Integrating intermittent energy sources in liberalised electricity markets: from technical costs to economic penalties as a result of market rules

Philippe MENANTEAU, Dominique FINON, Marie-Laure LAMY
The Institute of Economics and Energy Policy (CNRS, University of Grenoble)

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1. Introduction

With the aim of preventing climatic change and ensuring the security of energy supplies, the recent European Directive on renewable energy production sources is aimed at bringing about a very substantial increase in electricity production from renewable sources in Europe by the 2010 horizon. On average, the proportion will increase from 3.5% to 12.5% of total electricity consumption if one excludes the large hydroelectric power stations, whose potential for development in Europe is very limited. If the targets set for the Member States are reached, the proportion of renewable electricity, excluding the large hydroelectric power stations, could exceed 20% in some countries, reaching for example 29% in Denmark, 22% in Finland and Portugal, and 21% in Austria.

Generally speaking, production of electricity from renewable sources will be assured by biomass and wind, and to a lesser extent by micro hydro, technologies whose characteristics are very different from the point of view of their integration into the electricity system. Although the technology for producing electricity from biomass or from waste is highly flexible because of the possibility of storing resources, micro hydro and wind energy are by nature intermittent; in other words, their production cannot be programmed accurately from one day to another as it varies according to availability of resources. Their inclusion in the electricity systems will cause problems because of the intermittent nature of the production, a factor that does not enter into the paradigms of producers, system operators or regulators.

The problems raised by the integration of intermittent production are technical in nature (risk of non-availability in peak periods, the need for additional reserves) and will incur adjustment costs, but the way in which the electricity markets function will impose economic penalties generally more substantial than the added technical costs. In this paper we will examine in succession: (i) the additional costs raised by intermittence; (ii) the economic penalties imposed by the operating rules of deregulated electricity markets with electricity production from renewable sources included, with particular reference to the case of the British and Nordic markets; and (iii) an analysis of the options that could limit the gap between the additional cost of intermittent production for the system and the adjustment surcharges imposed by the electricity markets, with the aim of reducing the tension between deregulating the electricity market and promoting the development of renewable energy sources.

2. The costs of large-scale integration of intermittent and non-programmable energy sources into electricity systems

The technical costs incurred through the integration of intermittent energy sources into electricity systems are linked to the risk of non-availability in peak periods and to the need for additional reserves to maintain an immediate balance between supply and demand. Significant penetration of non programmable sources could lead to significant additional sources for the transport system operator, as is the case today in Denmark.

2.1 Additional technical costs linked to intermittence

The magnitude of the additional costs incurred by large-scale development of renewable electricity, and the relative contribution made by each of the elements depends on the mix of technologies available, their level of penetration and the geographical distribution of these production units within the electricity system.

A British assessment of the additional costs that would be incurred if the contribution made by renewable energy sources to electricity production exceeded the 10% planned for 2010 (Ilex Energy, 2002) shows that most of these costs (66-100% of the total additional costs) would be incurred because of intermittence. If the proportion of electricity produced from renewable energy sources reached 10-20%, the additional costs incurred would be 225-600 M€ per year, and if it reached 30%, they would total 750 M€ per year (Ibid).

Large-scale integration of non-programmable sources would incur additional costs on several different levels:

- the costs of setting up additional reserves to meet demand in peak period (system reliability) because of the increased proportion of intermittent sources,
- costs linked to the need to set aside greater reserves in real time in order to adjust equilibrium between consumption and electricity production.

- *The need for additional capacity*

Additional capacity is needed because of the uncertainty over the contribution made by the intermittent sources in peak period. We will not be covering this issue here which has been the subject of debate between specialists for several years now. The probability of failure of wind-based production in peak periods is in fact higher than that of failure of standard heat-based production[1]. Generally speaking, it is considered that although wind energy can contribute to available capacity in peak periods, the contribution cannot be guaranteed in the same way as that made by conventional production. The higher the proportion of wind energy in the peak period increases, the higher the risk becomes and the greater is the volume of production capacity that has to be kept in reserve to ensure that the safety of the system increases. The risk may be reduced by dispersing the production units geographically, but additional costs will always be incurred in guaranteeing the power.

- *Balancing the system*

The issue of balancing is set in another time scale, that of real time. It is no longer merely a question of planning for reserve production capacities to satisfy demand in peak period should intermittent sources fail, but one of ensuring a permanent balance between supply and demand in order to maintain quality of supply, because of the uncertainty of the wind energy contribution. In real time, both hourly demand and hourly supply are subject to fluctuations that can cause momentary imbalance which must be compensated by corresponding changes in production or in consumption. In a system mostly equipped with standard heat-based means of production, imbalances are mainly caused by fluctuations in demand, but when the proportion of intermittent sources in the system increases, unexpected variations in supply from producers constitutes an ever-increasing hazard, which must be compensated for. For this reason, the system operator must have access to spinning or immediately available reserves, the cost of which will increase as the magnitude of the imbalance increases[2].

It is generally estimated that the additional costs incurred by the development of intermittent power sources within the electricity system will remain low provided peak period contribution remains below a certain threshold, estimated to be between 5 and 10%. In this case, fluctuations in electricity supply will be absorbed by fluctuations in demand. For higher penetration levels, some people consider optimistically that diversification and geographical dispersion of intermittent production should smooth over the individual variations in each unit to a considerable extent, this reducing the overall effect on the system (Grubb & Vigotti, 1997).

Milborrow (2001) offers a more accurate estimation of the additional costs brought about by intermittence in the case of large-scale penetration of these energy sources. The analysis is based on the technical standards of the National Grid Company, which calculate the maximum production level subject to fluctuation, in other words, the rate of reduction or the immediate injection that the system can assimilate. These restrictions dictate the purchase of production capacity or additional spinning reserves depending on the level of penetration of intermittent production. They will lead to additional costs of between 2.00 and 3.35 €/MWh for a wind energy proportion of 10% (Milborrow, 2001 – PIU, 2002).

These additional costs are reflected in technical penalties based on the partially random nature of intermittent production, in contrast to the economic penalties imposed by the rules of the electricity markets.

2.2 The additional technical costs caused by large-scale intermittent production: the case of the West Denmark system

Because of the very favourable political incentives provided until 2001, the proportion of non-programmable electricity in Denmark is particularly high. The highly voluntarist policy of stimulating renewable electricity production mainly through feed-in tariffs for wind energy producers allowed large-scale, regular development of production capacities that reached almost 2,000 MW by the end of 2001. At the same time, Denmark favoured the development of small co-generation projects whose production capacity, stimulated by equally favourable must take policy and feed-in tariffs, progressed very rapidly throughout the 1990s and reached 1,500 MW by the end of 2001.

Wind energy and co-generation projects are given priority within the system. This so-called “bound” production must be integrated by the system operator and purchased by suppliers at the guaranteed price, regardless of effective hourly demand and market prices. In West Denmark, where most of the wind potential is located, this bound production now accounts for nearly 50% of total electricity production and the corresponding capacity largely exceeds basic demand (Table 1). It is, however, difficult to adapt. Wind production is only available when the wind blows, and production from co-generation units is closely correlated with demand for heat. The main contributions do not therefore necessarily correspond to period of high electricity demand. In addition Eltra, the transport system operator, is facing not only the two problems mentioned above but an ever-increasing incidence of electricity surplus, from which it is very difficult to benefit on the electricity market.

Table 1: The electricity system in Western Denmark (2000)

Supply	Installed capacity	Demand	
Wind energy	1866 MW		
Co-generation	1467 MW	Basic	1150 MW
Electric power stations	3201 MW	Peak	3650 MW

Note: Power consumed – 19.3 TWh
Source: Jensen, 2002

The presence of interconnections with neighbouring energy systems (Sweden, Norway and Denmark), and the integration of Denmark into Nord Pool, the Nordic electricity market, play a key role in allowing the system operator to absorb a significant quantity of the non-programmable production. However, there is a risk of the flexibility of operation allowed by interconnections with neighbouring systems rapidly becoming insufficient to integrate the additional, non-programable electricity sources into the Danish system. Significant and non-exportable surpluses will appear from 2005 onwards (1,000 MW over 500 hours) because of the likelihood of saturation of transport capacities to Sweden and Norway[3] (cf. study carried out by Eltra and the Danish Energy Authority, quoted by Eriksen et al., 2002). Eltra does not exclude the possibility of having to reject some wind energy if supply exceeds demand[4].

3. Intermittent production and “balancing price” penalties: the influence of the market rules

Intermittent production raises the issue of instant adjustments to hourly production. In the previous case of the vertically integrated monopoly, the system operator, who benefits from having full information on the nature of production fleet, can choose the production units to be mobilised to satisfy demand at minimum cost, on an hourly basis. Similarly, the system guarantees instant balance between supply and demand, by mobilising available reserves or calling upon interruptible contracts, so that quality of service is kept constant. Intermittent production is therefore included within the system without dissociation of the adjustments that it necessitates from the overall hourly adjustments.

On the deregulated electricity market, the actors have to advise the quantities that they anticipate injecting into or taking from the system several hours in advance. Technical adjustment costs linked to intermittence of production based on renewable sources can no longer be mutualised as a matter of principle. Competition logic leads to individualisation of responsibility for the market actors, who are involved in bilateral or multilateral relations. The difficulty arises from the existence of a number of externalities, mostly inextricable from transactions, because of the nature of electricity itself. It is established knowledge that the system operator no longer determines the optimal economic dispatch from the production units: this is now determined in part by contractual relations between producers and purchasers and in part by competition between anonymous supplies and demands organised on a market. The system operator must however continue to ensure that instant balance can be provided between production and consumption in order to maintain system stability, and must have authority to do so.

In theory, there are three ways of organising an instant balance between supply and demand on a deregulated market.

- If, and only if, in the case of an obligatory market such as the former British Pool, the Spanish Pool (OMEL) or the North-East American markets, it is possible to manage the consolidation of the balancing costs as in the previous electricity monopoly; in addition, this allows compensation for the ongoing hazards of production by all the producers.
- In decentralised markets (such as NETA, Nord Pool, APX, etc), the first solution is to make every producer or load servicing entity responsible for balancing the cost of their imbalance , in order to encourage them to acquire sufficient reserves or negotiate contracts with other producers for the supply of this type of services.
- In these markets an additional solution will also be required, as in real time, even with the incentives mentioned above, the system is never in a state of spontaneous balance of supply and demand. The state of ultimate balance must be provided not by the producers or by the suppliers, but by the system operator. The operator has the power to mobilise the production capacities necessary for obtaining balance, on the basis of day-ahead reserves offers, but the solution most commonly adopted today consists of organising an intra-day *balancing market*. On this market the system operator selects offers for injection of reserves or reduction of power demand in order to maintain balance in real time.

Several philosophies can be adopted for integrating non-programmable intermittent production into decentralised markets. Both NETA and NordPool made different choices for adjusting their imbalance situations. In Great Britain, the price of imbalance is attributed to producers individually (NETA). In addition, the rules are designed to provide producers or *load servicing companies* with a powerful incentive to respect their commitments of capacity offers and demands. This avoids the creation of imbalances between supply and demand. These rules impose substantial penalties on any intermittent producers unable to precisely anticipate the quantities to be effectively injected into the network some hours before.

In Scandinavia, imbalances are dealt with collectively between all the producers (NordPool) and they are only required to pay for imbalances that penalise the system at the precise time considered. The rules are not particularly strict, most notably because of the possibility of the hydro-based system responding to the situation very quickly. It will be seen that the “renewable” producers are not penalised, but that recourse to the Scandinavian balancing market by the Danish system operator because of fluctuations in his intermittent production incurs additional costs for him. These additional costs are then passed onto the “renewable” electricity purchasers. Of course, the second situation is much more favourable to intermittent producers.

Table 2: Methods of managing technical balance according to electricity market configuration

Method of dealing with imbalances	Consolidating costs and compensating for fluctuations	Methods of dividing the balancing costs			Examples
		Producers	System operator	Purchasers - Suppliers	
Individual treatment by the market	No consolidation or optional consolidation between producers	Individual imbalance cost	Adjustment costs compensated for by imbalance prices (income)	No direct effect on price	NETA
Collective treatment by the market	consolidation between network users	No effect	Adjustment costs aggregated (purchase on adjustment market)	Cost integrated into sale price	West Denmark, supported by Nord Pool
Collective treatment integrated into overall dispatching	consolidation between network users	No effect	Full consolidation of technical cost; integration into network service price	Cost integrated into network service price. Over-evaluation of adjustment cost possible	Former British pool

The following paragraphs detail how the adjustments are organised and define the prices paid by the producers or purchasers.

3.1 Market rules unfavourable to intermittent production: the case of NETA

The operating rules of NETA's *balancing mechanism*, designed in theory to allow balancing costs to be minimised and encourage suppliers to adjust their hourly purchases and sales as precisely as possible, has *de facto* penalised intermittent production over and above the technical costs imposed by the random nature of renewable production. Those involved in the electricity wholesale market (suppliers or purchasers) have to announce their offers of production or consumption early. The announcement must be made at the latest, at the "*gate closure*" stage, 4½ hours before the actual exchange period. If the operators are unable or unwilling to respect the undertakings that they have made, the result will be an imbalance, which the system operator manages by calling for specific additional offers intended for the balancing market.

To do this, in addition to the standard offers made on a given day for the next day, those participants who so wish can submit balancing offers on the form of prices for higher production or lower removal, or conversely for lower production or higher removal. If the system operator notices that demand is too high in relation to supply, he must accept offers that have the effect of reabsorbing the deficit (increased production / reduced consumption) and the other way round if supply exceeds demand.

Recourse to these offers will incur a cost for the system operator, a cost that is supposed to be passed on to those participants responsible for the imbalances through the price-making of the balancing mechanism. For each participant, the contractual volumes notified are compared to the actual volumes injected or withdrawn. The individual differences that result correspond to surpluses or shortfalls within the system; their function is to pay the operators who made a contribution to the system and to make those who caused the imbalances pay. This system carries penalties for producers unable to make sufficiently reliable forecasts day ahead, which is the case with the wind-energy producers.

The system functions on the basis of a double imbalance price: the average price of offers accepted for increased production or reduced withdrawal - "system buy price" or SBP- on one hand, and the average price of offers accepted for reduced production or increased withdrawal - "system sell price" or SSP - on the other hand. The sale prices of the surpluses are relatively low, while the purchase price of production intended to compensate the deficits is higher. Generally speaking, producers are "poorly" paid for production that is delivered and not contractualised, and have to pay "dearly" for contractualised production that is not delivered (C. Staropoli, 2001). For intermittent producers, the penalty increases in magnitude as the difference between the imbalance prices for the producers selling the surplus and for those who purchase in order to cover their production deficits.

In a system where the price would reflect the actual costs imposed by each participant in the system (that is not the aim of the UK's "balancing mechanism"), the penalty required to be borne by the intermittent production would correspond to the extra technical cost that it incurs, namely 2.0-3.0 €/MWh (see above). Using as a basis the actual figures for wind-energy forecasts and production, Milborrow has calculated that the effective penalty[5] levied on wind-energy producers in the context of NETA totalled 7.5 €/MWh[6], making the economic penalty very much higher than the technical cost mentioned earlier (Milborrow, 2001). In addition, NETA imposes a penalty on each intermittent producer even if the cumulative effect of the imbalances arising for "renewable" production as a whole at a given moment is limited or even zero. The fluctuations in production observed in each unit can be smoothed out to some extent when a large number of producers is connected to the network by random balancing as the overall adjustment is then much less than the sum of individual imbalances. Unlike the previous UK's "pool" system, which operated wholly on the system of consolidation of adjustments like the previous electricity monopoly, NETA does not allow producers to be aggregated or the risk of imbalances to be mutualised between intermittent producers.

3.2 Adjustment surcharges borne by the system operator: the Scandinavian case

There is a significant risk of imbalance on the renewable productions in Nord Pool. In fact, the injection proposals are stopped at midday for timetable sections relating to 0000-2400 hours the next day, and this creates a requirement to send wind-energy production totals 12-36 hours in advance. Despite significant improvements in the quality of forecasting tools, anticipating wind-energy production on a given day for the next day is still an uncertain process: in West Denmark the difference between the quantities announced and those delivered totalled 38% of total wind-energy production for 2000 (Eriksen et al., 2002). These errors of forecasting led to a total expenditure of €10 million in 2000, corresponding to the cost of purchasing electricity on Nord Pool to compensate for production shortfalls. The additional cost is therefore in the region of 3 €/MWh. However, that observation aside, the imbalance management rules are more favourable. As in the case of the British market, the differences between the quantities announced by the producers and the quantities actually injected are usually compensated for on the balancing market, but responsibility for the imbalances is here borne collectively.

The operating rules of Nord Pool differ from those of NETA in two respects. On one hand, in the British case, the current imbalance costs are allocated individually to the producers, regardless of whether they help increase or decrease the imbalance of the system as a whole. On the Scandinavian market, not only is there no effort to penalise individual imbalances, but penalties are only imposed on wind-energy producers when they aggravate the imbalance in the system (Holttinen, 2002). On the other hand, the cost of the hourly imbalance is not allocated to producers, either individually or collectively; they are imposed upon the system operator who pass them through to the suppliers and consumers subject to the purchase obligation. The assumption of the imbalances by the system operator allows the individual fluctuations and differences to be compensated for: the system operator manages only the residual overall random differences that dictate the purchase or sale of additional quantities on the balancing market[7].

In conclusion, additional costs linked to the integration of intermittent production into electricity systems are not simply the result of hourly production uncertainty that can be reduced by the level of accuracy of the weather forecasting models. They can also arise from the operating rules of the electricity markets. If the markets were more flexible in their operating rules by accepting offers up to one hour before the effective exchanges, errors of forecasting would be significantly reduced and the value of the wind-energy kWhs increased. Shortening the "gate closure" delay and consolidating the technical cost of imbalances amongst producers (or suppliers) are important options in making the operating rules of electricity markets more flexible in order to improve the value of renewable electricity sources.

4. **Adapting the design of the electricity market rules**

It will therefore have been noted that there is a difference between the technical costs of adjusting the system in real time (production and system) and the penalties paid by the producers (as in Great Britain) or the additional costs paid by the system operator on the balancing market (as in Denmark). The balancing price should reflect the costs, most notably the adaptation costs imposed by the integration of intermittent production. However, it also depends to a considerable extent on the design of the market rules, which are by nature imperfect because of the complexity of electricity as a product and the difficulty in creating clearly defined rights of ownership (Joskow, 1997). This design could consequently follow some specific incentive objective, such as that of dissuading opportunistic behaviour on the part of certain producers or suppliers who could move kWh offers from the day-ahead energy market to the balancing market if this proves more profitable. The existing rules can therefore be considered as being partly contingent upon the designers' objectives. It is therefore legitimate to look to make them develop, in order to resolve the conflict between two objectives: ensuring the efficiency of the electricity markets and supporting the development of energy products from renewable sources.

Of the foreseeable options, the following will be examined[8]:

- improving the forecasts by reducing the delay of "gate closure" (partial solution);
- reducing the difference between the imbalance prices;
- aggregating the producers through mutualisation of risks.

4.1 Reducing the "gate closure" period

On an electricity spot market, offers are generally made a day ahead for each half-hour period, up until the "gate closure", after which the proposals are made on the balancing market. The further this point is from the actual supply of electricity to the network, the more difficult it is for intermittent producers to forecast the quantities actually injected and the higher the economic penalty will be.

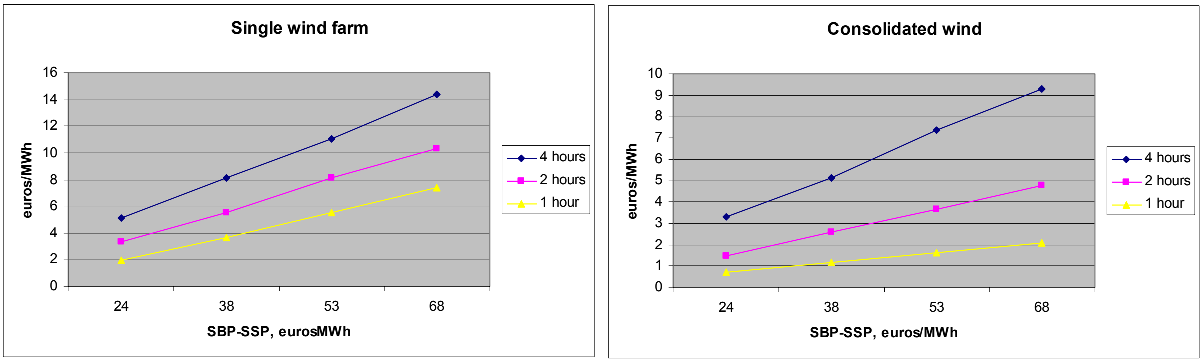
As was stated previously, improving the weather forecasting models is an area worth exploring with a view to increasing the value of intermittent production. A reduction in the "gate closure" period would produce similar results, while being easier to implement[9] and without calling into question the existence of the balancing market, as envisaged by a number of British critics. Reducing the "gate closure" period from 3½ hours to 1 hour on NETA significantly reduces the price penalty associated with the offer deficit for a wind-energy production (from 81 €/MWh to 37€/MWh for a difference between the two balancing prices of 38€/MWh) (Milborrow, 2001). On the Scandinavian market, if the offers are made within 6 to 12 hours in advance (instead of the current 12-36 hours), the balancing costs will be reduced by 30%; and if the "gate closure" period is cut to just two hours, the adjustment costs will be reduced by 70% (Holttinen et al., 2002). The "zero gate closure" option, also known as "ex post trading" could be envisaged (it is currently applied on the New York electricity market), but it carries the problem of not encouraging producers to maintain their positions, and this in turn can lead to an offer deficit and therefore additional costs for the system operator, counter to the objective sought.

On this account, the NETA's operating rules have been altered in July 2002; the "gate closure" period was reduced from 3½ hours to 1 hour.

4.2 Reducing the adjustment price

Another method of reducing the penalties imposed on intermittent production on the balancing market would be to reduce the difference between the imbalance charges and even to keep only one price (the "*single cash out price*"). The projection made by Milborrow (2001) clearly shows that the adjustment cost for intermittent producers is highly sensitive to the existing difference between the System Buy Price and the System Sell Price (Figure 1).

Figure 1: NETA penalties* for a range of gate closure



* Average annual decrease in value of kWhs
Source: Milborrow, 2001

As has been said, having a difference between the two prices is intended to dissuade the producers from deliberately putting themselves in an imbalance situation. The abolition of the double imbalance price would work against one of NETA's objectives, which was to encourage the participants to negotiate bilateral contracts (with identical quantities injected and quantities withdrawn) before the "gate closure" period and to adjust their offer on the spot market so as to minimise the balancing work for the system operator (DTI, 2001). Of course the effect is to reduce the value of non-programmable production, but this effect was in fact initially forecast, if not even sought by the designers: "*It has been suggested that a single cash-out price would remove the distinction between the values placed – deliberately – on predictable and unpredictable generation* respectively" (DTI, 2001). The NETA allows yet some strategic manipulation, but it is nevertheless considered to be the least ineffective in relation to the main initial objective, which is the efficient development of bilateral transactions and on the electricity exchanges (Staropoli, 2001).

4.3 Encouraging the aggregation of producers to compensate for fluctuations

In both NETA and Nord Pool, the presence of a balancing market leads to economic costs either for independent producers or for the trans system operator. A major difference between these two markets is however created by allocating the imbalance costs between the participants. In NETA, each participant has to bear responsibility for the imbalances that they bring about, whereas in Nord Pool, the drop in value of the wind kWh is not attributed directly to the intermittent producers. In the case of wind production, for example, the Danish producers benefit from guaranteed prices, the imbalance costs being the responsibility of the system operator who then recovers them from all the purchasers obliged to acquire green electricity. At the same time however this cost per kWh for the system operator is less than the unit adjustment cost which would be affected to each producer by the NETA in the UK. This matter is being debated in Great Britain: aggregating wind-energy production across British territory as a whole would reduce the penalty linked to the balancing market by 35-40% in comparison to a situation where there is no aggregation between producers (see Figure 1) (Milborrow, 2001).

Aware of the specific problem posed by NETA for intermittent and low-programmable producers, the British government has not sought complete consolidation. It is however looking to encourage the emergence of offers through private aggregation of "renewable" producers and co-generators. The advantage sought is to smooth over the individual fluctuations in production and allow entry to the electricity market under the best possible conditions. The aggregation process could involve small producers with a diversified technology portfolio (wind, microhydraulic and co-generation, for example); this would carry the advantage of still better smoothing out the fluctuations inherent in each source. The first moves in this direction did not however lead to anything, as the consolidation offer was still very much in the embryo stage (DTI, 2001). Those actively involved in the renewable energy sector, especially wind-energy producers, are still sceptical of the possibility of a commercial aggregation offer emerging in which profit-sharing would not be too unfavourable to them, in view of the costs that the aggregator would have to bear (BWEA, 2001).

5. Conclusion

There is a place for intermittent production with daily programmability in the deregulated markets. Clearly, integrating this production would lead to additional technical costs because of the risk of non-reliability at peak periods and the need for additional reserves required to maintain the system in an instant balance situation. However, the operating rules of the electricity markets could give rise to economic penalties very much higher than these additional technical costs. These penalties are caused by the existence of balancing markets whose rules are aimed at compensating for situations of imbalance between supply and demand, which are generated, deliberately or otherwise, by differences between quantities injected and quantities withdrawn. In fact, they could lead to conventional production being overly favoured over intermittent supplies.

The market rules are by nature imperfect. They are a response to many different objectives, most notably the wish to limit opportunistic behaviour on the part of producers and suppliers in relation to the need to balance in real time. The economic penalties imposed on intermittent producers as a result do not therefore reflect the reality of the additional technical costs that their production processes impose. The rules may be modified if, as in this case, they lead to conflict between the aim of achieving effective operation of the electricity market and the aim of supporting renewable energy sources. Developments such as reducing the "gate closure" period or the difference between the imbalance prices are movements in the direction of reducing the penalisation of intermittent production.

In conclusion, it will be noted that the instruments chosen for supporting renewable energy sources are not indifferent for the treatment of the cost of random intermittence.

- The feed-in tariffs systems go hand-in-hand with a priority injection of intermittent production and in fact lead to the additional balancing costs being imposed on the system operator.
- On the other hand, the green certificate exchange mechanisms, which require producers to sell physical electricity on the market (wholesale market or bilateral contracts) would expose the producers, either individually (NETA), or collectively (NETA with private mutualisation), to excess balancing prices; this would penalise intermittent production by devaluing it.

The consequence would be excessive prices for green certificates issued in countries in which the markets operate on the basis of the NETA rules model, as opposed to the Nord Pool markets in which the additional costs are mutualised; this would lead to distortions in thefuture European certificates market.

In these circumstances, the solution of dealing with imbalance collectively by applying a Scandinavian (or Danish) solution appears to be an interesting compromise between the individual, penalising solution (NETA with or without private aggregation between "renewable" producers) and collective treatment (integration with overall dispatching), which would be deprived of the interest in dealing with differences on an organised market, as was the case with the former British pool.

[1] Some people believe that wind-based contribution to available capacity in peak periods should be considered to be zero because of this probability of failure.

[2] Three types of reserve can be distinguished, according to their activation periods.

- The primary reserve, which is mobilised automatically and allows 1-2 seconds' reaction time.
- The secondary reserve, which should allow reconstitution of the reserves and make the primary reserve consumed available to the system again. These means of production are also mobilised automatically, within 30 seconds.
- The tertiary reserve, which groups together a series of "peak sources" that the system operator can mobilise over much longer periods, between 30 minutes and half a day, in order to reconstitute the secondary reserve consumed.

The total of the primary and secondary reserves makes up the system services supplied by the transport system operator. The tertiary reserve can be guaranteed on a deregulated market by introducing competition of offers either for instant capacity reduction or for capacity increase issued by market players.

[3] Jensen (2002) describes a classic example of a critical situation. On 21st April 2001, the weather forecast had predicted a fall in wind energy production, to be compensated for by an increase in co-generation. However, the wind increased and led to overproduction of 800 MW at a time when the transport capacity to Sweden, Norway and Germany were already saturated. The emergency plan in these circumstances was to reduce co-generation production, stop production at certain power stations, and overload the transport lines to Sweden and Norway. There was however a residual overproduction of 180 MW, which could have created a critical situation. This critical situation did not occur, because of a sudden restoration of the anticipated wind situation; but the system operator believes that a critical situation of this type is increasingly more likely to occur in years to come (Jensen, 2002).

[4] Before this solution is resorted to, the first one anticipated involves changing the rules for taking co-generated electricity from the network (no longer considering co-generation as priority), and then developing technical solutions for storing heat as a second solution. The possibility of storing heat for a number of hours would make dispatching from co-generation units easier, and it would then be less dependent on demand for instant heat.

[5] All excess production is assumed to be valued at SBP levels, while deficits are covered at SSP levels. Production forecasts are made at this time with a "gate closure" period of 3½ hours.

[6] Cost differences between SBP and SPP on NETA have been about 30 €/MWh in the last few months (PIU, 2002)

[7] When errors in wind-energy production forecasts contribute to an imbalance in the system, the double imbalance price is applied. On the other hand, when they have the effect of reducing imbalances in the system, the pool price is applicable, corresponding to 30% of errors (Holttinen, 2002).

[8] We will not be dealing here with the technical answers to the problem of loss of value of renewable kWhs because of intermittence, or the adoption of an increasing quantity of intermittent electrical production into the networks. Its non-programmable nature can be compensated by equipment of decentralised storage (such as batteries) or centralised storage (pumps, turbines, hydrogen production etc). In view of their exploratory nature or high cost, these solutions will not be dealt with here, but it is clear that they represent a possible medium-term or long-term option in the perspective of large-scale development of renewable source energy production. In countries equipped with pumping stations in particular, the acquisition of units of this type by major producers of electricity based on renewable sources could turn out to be a major asset.

[9] Improving the forecasts would have a similar effect to reducing the "gate closure" period on the adjustment costs, but unlike an improvement in the forecasts, reducing the "gate closure" periods would not have any effect on reducing the need for spinning reserves.

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