different configurations (level of interconnection capacity, level of wind power capacity, correlation, etc.). The goal of this section is to understand the role of interconnection capacity on adequacy and to study the impact of large amount of wind (intermittent) capacity. It is important to note that only the value of transmission interconnection concerning adequacy is evaluated in this section. We do not deal with other valuable roles of interconnection capacity as increase efficiency connecting two zones with different economical characteristics and the reduction of market power.

A. Adequacy model (at a level of risk)

We use an analytical method that characterize the probability distribution of the random variable « margin » (i.e. available generation minus peak load) and that allows to evaluate the requirement of generation capacity to have the variable margin less than zero only for a given probability. This is a probabilistic method that characterizes the generation capacity margin as a random variable that follows a normal distribution. The adequacy criterion associated with this method is LOLP and it indicates the level of risk. The risk could be settled at different level but a value that is currently used is 0.01 or 1% risk [11]. Fig. 1 illustrates the adequacy method that can be computed using the following equation:

$$LOLP = P(\ cap.margin\ <\ 0) =\ 0.01 \qquad (1)$$

This standard method is used by several TSO (e.g. RTE in France). However it does not consider the interaction with other systems and the role of interconnections.

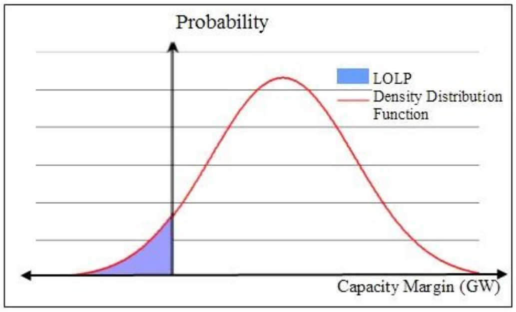

Fig. 1. Illustration of the method margin to risk 1%

B. Adequacy model and interconnection capacity

Based on [12] and [13] we adapted the analytical method to take into account interconnections. Our model considers a system made up of two zones interconnected by a transmission line of capacity K (fig. 2). Each zone is represented by three random variables: demand and two generation technologies: a "correlated" technology (e.g. wind power or hydro) that could be correlated with other random variables (demand and generation in both zones) and a "non-correlated" technology (e.g. conventional thermal) that is not correlated with other variables. It is important to note that we do not consider transmission constraints whithin the zones.

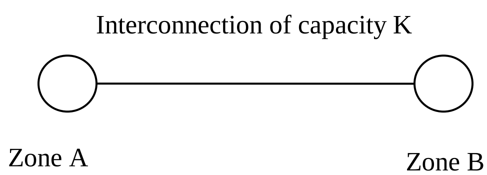

Fig. 2. Scheme of the two-zones system.

TABLE I
DATA OF REFERENCE SYMMETRIC SYSTEM

	mean [GW]	standard deviation [GW]
Demand	$\mu_d^{A,B} = 82$	$\sigma_d^{A,B} = 6.3$
Correlated Generation	$\mu_{cg}^{A,B} = 1.4$	$\sigma_{cg}^{A,B} = 1.2$
Non Correlated generation	$\mu_{ncg}^{A,B} = 75$	$\sigma_{ncg}^{A,B} = 1.9$

Normal distributions are used to represent each one of these random variables. Table I shows the mean and the standard deviation (μ and σ) of each random varaible for the reference "symmetric" system. These values could mimic a system of on important size in Europe (e.g. France). Within this reference system correlation coefficients between random variables (demand & wind power in each zone) are set to zero.

The model computes Loss of Load Probability (LOLP) by using a "Monte Carlo" method (10000 random numbers are simulated in Matlab) for different values of transmission capacity. For instance, LOLP corresponding to zone A could be computed using (2).

$$LOLP^{A}(K) = P((m^{A} < 0) \cap (K < |m^{A}|) + P((m^{A} < 0) \cap (K > |m^{A}|) \cap (m^{B} < -m^{A})) \quad (2)$$

where m^A and m^B are respectively the margin of each zone and K is the interconnection capacity between the two zones. This interconnection capacity, can be modelled as a random variable that follows a probability distribution given. However, in order to simplify our analysis, we assume that the transmission line is fully reliable and therefore, is a deterministic value ranging between 0 and 20 GW. The model also computes the requirement in additional generation in a zone to achieve the desired LOLP (see method of 1% risk).

IV. WHICH IS THE POTENTIAL ROLE OF INTERCONNECTIONS IN THE ADEQUACY OF THE NATIONAL SYSTEMS?

In this section results of simulations are presented and discussed. In order to understand the role of the interconnection capacity in progressive steps we first study the "symmetric" case with small proportion of wind power, secondly the "symmetric" case with an increasing amount of wind power and finally the asymmetric case is evaluated.

A. The adequacy value of interconnection capacity

Given the stochastic characteristics of power system, increasing the size of system could improve the adequacy concerns. In fact this is a consequence of the diversification of risk via random events not perfectly correlated (reference). Fig. 3 shows that increasing transmission capacity improves the adequacy (reduces LOLP) of each zone and that improvements stop once the level of capacity reaches a given value (here around of 10% of expected value of demand).

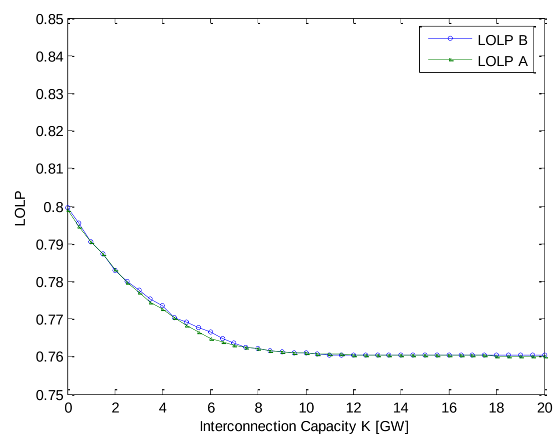

Fig. 3. Lost of Load Probability (LOLP A and LOLP B) vs. transmission capacity K

However the level of adequacy of this system is far from the level normally required (e.g. risk=1%). The requirement in additional generation capacity in each zone is computed to have a level of risk of 1%. Economically one can understand this calculation as a tool for the public authorities to set up the "adequacy model" parameters. For instance if the adequacy model is of type "energy-only market" with "Price Cap", the public authorities would set a higher “Price Cap” if she finds that the requirement in generation capacity to ensure the adequacy criterion is positive.

Fig. 4 shows results of the additional generation capacity needed for each zone in order to have a risk of 1% or 2%. The value of interconnection capacity could be seen here, in fact, the increase of the interconnection capacity allows a reduction of the “requirement” of additional generation in each zone. This could be quantified economically considering the fixed cost of peak generation capacity. Even more, optimal combination between transmission capacity and generation (making the assumption that only the adequacy problem exists) could be found looking at the ratio between generation and transmission interconnection fixed cost. Note that this possible trade-off between generation and transmission capacity for achieving a level of adequacy shows the need of good coordination between zones in setting adequacy policy and transmission interconnection investments. However, in Europe adequacy policies are actually settled a national level [7].

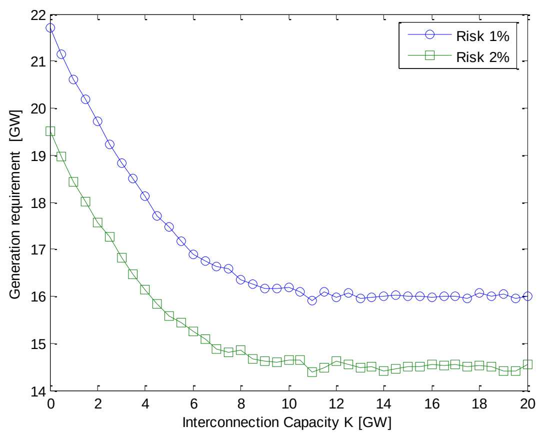

Fig. 4. Generation requirement for a risk of 1% or 2%

B. The value of interconnection capacity & wind power (symmetric case)

Wind power is known for his high variance (with respect to conventional thermal technology – see this in the ratio μ / σ in Table I). In this subsection the effects of increasing wind power generation capacity in both zones are studied. In other terms, we compute the requirement in additional generation in each zone with additional wind power capacity (μ_{cg}) of 5, 10 and 15 GW with the corresponding increases of σ_{cg} (the ratio μ / σ is kept constant). In order to keep the system comparable demand is increased of an equivelent amount of wind power capacity.

Fig.5 shows the “requirement” of generation capacity for having a risk of 1% for each interconnected zone and for several levels of wind power capacity. Two things have to be noticed. Firstly, higher the wind power (more variable) capacity, higher the requirement in generation capacity for having a risk of 1%. Secondly, the level of interconnection capacity at which the “requirement” stops to decrease is higher when wind power capacity increases. This means that with more wind power capacity in the system, the transmission capacity is more valuable. This result says that, if we consider only the adequacy problem, the “optimal” interconecction capacity changes for different level of wind power, so this has to be taken into account in the definition of the policy.

Up to now, all the cases considered supposed that there were no correlations between variables. In reality there are correlations between demands and wind power generations whithin the each zone and between zones. In fact demads and wind power are highly related to meteorological phenomena and this contribute to the correlation of the variables [13]. We now study the influence of the correlation on our results.

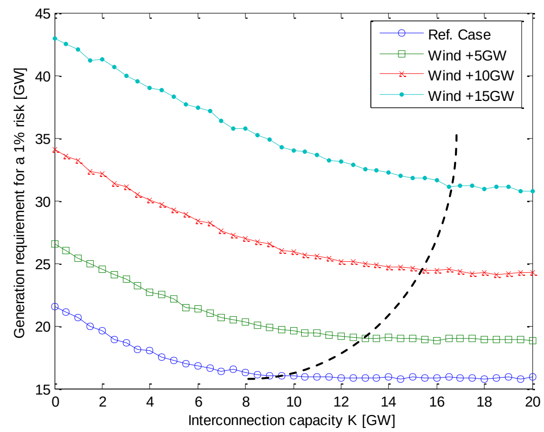

Fig. 5. Generation requirement for a risk of 1% for several levels of wind power capacity (Dotted black line indiquates the transmission capacity at which reduction of requirement stops)

Fig. 6 shows the generation requirement for a level of risk, by interconnected zone, for three cases: no correlations, zones correlations (corr. coeff. Wind/Demand of 0.3) and zones & interzones correlations (corr. coeff. Interzone Demand of 0.9, interzone Wind/Demand of 0.2 and interzone Wind of 0.1).

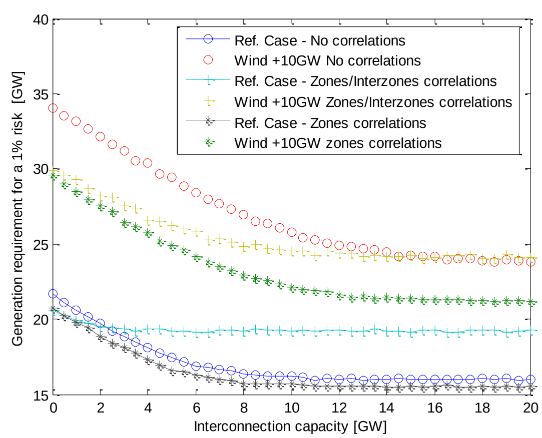

Fig. 6. Generation requirement for a risk of 1% for several levels of wind power capacity and correlations

It could be seen that the generation requirement with zonal wind&demand correlation is lower than the case without correlations. This effect is more important with more wind power in the system. However, the impact of interconnection capacity is similar. When interzones correlation are introduced the said effect becomes less important for higher values of interconnection capacity. In other terms, the adequacy requirement for a zone is lower when wind power and demand are more correlated and transmission interconnection capacity is more valuable for cases with less interzone correlations.

C. The value of interconnection capacity & wind power (asymmetric case)

In this last subsection the value of interconnection capacity is studied with an asymmetrical increase of wind power production. This is the case when a great amount of wind power capacity is introduced in one zone of an interconnected system (e.g. Germany in Europe). When this happens, increasing interconnection capacity lead to different effects depending on the zone studied. Here only the case with no correlation is studied.

Fig.7 and 8 show the effects of the "requirement" of generation capacity in zone A (no wind power increase) and in zone B (huge wind power increase) compared to the symmetrical case (both zones compute the "requirement" with normal wind power.) These figures show that zone A's requirement relatively increases when transmission capacity increases. Conversely, zone B's requirement decreases when transmission capacity increases. These results indicate that the benefit of transmission capacity, in terms of generation capacity requirement, is not symetrically shared between zones and this effect may lead to free-riding behaviors.

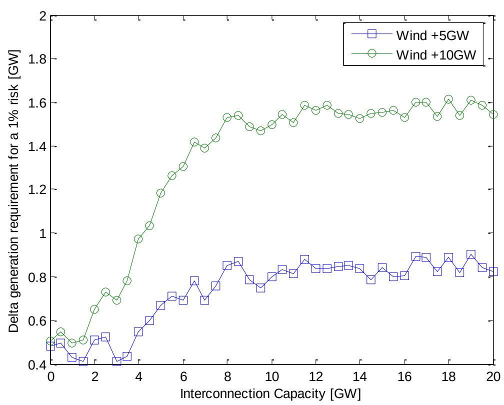

Fig. 7. Difference between generation requirement for a risk of 1% with wind and without wind corresponding to zone A

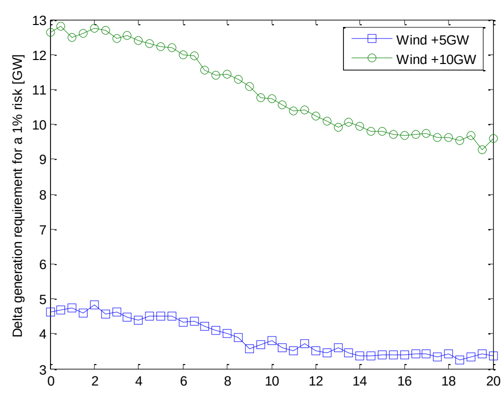

Fig. 8. Difference between generation requirement for a risk of 1% with wind and without wind corresponding to zone B

V. CONCLUSIONS

Using a simple model this paper studies the effects of transmission interconnection capacity in the adequacy of a system under two scenarios: low wind power penetration and high wind power penetration. First results indicate that increasing interconnection capacity between systems improves adequacy up to a certain level; then further increases do not produce any adequacy improvements. Moreover the improvement of adequacy due to interconnection increases when wind power generation in different countries are more decorrelated. This effect depends upon the amount of wind power installed in each zone. Furthermore, besides adequacy improvement, increasing transmission capacity under asymmetrical amounts of installed wind power could create several externalities (free-riding) concerns.

VI. BIOGRAPHIES

Mauricio Cepeda (b. 1981) received the M.S. degree in Industrial Engineering from the ENIM Metz (2006), France and the M.S. degree in Electrical Engineering from de ECI Bogotá, Colombia (2004). He also holds a Master's degree in Energy Economics from the Institut Françcais du Pétrole Paris, France (2007). Presently, he is PhD student in Economics at EHESS-Paris, and member of the LARSEN (www.gis-larsen.org) electricity research group. His main topics of research include power systems reliability, electricity markets modeling and electricity markets integration.

Marcelo Saguan (b. 1977) received the M.S. degree in Industrial engineering from the ENIM de Metz, France and from the University of Cuyo, Argentina (2001). In 2007, he received the PhD degree in Economics from the University of Paris 11 and from the Ecole Supérieure d'Electricité. Presently he is a member of the GRJM electricity research group of University of Paris 11 (www.grjm.net) and of the Energy Department of SUPELEC. His main topics of research are on energy policy, electricity market design, power systems and renewable energies integration in competitive markets.

Virginie Pignon (b. 1975) received a PhD in Economics from the University Paris 1, Panthéon - Sorbonne on transmission pricing in Europe.

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