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DEVISING A SOUND REGIONAL APPROACH IN CROSS-BORDER CAPACITY ALLOCATION

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ABSTRACT

In the last years, the integration of the European electricity markets belonging to the so-called Internal Electricity Market has been continually discussed. In this frame, the implementation of a unified methodology for allocating interconnection capacity is one of the most significant topics. Since IEM is (and will stay, at least in the short term) constituted by a set of independent entities featuring quite different market models, the most viable solution seems to be resorting to co-ordinated methodologies that allow each market to clear prices and quantities following its own rules but, at the same time, provide a common allocation procedure for cross-border capacity. Thus, both explicit (co-ordinated auctions) and implicit (de-centralized market-coupling) methodologies have been proposed. This paper shows that both approaches are subject to drawbacks. Co-ordinated auctions are liable to the exercise of market power. Market coupling is less subject to this problem, but care must be taken in order to devise an algorithm capable to be gradually extended up to cover the entire IEM area.

KEY WORDS

Cross-border capacity allocation, market power.

1. Introduction

In the last years, the European Commission (EC) has been pursuing the integration of all the EU national electricity markets into one only entity called Internal Electricity Market (IEM). With this aim, in 1998 the so-called *Florence Forum* was founded, in order to discuss all the issues concerning cross-border trade. Among these issues, one of the most important topics concerns establishing general rules for a sound allocation of interconnectors capacity (i.e. transmission network sections lying across the borders and connecting different countries).

On 26 June 2003 the new directive 2003/54/EC was approved, together with a *regulation on cross-border trade in electricity* (1228/2003). This regulation requests that the following congestion management principles are enforced:

- *network congestion problems shall be addressed with non-discriminatory market based solutions which give efficient economic signals;*
- *the maximum capacity of the interconnections and/or the transmission networks affecting cross-border flows shall be made available to market participants, complying with safety standards of secure network operation;*
- *transmission system operators shall, as far as technically possible, net the capacity requirements of any power flows in opposite direction over the congested interconnection line in order to use this line to its maximum capacity. Having full regard to network security, transactions that relieve the congestion shall never be denied.*

The same document states (art.1): "*This Regulation aims at setting fair rules for cross-border exchanges in electricity, thus enhancing competition within the internal electricity market, taking into account the specificities of national and regional markets*", making specific reference to the concept of *region*, meant as a multi-national entity internal to the IEM the borders of which should not necessarily coincide with geographical ones but be determined on the basis of electrical criteria, highlighting the most frquently congested sections. Thus, a region could encompass control areas under the control of several TSOs.

In 2004, the EC issued a Strategy Paper ([1]) outlining the envisaged medium-term evolution of the IEM. Such document describes the process of gradual integration of the IEM into one only entity. An intermediate stage of this process should see the formation of independent regions, comprising a set of member states characterized by a sufficiently strong mutual interconnection. Within each region, market rules should be fully harmonized, while regions should not diverge between each other. By 2008 the regional markets should achieve a full developement and, from 2010 on, their integration should be carried out.

In order to activate the regional approach, the 11th Florence Forum established the so-called *Mini Fora*, with the aim *to make progress in the different regions where* [non-discriminatory market based solutions congestion management mechanisms in compliance with Regulation 1228/2003 still] *need to be introduced*". The first round of Mini Fora took place during the first months of 2005.

In July 2005, ERGEG[1] published a new set of draft Guidelines on Congestion Management[2]. This document

[1] European Regulators Group for electricity and gas.

[2] Previous versions of these guidelines were issued directly by EC.

maintains (par. 1.7) that co-ordinated allocation procedures for allocation of capacity to the market, at least yearly, monthly and day-ahead, shall be applied at latest from 1 January 2007 inside all the areas corresponding to the seven Mini Fora. Co-ordination implies a joint application of one allocation method over all the borders of a given region.

As far as Italy is concerned , previously to the application of the Regulation 1228/2003, a pro-rata allocation method was applied to the borders with France and Austria.

This method was not market-based, then, not compliant with the Regulation. Thus, in 2005, a new method was applied. This method integrated the interconnectors inside the Italian zonal market by defining the concept of "virtual zones" corresponing each to an electrical border. Bids could be entered in these special zones and price differences could result between these zones and phisical market zones whenever congestion occurs.

This method, although market-based and compliant with the Regulation, didn't meet the favor of the foreign countries, that didn't like to see the formation of a reference price at their borders, distinguished from the clearing prices present in their own markets. Thus, no agreement for a common allocation in 2005 was reached and on each border capacity was allocated 50% by the Italian TSO (GRTN) and 50% by the foreign one.

From this point of view, the Central-South Region Mini Forum, that took place in Milan on 25 January 2005, didn't succeed in smoothing the divergences between the countries. The situation is made even more complicated by the presence in the region of two states which are not bound to apply Regulation 1228/2003: Switzerland, which is no EU member, and Slovenia, which obtained a delay up to 2007.

Thus, in order to help providing a foundation for the application of a common (possibly co-ordinated) allocation methodology between Italy and the neighboring states, CESI was asked to provide a consultancy during the year 2005. This paper describes some achievements reached in the frame of this consultancy.

In particular, some problems with applying co-ordinated methodologies will be highlighted. As far as explicit auctioning methodologies are concerned care must be taken to limit the possibility to exercise market power by incumbent producers in the importing country (i.e. Italy). This entails to modify the general methodology by preventing a single operator to acquire a significant amount of capacity paid at high prices.

As concerns implicit procedures, we will show an implementation of Decentralized Market Coupling (DMC) that doesn't require the single markets to provide a clearing curve function of the import. This new iterative approach allows to easily extend the application of DMC to a meshed configuration of whatsoever complexity as it could be the case if this methodology were applied on the whole European grid. However, as we will show in a simple numerical example, because of the decentralized structure of the market coupling algorithm, particular care must be taken in the calculation of the zonal prices.

2. Cross-border congestion management

Congestion can be managed with different methodologies:

1. *Nodal market* – In nodal markets, the energy prices differ from one node to another when congestion[3] occurs on interconnection lines. The impossibility, due to transport constraints, of importing energy from cheaper nodes compels buyers to accept the more expensive bids of generators that are local or connected through non-congested lines. Thus, nodal energy prices differ and some nodes are more expensive than others. The difference between the prices of two nodes connected by a congested line may be seen in terms of opportunity cost: the cost that would be spared if it were possible to allow an extra transit on the congested line. Loads in expensive nodes pay a higher price than the one paid to generators in the cheap nodes where this energy is produced: TSOs extract a congestion revenue.
2. *Market splitting* – This method is a simplification of a nodal market. The whole transmission network is partitioned into aggregates of nodes and lines, called "zones", representing sorts of "virtual" nodes, interconnected by the lines that are most frequently congested; conversely, congestion rarely takes place in lines contained inside each zone.

   The market is first cleared without taking into account transmission constraints, obtaining the so-called "unconstrained" market clearing price. Then, the "unconstrained" solution is checked against inter-zonal transmission constraints. In case of congestion between two zones, the market is split into two different markets, where prices are differentiated: the price in the exporting (importing) zone is decreased (increased) w.r.t. the "unconstrained" price in order to reduce the production (consumption) until the flow through the congested inerconnection is reduced exactly to the maximum transfer capability. Market splitting provides the TSO with a congestion revenue, just like a nodal market.
3. *Explicit auction* – TSOs sharing interconnectors can choose to auction off the transmission capacity of one or more interconnections. If the implemented capacity market is sufficiently sound and competitive, it can be shown that it is equivalent to market splitting.
4. *Counter trading* – In case of congestion, the TSO requests generators to regulate down a certain amount of generation on the surplus side of the congested line, for which they are paid. Similarly, generators on the shortfall side are paid to regulate generation up

[3] Prices also differ due to losses.

the same amount. This amount of power will flow in opposite direction w.r.t. the power the market players wish to transmit, making an extra transmission capacity available in the direction of congestion. In order to identify the lowest-priced counter trading parties, the TSO usually refers to a merit order built on the basis of the bids submitted by generators on the real time balancing market or in the day-ahead energy market.

Counter trading is not considered as a market-based method by the ERGEG guidelines, as it provides economic signals only to those generators and loads which are paid to be regulated up or down.

Among market-based methods, nodal markets and market splitting, although being the most efficient methods cannot be applied presently between IEM countries because they require the existence of a common electricity market. However, as shown by EuroPex[4] and ETSO[5] in [2][3], a *Decentralised Market Coupling* (DMC) implicit procedure may indeed be applied, consisting in the following steps:

- *national stage:* each market calculates a clearing price in function of the sell/purchase bids. This price also depends on the import across the borders, that can be thought of as equivalent to a zero-price sell offer in the import countries and to a purchase offer without indication of price in the export countries. This dependence results in a clearing curve function of the quantity of import/export.
- *coordination stage:* price differences between market clearings are minimized taking into account limits on interconnectors capacity. If limits are not binding, one only price results for the two markets and import/export levels are calculated consequently. In case of congestion, instead, price differences between markets determine a congestion fee that provides economic signals to the subjects (see Fig. 1).

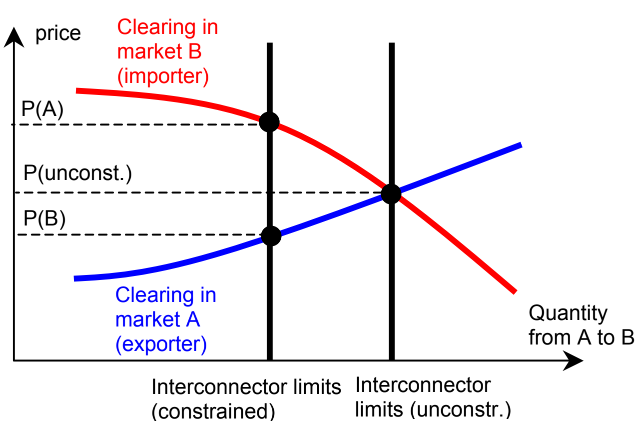

Fig. 1 - Decentralized Market Coupling

[4] Organization grouping European Power Exchanges

[5] Organization grouping European TSOs.

DMC has the advantage that it can be co-ordinated among several markets, thus it can provide a good basis for a joint allocation.

Also explicit auctions can be applied in a multi-market environment, provided that the interconnection capacity market precedes the national electricity markets, where the market players may bid for the use of the acquired interconnection capacity or, alternatively, notify bilateral agreements making use of it. A co-ordinated version of explicit auction has been proposed by ETSO (see [4][5]), and a dry run of this mechanism is being experimented in the South-East European region. Details on the co-ordinated auctioning algorithm are shown in the next section of this paper.

Co-ordinated auctions and DMC could both be implemented in order to set up a regional congestion management procedure. However, as it will be shown in next sections, care must be taken when implementing explicit auctions, because the temporal decoupling between the two markets (regional capacity market and national energy market) may provide incumbent producers extra possibilities to exercise market power in the importing market.

3. The co-ordinated auctions methodology

By applying allocation procedures co-ordinated over several borders it is possible to maximize the allocated quantity without resorting to post-clearing non market-based procedures like counter trading. In this way, we can satisfy one of the main requirements of the Regulation 1228/2003.

Let's demonstrate it on a hypothetic meshed triangular network the nodes of which are Italy (I), Switzerland (CH) and France (F), see Fig. 2. An application of the co-ordinated auctioning procedure for the allocation of export capacity from F and CH to I is shown.

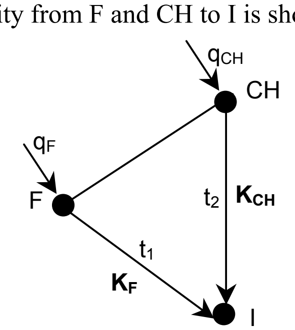

Fig. 2 – Three nodes meshed network

First, provided that the two injection powers (q_{CH},q_F) and the PTDF factors[6] related to the three interconnection

[6] The Power Transfer Distribution Factors (PTDF) represent the amount of flow on a given line due to a transaction of a unit of power (MW) between a given injection node and a common slack withdrawal node.

lines are known, the following unequalities can be written to enforce the limit of transit between Switzerland (K_{CH}) and Italy and between France and Italy (K_F):

$$\begin{cases} q_{CH} PTDF(CH,t_2) + q_F PTDF(F,t_2) \le K_{CH} & (1) \\ q_F PTDF(F,t_1) + q_{CH} PTDF(CH,t_1) \le K_F & (2) \end{cases}$$

These two equations can be rearranged as:

$$\begin{cases} q_{CH} \le \dfrac{K_{CH} - q_F PTDF(F,t_2)}{PTDF(CH,t_2)} = a_1 - b_1 q_F & (3) \\ q_{CH} \le \dfrac{K_F - q_F PTDF(F,t_1)}{PTDF(CH,t_1)} = a_2 - b_2 q_F & (4) \end{cases}$$

that represents a symplex in the plane q_F-q_{CH}, delimitated by the two axes and the two transit limits (see Fig. 3).

Within the admissible area, we can distinguish two regions:

- A rectangular area (in cyan) where the capacity available on one border doesn't depend on the allocation performed on the other border. This capacity could also be allocated separately on each border;
- Two triangular regions (in yellow), where any allocation on one border reduces the amount available on the other. If this capacity is allocated separately on each border, either the available capacity is not maximised or ex-post counter trading procedures are needed in order to obtain a feasible allocation of the interconnectors.

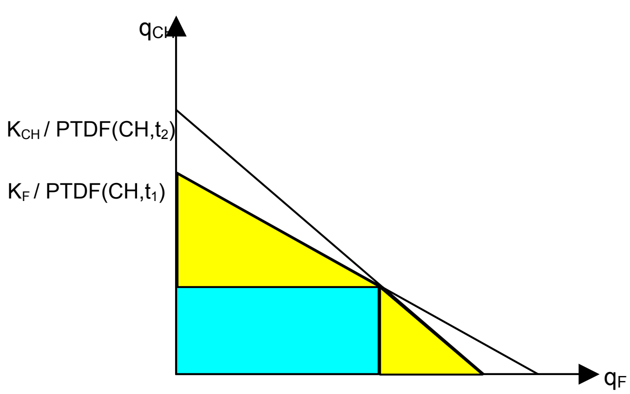

Fig. 3 – Symplex defining transit limits

Finally, the co-ordinated allocation algorithm is translated into a procedure maximizing the sum over all the border of the products between the allocated injection quantities and their related bid price. Considering only injections in CH and F destined to Italy, we get:

$$\begin{cases} \min\left[\sum_i q_{CH}(i) P_{off}(i) + \sum_j q_F(j) P_{off}(j)\right] & (5) \\ 0 \le q_{CH}(i) \le q_{off\,CH}(i);\ 0 \le q_F(j) \le q_{off\,F}(j)\ \ \forall i,j & (6) \\ \sum_i q_{CH}(i)\, PTDF(CH,t_2) + \sum_j q_F(j)\, PTDF(F,t_2) \le K_{CH} & (7) \\ \sum_j q_F(j)\, PTDF(F,t_1) + \sum_i q_{CH}(i)\, PTDF(CH,t_1) \le K_F & (8) \end{cases}$$

4. Co-ordinated auctions and market power

In principle, it is possible to show that implicit and explicit allocation bring to the same kind of efficiency in the clearing of the capacity market. Efficiency can be measured by means of the parameter *social welfare* that, in the market clearing diagram, corresponds to the area between demand and offer curves.
However, in presence of imperfect markets, implicit and explicit allocation are not equivalent (see also [6]). In particular, there are at least two situations where the implicit solution is more efficient than the explicit one (see [7]):

- **Imperfect information:** in an explicit allocation, due to the fact that capacity and energy are not cleared together, events occurring during the period between capacity allocation and clearing of the energy market may cause a loss of efficiency. For instance, supposing that during this period the subjects are informed that some power plants will be unavailable, capacity bids based on the forecast of the price differentials between the two markets could no longer be adequate to the market conditions. At the end, capacity will be assigned in a non-optimal way, w.r.t. an implicit allocation, in which capacity and energy are allocated contemporarily.
- **Exercise of market power:** due to the sequential solution of the capacity and the energy market, an incumbent operator can bid in the energy market in dependence from the results of the capacity allocation If he has got a significant share of capacity, he will feel more incentivized to exercise his market power in the importer country (e.g. Italy). Let's exemplify it with the example shown in Fig. 4. Suppose two mutually interconnected countries: A (exporter) and B (importer) and that the expected prices of energy are, respectively, p_A = 40 €/MWh e p_B = 50 €/MWh.

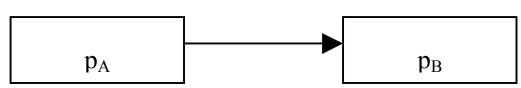

Fig. 4 – Two interconnected markets

In conditions of perfect market (no market power and perfect information), a producer in A that wants to offer competitively energy in B, should sell it at a price lower than p_B. On the other hand, this price should be at least equal to the one he could have got by selling it in A (p_A) plus what he had to pay in order to take energy from A to

B, equal to his offer in the capacity market (p_{off}). Thus the following condition must hold:

$p_A + p_{off} \leq p_B$, $\rightarrow$ $p_{off} \leq p_B - p_A$.

In a perfect market, a bid higher than ($p_B - p_A$) would be inefficient, whereas a lower one would leave possibilities to competitors. Thus, the bid price on the capacity market would be exactly equal to ($p_B - p_A$) = 10 €/MWh.

Now, let's suppose that in B there is a dominant producer. In this case, p_B depends from the behavior of this subject. Let's suppose that this producer bids in the capacity market at a price slightly higher than 10 €/MWh. Here two cases are possible:

Case 1: the other producers assume the incumbent doesn't exercise his market power - Therefore, they will bid at 10 €/MWh on the capacity market. If the incumbent bids at a price higher than 10, he will get the capacity from A to B. Then, he could decide to exercise market power in B, raising p_B up to 60 €/MWh and gaining an extra-profit of 10 €/MWh on the energy sold in B, being able, at the same time, to be competitive with the imported energy, that he will be able to resell at a price equal to $p_A + p_{off}$.

Case 2: : the other producers assume the incumbent will exercise his market power – By supposing that the price in B is 60 €/MWh, they will bid in the capacity market at a price equal to 60 – 40 = 20 €/MWh. As the incumbent's offer is slightly higher than 10 €/MWh, he won't be assigned interconnection capacity. Consequently, he will be less incentivized to exercise market power in B. If he doesn't exercise it, the price in B will be 50 €/MWh. At this point, if the other producers would offer capacity in B at a price equal to $p_A + p_{off} = 40 + 20 = 60$ €/MWh they couldn't be competitive in B. Thus, they have to offer it at a price lower than $p_B = 50$ €/MWh with a loss of at least 10 €/MWh.

The example shows that in a pure explicit allocaton a dominant producer could exercise market power by modifying his behavior exploiting the information drawn from the sequential solution of capacity and energy markets.

As this behavior is based on bidding at a price higher than the price difference between the two markets, a price cap could have very beneficial effects, preventing (or at least attenuating) unfair behaviors by incumbent producers. In particular, let's show that the problem shown above can be alleviated by reducing the maximum capacity share that can be allocated to a single operator decrease with the increase of his bid price.

For simplicity, let's introduce the following simplifying hypotheses:

- to consider two markets A and B separated by an interconnector (Fig. 4);
- that a *pay-as-bid* scheme is implemented in the auction for interconnection;
- that the market in B (importer region) is characterized by an incumbent producer, able to set at will energy prices and a certain number of di *price takers* without influence on prices;
- that the incumbent in B bids in the interconnector market taking into account the level of price he is going to set in the energy market, so as to maximize his profit.

The profit function of the incumbent is made of two terms: one relating to the energy produced and sold in B, another to the energy purchased in A and re-sold in B.

Leaving out the first term, that doesn't depend on the imported energy since we supposed that the incumbent can set prices in B at will, the remaining portion (Π) of the profit function is[7]:

$$\Pi = q\,(P_B - P - P_A) \qquad (9)$$

being q the portion of interconnection awarded to the dominant producer, P the capacity auction price (equal to the bid price), P_A and P_B the energy price in A and B[8].

By supposing the price in A can be forecast with a good level of approximation, a good strategy of the dominant operator could be, knowing the level of price he is going to set in B, to bid in the capacity market lower than the real price differential ($P_B - P_A$) so as to get a profit from selling the capacity he obtains in B but higher than the competitive differential ($P_B^C - P_A$) so as to put out-of-market the other competitors who, being price takers, don't dispose of a reliable information on the real value of P_B . In other words, the incumbent will bid the real prices differential minus a certain quantity K[9]:

$$P_{BID} = P_B - P_A - K \qquad (10)$$

$$K = \vartheta\,(P_B - P_B^C) \quad \text{con } 0 \leq \vartheta \leq 1 \qquad (11)$$

As the auction is settled *pay-as-bid*, the value P the dominant pays is equal to his bid price P_{BID}.

Now, let's compare two possible regulatory cases:

- maximum amount of capacity that can be acquired independent from bid price;
- maximum amount of capacity that can be acquired in function of bid price.

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7 In this example, the energy corresponding to the purchased capacity is re-sold at price P_B. Indeed, it will be re-sold at a slightly lower price, allowing to be competitive w.r.t. the energy produced in B.

8 For the sake of simplicity, we consider one single hour, but the same could be replicated over an amount of hours.

9 If $\vartheta = 0$, then $P_{BID} = P_B - P_A$ and the unit profit is zero. If $\vartheta = 0$, then $P_{BID} = P_B^c - P_A$ and the unit profit is $P_B - P_B^c$: the dominant's profit is equal to the whole overprice in B.

Case 1: maximum amount of capacity that can be acquired independent from bid price

By replacing (10) and (11) into (9), we get:

$$\Pi = q\,(P_B - P - P_A) = q\,(P_B - P_B + P_A + K - P_A) = q\,K = \\ = q\,\vartheta\,(P_B - P_B^C) \qquad (12)$$

highlighting that, for any level of interconnection quantity, the profit of the incumbent grows with P_B. Hence, the incentive for the dominant to increase P_B by exercising his market power.

Case 2: maximum amount of capacity that can be acquired function of bid price

Now, let's introduce a regulatory provision reducing the maximum capacity that can be acquired with the increase of bid prices:

$$q_{max} = b - a\,p \qquad a, b > 0 \qquad (13)$$

Supposing the dominant purchases an amount of capacity equal to q_{max} and replacing (10) and (11) into (9), yields:

$$\Pi = q\,(P_B - P - P_A) = q\,(P_B - P_B + P_A + K - P_A) = \\ = [b - a\,(P_B - P_A - K)]\,K = \\ = -a\,\vartheta\,(1 - \vartheta)\,P_B^2 + f_1(a, b)\,P_B + f_2(a, b) \qquad (14)$$

that is a parabola with negative convexity. In particular, parameters *a* and *b* can be set in such a way that the maximum of the function occurs for $P_B = 0$. In this way, the purchase of interconnection capacity provides the dominant with no incentive to exercise market power in B.

In conclusion, the introduction of a provision reducing the maximum capacity that can be allocated to a subject at the increase of the bid price can be arranged so as to discourage dominant producers from exercising their market power in the receiving market.

5. Decentralised Market Coupling

The scheme of DMC application shown in par. 2 according to what explained in [2][3] is clearly exemplified for the case of two interconnected markets. When the number of interconnected markets and the number of borders inside each of them grows, the necessity, formulated in [2], that national markets provide the co-ordination level with a parametrical curve calculating the clearing price in dependence from the import/export level on each border seems to be a quite strong hypothesis. In fact, this curve is a very complex parametric function of many variables, the calculation of which is rather complex.

Thus, in the mid-term perspective to extend the application of DMC to the whole interconnected countries of IEM, a very complex meshed network, we searched for a new implementation that removed this hypothesis.

The starting point was given by a few basic principles of DMC that stay valid with a whatever number of markets generically interconnected in a complex mesh:

- the interconnection capacity is implicitly allocated, together with the clearing of the involved national markets;
- national energy markets and co-ordinated allocation of interconnection capacity are mutually dependent:

a) national markets may calculate their demand-offer equilibrium (clearing quantities and prices), only once the relevant level of import/export is known;

b) in order to perform an optimal allocation of the interconnection capacity we need to calculate cross-border flows that maximize the overall social welfare, that, in turn. can be calculated only after clearing price and quantities of the national markets are known.

This brings to the following iterative process: moving from a given level of cross-border flows, national markets (*local stage*) provide clearing prices and quantities to the *coordination* level that, in turn, re-dispatches generation among the countries so as to satisfy demand in the most efficient way (i.e. maximizing the overall *social welfare*) and calculates new cross-border flows, with which the local stage can be solved again, see Fig. 5.

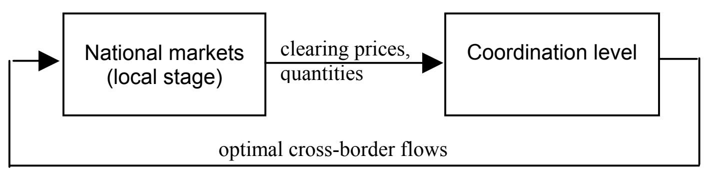

Fig. 5 – Iterative DMC procedure

Convergence of this algorithm is assured if the iterations are built so as to achieve a gradually growing level of overall social welfare.

The DMC modification explained above achieves the important target to keep the clearing of the national markets under national responsibility. The routine calculating the clearing of a national market can incapsulate inside any kind of complexities required in order to take into account all the different regulatory provisions that differentiate one market from another, provided that this routine talks with the coordination level through a standardized interface. For instance, the Italian market may be seen by the coordination as a monolithic entity, although being a complex zonal market (see Fig. 6), provided that it gives back to the coordination level one set of clearing values.

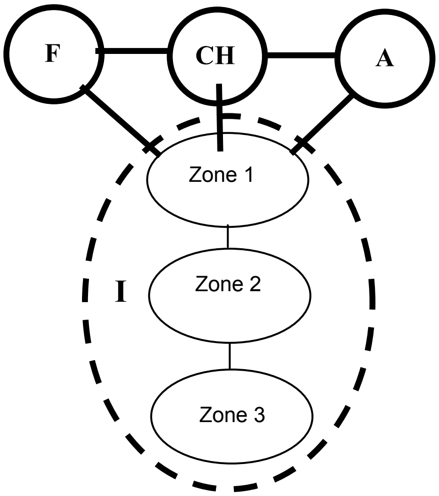

Fig. 6 – Complex zonal market incapsulated into a DMC area

Thus, the modified DMC algorithm is based on the following steps:

1. **initialization**: national markets are cleared with all cross-border flows at zero. Each market provides clearing price and quantity;
2. **coordination level**: minimum cost re-dispatching of overall national generation levels keeping national consumption fixed. In this way, optimal cross-border flows are calculated;
3. **local (national) stage**: national markets are solved again with the transit levels calculated in step 2. Cross-border flows are considered as generation bids at zero price (import) or as consumption bids without indication of price (export), so that they are scheduled with maximum priority;
4. **test**: if the sum of the values of *social welfare* calculated by all the national markets (excluding the contribution of fictitious generators and loads) has grown w.r.t. the previous iteration, next iteration is performed by going back to step 2., otherwise the solution featuring the maximum level of social welfare is accepted.

Particularly critical for the modified DMC algorithm is the implementation of the coordination level. In fact, the routine clearing the national markets may encapsulate any level of complexity, provided that a standardized interface is provided to the coordination level. Conversely, the coordination level is run in a centralized way and must guarantee transparency, equal treatment to all the cross-border flows, be convergent and perform its calculations as fast as possible. The following equation set performs the coordination level[10]:

$$
\begin{cases}
\min \sum_{i=1}^{NM} \hat{p}_i^G \, q_{Gi} & (15) \\
\sum_i q_{Gi} - \sum_j \hat{q}_{Dj} = 0 & (16) \\
\hat{q}_{Gi}(1-perc) \le q_{Gi} \le \hat{q}_{Gi}(1+perc) \quad \mathrm{i} \in 1...NM & (17) \\
-F_k^- \le T_k \le F_k^+ \quad \mathrm{k} \in 1...\mathrm{NT} & (18) \\
T_k = \sum_i PTDF_{zIi,k,S} \; q_{Gi} - \sum_i PTDF_{zOj,k,S} \; \hat{q}_{Dj} & (19)
\end{cases}
$$

Equation (15) re-dispatches the overall generation level of each national market (q_{Gi}) at minimum cost, using the price levels (p_i^G) obtained by the clearing procedures of the national markets.

Constraints take the following meanings:

- the sum of all the national generation q_{Gi} must balance the sum of all the national demand q_{Dj}, the latter supposed fixed to the values provided by the clearing of the national markets (equation 16);
- the overall national level of generation is allowed to deviate at maximum by a given percentage *perc* from the national claring value (equation 17). This constraint is important because convergence is obtained only in a linearized domain, i.e. forcing the generation re-dispatching to stay around the value obtained from the national clearing: otherwise two adjacent iterations could see very different national clearing values and simple stability or even instability could occur. Furthermore, we verified the beneficial effect of a gradual reduction of the *perc* value. Greater displacements are allowed during a first run, up to reach a coarse solution. This solution is used to initialize a second run of the algorithm in order to achieve a further refinement around this solution with a smaller *perc* value. Many subsequent re-runs may be arranged with gradually diminishing values of the parameter *perc*;
- cross-border flows must stay within the maximum levels of transits on the interconnections (equation 18);
- cross-border flows are calculated in function of the power injections due to generation (q_i^G) and of the withdrawals due to loads (q_{Dj}). This relationship makes use of the so-called PTDF factors, calculated as a function of a common slack node *S* (equation 19)

This model is equivalent to setting up a hypothetic over-national market, the zones of which are the single countries. This market maximizes the *social welfare* considering a rigid zonal demand equal to national clearing value, while generation, although allowed to change, must stay within a band around its national clearing quantity. Generation bid prices correspond to the clearing values of the national markets.

[10] In the equation set (15)-(19), the sign " ^ " indicates clearing values calculated by national markets.

6. Numerical example

In this section, we present a numerical application of the DMC algorithm explained above.
Setting up a realistic scenario concerning several European countries is a non-trivial work that goes far beyond the scope of this paper. In the following, we just limit ourselves to a simple example that allows to highlight some critical points in view of a real application. *These criticities are not a characteristic feature of the presented algorithm but common to all the decentralised market algorihms.*
Let's consider the triangle network shown in Fig. 7, where each node is meant to represent a non-zonal national market.

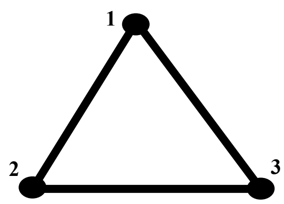

Fig. 7 – Triangle network

Nodal generation bids (G) and load purchase bids (L) are shown in Tab. 1, Tab. 2 and Tab. 3.

q(G)	P(G)	q(L)	P(L)
10 MWh	0 €/MWh	10 MWh	500 €/MWh
20 MWh	10 €/MWh	20 MWh	50 €/MWh
20 MWh	20 €/MWh	20 MWh	10 €/MWh

Tab. 1 - Bids at node 1

q(G)	P(G)	q(L)	P(L)
10 MWh	0 €/MWh	50 MWh	500 €/MWh
10 MWh	10 €/MWh		
20 MWh	30 €/MWh		
5 MWh	40 €/MWh		
5 MWh	50 €/MWh		

Tab. 2 - Bids at node 2

q(G)	P(G)	q(L)	P(L)
20 MWh	5 €/MWh	5 MWh	500 €/MWh
10 MWh	10 €/MWh	25 MWh	30 €/MWh
10 MWh	20 €/MWh	20 MWh	20 €/MWh
5 MWh	30 €/MWh		
5 MWh	40 €/MWh		

Tab. 3 - Bids at node 3

Our DMC algorithm, programmed in MATLAB, calculates the market clearing solution in 27 iterations[11] (4.2 s on a Pentium 4 - 2.6GHz):

- social welfare: 33150.00 [€]
- zonal clearing prices: 20.00, 10.00, 20.15 [€/MWh]
- zonal generation: 50.00, 20.00, 40.00 [MWh]
- zonal load: 30.00, 50.00, 30.00 [MWh]
- transits: T_{12}=16.67, T_{23}=-13.33, T_{13}=3.33 [MW]

As no transit is congested, the three zonal market clearing prices should not differ. Thus, the calculated set of market prices is not acceptable.
A centralized algorithm, either programmed in MATLAB, provides the same dispatching as DMC but calculates different values for the clearing prices (26.45 €/MWh, equal for all the three markets).
An explanation for these facts can be easily found by performing a separate graphical clearing on each market, taking into account transits by including a zero-price generation offer (importing nodes) or a consumption offer without price indication (exporting nodes), see Fig. 8, Fig. 9, Fig. 10. While aggregated generation and consumption curves intersect in just one point for zone 1, they have a segment in common for both zone 2 and 3. This, lacking further regulatory indications, leaves a degree of freedom in the choice of the zonal price. A posteriori, knowing that no congestion occurs and, consequently, imposing that the three national markets are cleared at the same price, the complusory choice would be $MCP_1 = MCP_2 = MCP_3 = 20$ €/MWh. However, also this choice seems somehow arbitrary. In fact, as we know that no congestion occurs on the triangular network, we can also clear graphically the ensemble of the three markets as if they were one only entity (Fig. 11). In this way, we can notice that the aggregated demand/offer curves for the ensemble of the three markets intersect over a segment too and that the MCP can be an arbitrary number in the range {20 30} €/MWh. This interval includes both 20 €/MWh (coming out from the separate clearing of the three markets) and 26.45 €/MWh (resulting in the centralised solution).
In conclusion, the decentralised coupling of a set of markets is a very promising alternative to the fusion of national markets into one only entity. However the calculation of zonal prices, yet decentralised, must be carried out in a coordinated manner in order to prevent that the existing degrees of freedom, used in a uncoordinated way by the single markets, provide price differentials even in absence of congestion, thus contradicting one of the most important economical priciples: only scarce resources can bear a non-null value.

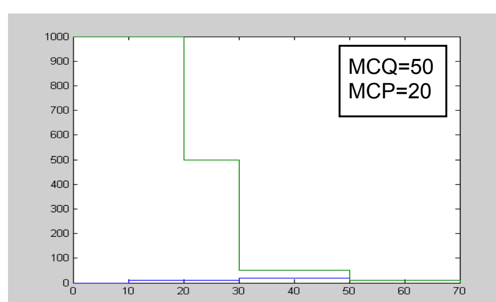

Fig. 8 – Clearing market zone 1

[11] This depends on the *perc* coefficients in eqn. (17) too.

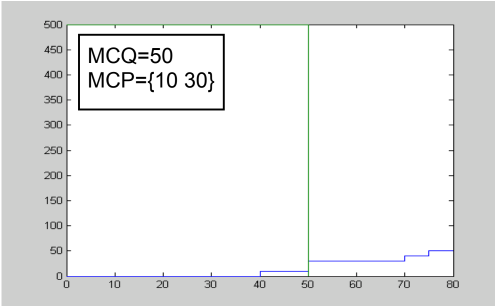

Fig. 9 – Clearing market zone 2

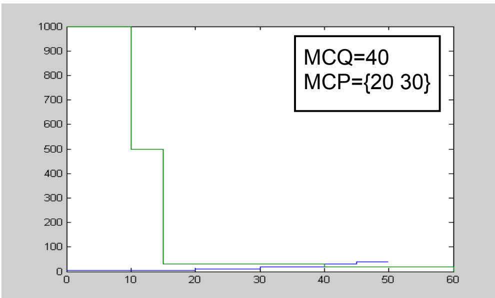

Fig. 10 – Clearing market zone 3

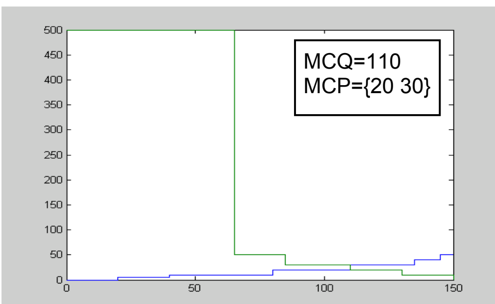

Fig. 11 – Triangular network clearing (uncongested)

7. Conclusion

This paper analyzes some issues of the debate, occurring presently inside the Florence Forum, about the adoption of a common methodology for the allocation of the interconnectors within the IEM. As the present IEM is constituted by set of distinct markets that will not integrate, at least in the short term, co-ordinated methodologies, like co-ordinated auctioning (ETSO) or decentralized market coupling (EuroPex-ETSO) seem to be the most suitable solutions.

However, the former is subject to the exercise of market power by dominant producers in the receiving market, while the latter, although easily implemented in a small-scale project (e.g. BelPex) seems too complex to be extended to the whole IEM. In particular, concerning:

- *co-ordinated auctions* - exercise of market power may be disincentivized by preventing operators to overbid in order to allocate a large share of capacity;
- *DMC* - a modified iterative algorithm may facilitate implementation and ease extension to a set of complex markets mutually interconnected in a meshed network. However, a certain level of regulatory harmonization is necessary between the markets to avoid that fictitious price differentials may arise even in absence of congestion.

The Florence Forum seems to be in favor of a set of cascading capacity markets: auctions would be preferable for long term allocation (yearly and monthly) while a daily allocation with DMC could integrate with national day-ahead markets. However, as far as long-term allocation is concerned, other problems emerge:

- On what network layout is it reasonable to perform the long-term allocation of interconnection capacity?
- What can a TSO do in order to guarantee the firmness of the capacity allocated in the long term (for instance, ETSO has proposed a preventive counter trading methodology)?
- How to enforce the firmness on the side of those operators who allocate capacity. Is the Use-It-or-Loose-It strategy the most fair? Should unavailability be compensated?

All these questions are still waiting for an answer at European level. The new version of the guidelines on congestion management as well as the recent ERGEG consultation on a discussion paper concerning the creation of regional electricity markets (see [8]) seem to be just a first step on this direction.

A more incisive policy by EC would be a key factor for the implementation of an efficient Europe-wide capacity allocation and, more in general, for the realization of the wished medium-term integration of the IEM.

References

[1] European Commission – Strategy paper: medium term vision for the internal electricity market – 1 March 2004

[2] EuroPex – Using implicit auctions to manage cross-border congestion: “decentralised market coupling” – 8 July 2003

[3] ETSO-EuroPex – Flow-based market coupling. A joint ETSO-EuroPex proposal for cross-border congestion management and integration of electricity markets in Europe – Interim Report, September 2004

[4] ETSO – Co-ordinated auctioning: a market-based method for transmission capacity allocation in meshed networks – Final Report – Aprile 2001

[5] ETSO – Reconciliation of market splitting with co-ordinated auction concepts: technical issues – Draft discussion paper – Febbraio 2002

[6] K. Neuhoff – Coupling transmission and energy markets reduces market power – 26th IAEE International Conference, Prague, 2003

[7] Frontier Economics – Consentec – Analysis of cross-border congestion management methods for the EU Internal Energy Market – Study commissioned by the European Commission Directorate-General Energy and Transport – Final report June 2004

[8] ERGEG – The creation of regional electricity markets. An ERGEG discussion paper for public consultation – 8 June 2005