EuroPEX
Association of European Power Exchanges

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

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Introduction

ETSO and EuroPEX have previously published separate proposals for congestion management and market operation across borders in Europe. ETSO has described a 'vision' (refs. 1,2,3) in which Transmission System Operators (TSOs) would support trade between a variety of different markets by taking explicit account of the physical flows of electricity between them ('flow-based modelling'). EuroPEX (ref. 4) has described 'Decentralised Market Coupling' as a method to integrate regional energy markets with cross-border congestion management.

In most respects the ETSO and EuroPEX proposals are consistent and complementary. In particular, both organisations agree that market-based congestion management mechanisms should be used at all borders wherever possible, and that they should be co-ordinated to take account of the inter-dependence of physical flows. Furthermore, both ETSO and EuroPEX recognise that integrated markets are in general more efficient than separate ones, but accept that coupling of regional markets is the most realistic way of achieving efficiency benefits in the short and medium term.

The commonality between the ETSO and EuroPEX proposals has been noted by the 'Florence' Regulators' Forum, which has therefore encouraged ETSO and EuroPEX to work together to develop joint proposals. They have responded by setting up a Joint Working Group, which has produced this report to describe its progress to date.

Currently, there exists a wide variety of organisational structures and operational practices in Europe. Consequently, ETSO and EuroPEX agreed at an early stage that, although a joint vision of a flow-based market coupling (FMC) model should be developed, it was equally important to identify how the current arrangements could evolve towards it in a series of practical steps.

The work is not yet complete. This is an interim report designed to expose ideas at an early stage to enable Regulators, Users and other interested parties to join the debate and provide feedback. In particular, it does not attempt to put forward a prescriptive 'blueprint' for a particular market model, but rather to signal a general direction. It is assumed that implementation of changes in practice would proceed through a series of regional initiatives, governed where necessary by the EU Regulation on Cross-border Exchanges of Electricity, together with the associated Guidelines.

Objectives

Benefits

The overall objective of FMC is to provide significant benefits by introducing two major innovations:

1. Flow-based modelling: this provides the means to maximise the inter-regional transmission capacity that can be made available without compromising system security.

2. Market coupling: this provides the efficiency advantages of competition across regions, subject to the availability of inter-regional transmission capacity.

On borders that are currently managed without market-based methods, such an approach would enable effective inter-regional competition. Where market-based congestion management already exists, it would enhance efficiency by optimising inter-regional transmission utilisation and market operation.

Objectives of the Joint Working Group

As an initial step towards delivery of the above benefits, the Joint Working Group (JWG) has undertaken to pursue the following objectives:

- To identify the critical requirements of any cross-border congestion management approach.
- To agree on a joint technical outline to meet the critical requirements with timely implementation and at reasonable cost.
- To identify the harmonisation requirements that will facilitate a Europe-wide market in the longer term.
- To review the progress of individual local projects to implement cross-border congestion management arrangements, and to provide guidance and support as needed.

The first two objectives, and to some extent the third, are covered in this report. The fourth is a longer term objective, to be addressed in the future as and when required.

Trading and operational requirements

In accordance with the first of its objectives, the JWG has identified a number of specific requirements.

The JWG has agreed that the following are the basic requirements for market operation:

- Firm contracting.
- Maximum availability of potential transmission capacity.
- Efficient price discovery and liquidity.
- Accommodation of block (i.e. multi-period) contracts in day-ahead markets.
- Maximum market participation and easy access.
- Non-discriminatory treatment of exchange and bilateral trades.
- Development of day-ahead market indices to support derivatives trading.

- Support to price hedging tools.
- Compatibility with optional intra-day markets.
- Market confidence, requiring transparency and stability of the arrangements.

The JWG has agreed that the following are the basic requirements for system operation:

- Viability, clarity and timely declaration of participants' physical intentions.
- Ability for system operators to influence generation and consumption – preferably by commercial means, but as a last resort by direct instruction.
- The availability of balancing reserves and ancillary services.
- Incentives on all parties to maintain safe and secure operation.
- An ability to accommodate all users without discrimination.

Subject to the above requirements, the JWG has adopted the principle that users should be offered the maximum degree of choice in the way they trade and use the transmission system. This has led to a proposed FMC structure with core processes that are required to deliver the basic requirements, together with alternative processes that provide a choice of trading and transmission access facilities. This structure is described in the following section.

Flow-Based Market Coupling

Overview and general principles

At the beginning of its work the JWG agreed that its priority should be to focus on market co-ordination at the day-ahead stage. If the day-ahead markets are sufficiently comprehensive and compatible, they should provide the minimum facilities necessary for market participants to trade their energy and access the transmission system. FMC is proposed as a means of providing such facilities for inter-regional trade. It is also intended to bring the benefits described in the previous section by coupling the regional day-ahead markets using flow-based modelling.

The principles behind flow-based modelling are described in detail in ref. 1, and summarised here in Appendix A. An underlying assumption is that the European system can be operated as a number of single-price regions, each of which can be represented as a single node in a simplified transmission model. The regional nodes are connected by notional transmission circuits. The flow properties of this simplified model are described by 'flow factors', and limits ('bottleneck capacities') are placed on the notional inter-regional circuits to represent the effects of cross-border transmission constraints. This model is clearly a gross approximation to the complexities of the physical transmission system, and this reduces its accuracy as a congestion management tool. It is, however, expected to provide significant improvements over existing methods, and it is likely that this degree of simplification is necessary to provide adequate market liquidity at each node.

'Market coupling' is based on the assumption that an administered day-ahead market exists in each region (i.e. at each node of the simplified transmission model). Subject to the ability of the transmission model to support the associated flows, market coupling enables the regional markets to trade with each other if it is economically efficient to do so. The coupling process is complicated by the need to accommodate 'block' bids and offers (i.e. those specifying a multi-period time duration). This is likely to require iteration between a succession of regional and inter-regional calculations.

A number of processes are necessary to support the day-ahead markets, for example by supplying data and providing financial settlement services. Some means of short-term energy balancing is also required, and in some regions intra-day trading is considered necessary.

The decision to administer a market co-ordination scheme at the day-ahead stage does not mean that all trading must take place at this stage. A variety of forward contracting options, both physical and financial, is possible.

In view of the above, the JWG has developed its proposed FMC scheme as three sets of processes, i.e.

1. Day-ahead market and supporting processes.

2. Processes required to operate the co-ordinated day-ahead market.

3. Alternative forward market processes.

These are described in turn below, and specified in tabular form in Appendix B.

Day-ahead market and supporting processes

The co-ordinated day-ahead market, together with the basic processes that are considered necessary to support it, is illustrated in Fig. 1. Each process is identified as a 'system operation', 'user participation' or 'market operation' function. It is not necessary at this stage to identify the organisation that should operate each process; this could vary between Member States and will be considered at a later stage. In Fig. 1 each process is shown as taking place in one of four time intervals: before the day-ahead stage ('ex-ante'), day-ahead (D-1), on the day of operation (D), or after the day of operation ('ex-post').

The system operation processes S1 and S2 are considered necessary to inform market participants of estimated congestion parameters in advance of the day-ahead market. The relevant parameters are the bottleneck capacities and flow factors that describe the state of the simplified transmission model required for flow-based market coupling.

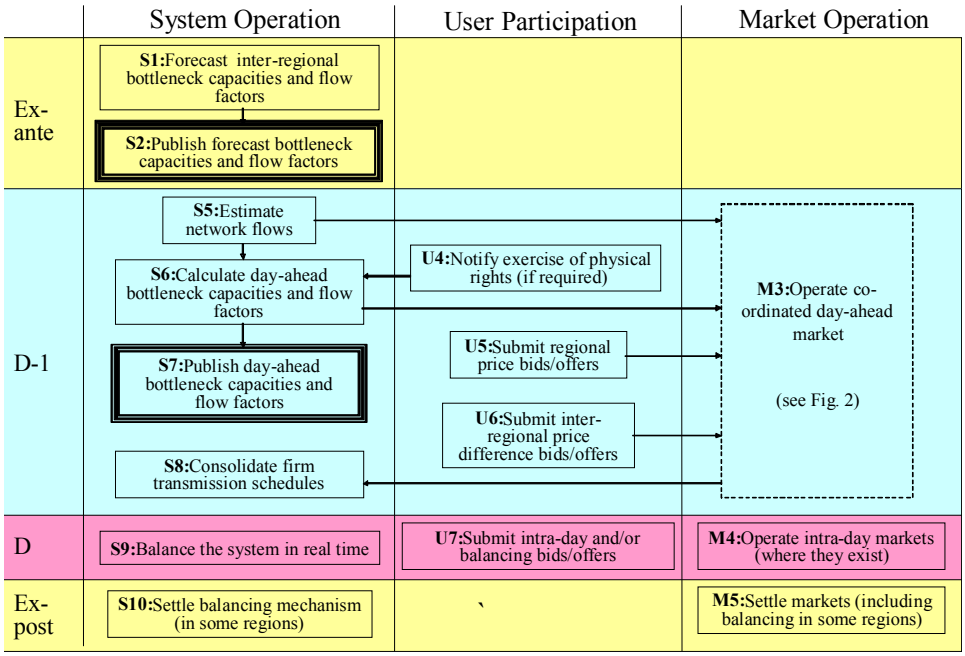
At the day-ahead stage, updated transmission data are required (from processes S5 and S6). These are used both to advise users (S7) and to feed into the co-ordinated day-ahead market process (M3).

Users may submit bids and offers to the regional day-ahead markets to buy or sell energy at the local price (U5). They may also submit price-difference bids whereby they offer to transfer energy between the two relevant markets and pay/earn the

inter-regional congestion price (i.e., the price difference between the two relevant markets) (U6). This enables non-discriminatory day-ahead access for cross-border bilateral contracts.

On the day of operation, the system must be kept in balance using some form of balancing mechanism or market, and trading may continue via intra-day markets (S9, U7 and M4). Financial settlement of all markets follows on ex-post timescales (S10 and M5).

Fig. 1 FMC model: Day-ahead market and supporting processes



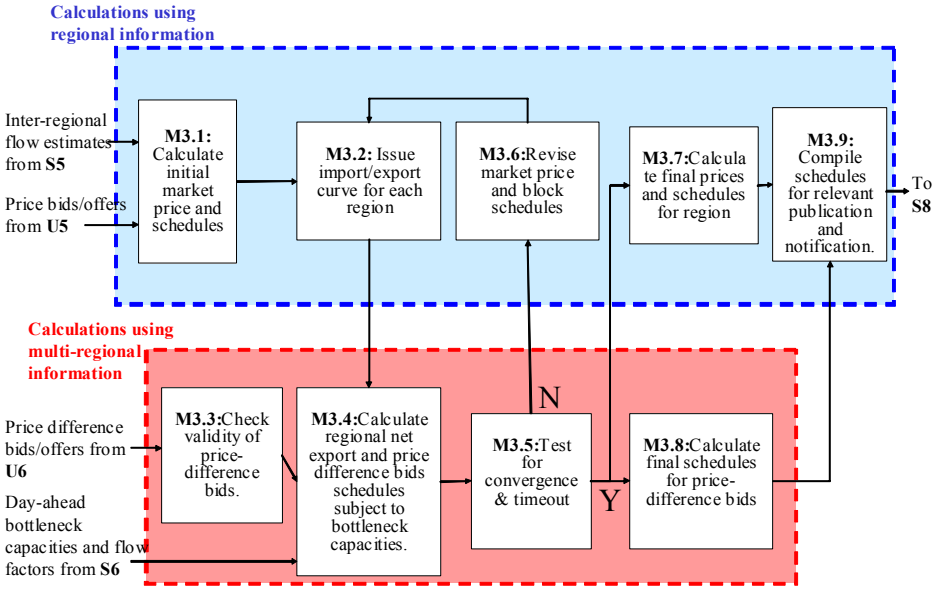
Operation of co-ordinated day-ahead markets

The processes required to operate the co-ordinated day-ahead market are shown in Fig. 2. Some of the processes require inter-regional data, and some can be performed using regional data only. Iteration is required between the two, essentially because block bids and offers introduce non-convexities that cannot be handled by a single optimisation calculation.

Process M3.1 clears the regional markets using price bids and offers, with initial assumptions regarding inter-regional trade. These assumptions can be based on inter-regional flow estimates from process S5 if they are helpful in providing an initial starting point. Process M3.2 calculates price curves for any imports or exports that might be superimposed on the initial solution from M3.1.

Inter-regional input data, in the form of transmission model parameters and price-difference bids and offers, are collected and checked by process M3.3 and used, with the import/export price curves, in the co-ordination process M3.4. This process optimises trade between the regions using the import/export prices and price-difference bids, subject to the inter-regional transmission constraints represented by the simplified transmission model.

Fig. 2 FMC model: Operation of co-ordinated day- ahead market



Process M3.5 tests whether the inter-regional flows and/or prices have converged, and checks whether the allocated time has been used up. If both tests are negative, regional prices and block schedules are revised and processes M3.2 and M3.4 are repeated. If either test is positive, the current solution is passed to processes M3.7 and M3.8 to finalise the regional and inter-regional schedules respectively, and process M3.9 combines them for publication and transfer to process S8.

In summary, each market produces its own clearing price. All energy bids/offers are matched according to the regional market rules and the resulting energy flows between the different regions comply with the bottleneck capacities and flow factors provided by S6.

Alternative forward markets

FMC can coexist with several forms of forward market arrangements. These provide opportunities for users to hedge cross-border price risk that they would otherwise face in the day-ahead market. Possibilities could include participation in electricity related financial markets and/or participation in explicit auctions of forward transmission rights. These arrangements would operate independently from the day-ahead FMC. They are included in Appendix B, but shown in italics to distinguish them from the core FMC processes.

To be of value for operational congestion management, system operation requires 'firm' transmission rights in the sense that users have an obligation to exercise them (if this is not the case, 'netting' of firm schedules is not possible). This implies some means of ensuring compliance with user obligations, either via legal/regulatory sanctions or regulatory/contractual incentives, such as imbalance settlement (S10 or M5). However, this does not eliminate the possibility of forward markets in physical options (i.e. rights without obligations), so long as there is an exercise notification process (U4, Fig. 1). This 'use-it-or-lose-it' (UIOLI) procedure can be used to impose

firm obligations on those rights that are nominated. In practice, a 'use-it-or-sell-it' (UIOSI) scheme is also available, because users can effectively sell physical transmission rights in the day-ahead market by submitting offers for counter-flow obligations (via process U5 or U6, Fig. 1).

Necessary Relationships between FMC Processes

This section describes a simple, preliminary analysis of the FMC structure. By examining the necessary relationships between FMC processes it is possible to deduce a number of basic requirements relating to accountabilities, harmonisation and relationships between functional roles. Note again that this is done without reference to organisational arrangements.

Accountabilities

Where the Member State legislation has created a regulated market, market operation is accountable to the industry regulator representing the general user interest. Where the Member State has not created a regulated market, market operation is accountable to users through contractual agreements. Even in the latter case, however, it is usually subject to some regulation of the level of service, for example to maintain financial standards.

Because the transmission system is a common facility shared by all users, system operation must be held accountable to the general user interest. Although in some cases this has been achieved by voluntary agreements, system operation in most countries is accountable to an industry regulator, and this may be required in future under EU legislation.

The proposed FMC co-ordinated day-ahead market adds a new factor to the scheme of accountabilities in many European countries because it involves the solving of cross-border congestion, albeit implicitly, as a market operation process. Consequently, day-ahead market operation must be made accountable to the general interest in a manner decided by each Member State. There appear to be two ways of achieving this. The cross-border congestion-related functions of day-ahead market operation could be held directly accountable to an industry regulator in the same way as system operation, as is already the case in some Member States. Alternatively, they could be treated as delegated aspects of system operation. In the latter case, suitable accountabilities would need to be provided by regulatory and/or contractual means.

Process harmonisation

The structure of the FMC model of itself implies a minimum level of harmonisation. This arises in two ways. First, the need for processes in different regions to meet common requirements necessitates a degree of harmonisation of the processes themselves. Second, the need to publish data and communicate between processes implies a requirement to harmonise process timing and data formats.

Minimum harmonisation requirements can be identified by taking each of the FMC processes in turn, noting the inputs and outputs associated with them, and assessing the need to harmonise the process and communication arrangements. This exercise is summarised in Appendix C. For this purpose, it is helpful to distinguish between

those market operation functions that use inter-regional data (Inter-reg. MO) and those using only regional data (Reg. MO).

There is a requirement to harmonise the methodology for evaluating inter-regional bottleneck capacities and flow factors (processes S1 and S6). The formats in which these values are published (S2 and S7), together with the formats for publishing the day-ahead market schedules (M3.9), should also be harmonised for ease of assimilation by users.

There is no particular need to harmonise the regional market operation or system operation processes themselves, provided the timing and formats of data exchanges with the inter-regional processes are compatible. If the inter-regional processes are replicated in each region, they must be identical across regions, and the schedules passed to process S8 for physical implementation must be feasible (i.e., compliant with the bottleneck capacities, as specified in process S6).

A complete list of the interfaces requiring format and timing harmonisation is included in the tables in Appendix C.

Regulatory/Contractual Framework

Introduction

The analysis of the FMC model can be taken a step further to identify a minimum set of regulatory/contractual relationships between the parties operating the processes. These are necessary to establish the necessary links between the processes, and to impose the necessary degree of harmonisation.

This section describes a possible set of organisational, regulatory and/or contractual arrangements that could support the development and operation of the FMC model. The focus is on the day-ahead market and supporting processes; the arrangements for the alternative forward markets are not addressed here.

Where process linkages do not involve more than one Member State, and harmonisation is not required, regulatory and/or contractual arrangements may be specific to each Member State and could be implemented using either:

- bilateral arrangements between, for example, a user and a power exchange (PX) or a user and a TSO, or
- multilateral arrangements.

Multilateral arrangements are, however, necessary to enable multilateral communication, or to harmonise processes in the interest of equity or efficiency. A summary of the arrangements required, and their minimum contents, is presented in Appendix D.

In practice, arrangements will not be process-specific, and a single regulatory and/or contractual arrangement can cover many of the FMC processes.

Objective

The regulatory/contractual framework needs to have the following capabilities:

- Enable the efficient operation of FMC according to the defined rules.
- Enable the development and enhancement of the coupling arrangements.
- Facilitate subsequent expansion of the regions within the FMC mechanism.
- Minimise the disturbance to existing regulatory/contractual and trading arrangements.

There are variations between the legal and regulatory frameworks in different Member States. The framework of multilateral relationships would need to be common, establishing the necessary common rules, but could be established via either regulatory or commercial agreements depending on the situation in each Member State. The framework would need to be enabled as appropriate by local regulatory arrangements.

There are also differences between Member States over how some system and market operation functions are performed. In particular, 'physical settlement' (for imbalances and ancillary services) is undertaken in different Member States by a TSO, a power exchange or a third party. To simplify the description of the contractual/ regulatory framework in this report, a single TSO and a single power exchange (PX) are assumed to perform the system operation and market operation functions respectively in each Member State. Nonetheless, local physical settlement can continue as at present, based on the specific arrangements in each Member State.

Overview of possible regulatory/contractual framework

The relationships in Appendix D could be established through a small set of regulatory or contractual arrangements:

1. A new regulated/ contractual multilateral arrangement between TSOs to calculate the capacities and flow distribution factors (including the setting up of any central service providers), and to distribute, according to the EU regulation, any resulting congestion revenue.

2. A new regulated/contractual multilateral arrangement between PXs to govern the use of cross-border capacity, interactions between regional and inter-regional processes, calculation of aggregate schedules, the arrangements for price-difference bids and the collection of congestion revenues.

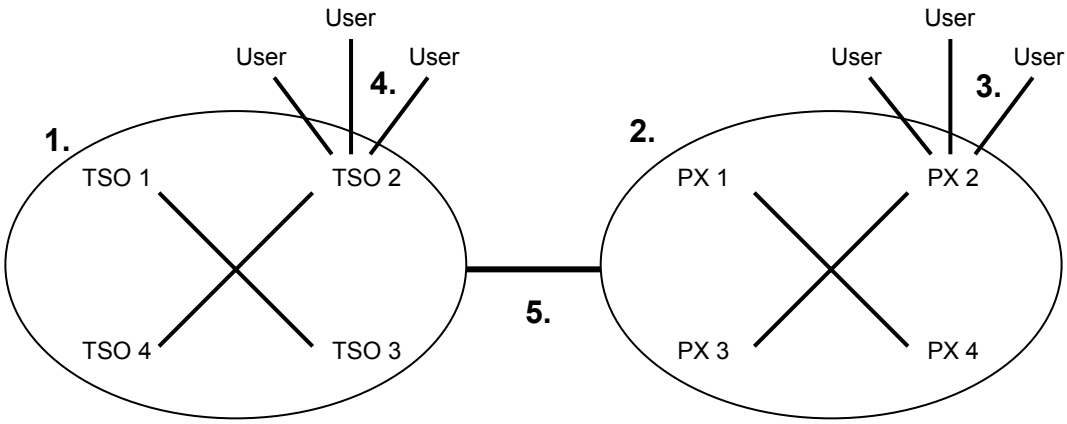
3. Regulated/contractual participant arrangements between users and PXs to govern the rules and use of the PX markets (i.e. modified versions of existing PX participant agreements to add the coupling rules and the submission and settlement of price-difference bids).

4. Regulated user arrangements between TSOs (or PXs in some Member States) and users (including PXs in some Member States) to establish regional balance responsibility (probably minimal change to existing arrangements).

5. A regulated/contractual arrangement or agreements between PXs and TSOs to provide to the PXs the capacities and flow distribution factors and accept back

from the PXs the resulting day-ahead schedule. (Note: this could be on a local TSO-to-PX or a multilateral basis).

This overall framework is shown below.



As indicated previously, PX accountabilities may be different in different Member States. However, their role within the FMC model must be made accountable to the general interest in a manner decided by each Member State. Two options appear possible:

- The PX is directly accountable to the industry regulator; in this case it may be necessary to modify the existing regulatory obligations.
- The PX is not accountable to the industry regulator; in this case, the PX acts as a delegate of the TSO and could become accountable to the TSO via a separate agreement.

Further work is required to clarify the set of arrangements needed.

Discussion

Major discussion points

The following issues have been the subjects of considerable debate during the course of the JWG's work to date:

- The EuroPEX members of the JWG expressed the view that physical transmission rights markets were unnecessary because inter-regional transmission capacity could be secured by submitting price acceptance bids into the day-ahead market, while the financial risks could be hedged using financial contracts. This would, it was argued, enable the most efficient use of the network physical capacity. The view of the ETSO representatives was that transmission rights markets should be retained as an option for two reasons. First, ETSO did not feel able to deny users an element of choice, especially as many seemed more comfortable when they could obtain forward rights. Second, where cross-border capacity auctions were already in place and working well, it would make no sense

to remove them. The JWG agreed that the FMC model should be able to co-exist with physical transmission rights because they are already in operation for some borders and some Member States might decide to maintain them.

- Given the continued existence of physical inter-regional transmission rights, the role of 'use-it-or-lose-it' (UIOLI) and 'use-it-or-sell-it' (UIOSI) arrangements was questioned. After discussion, the JWG agreed that UIOLI arrangements (essentially notification of intentions to exercise rights) were probably necessary to deal with legacy contracts and to provide an opportunity for users to acquire options. UIOSI could be provided by secondary physical rights markets, but is also available through the day-ahead market (see the description of FMC above).

- Some of the approximations necessary to provide a tractable transmission model were discussed. In particular, it was agreed that it would be unrealistic to provide flow factors for each of the contingency conditions implied by, for example, 'n-1' security. It was accepted that the alternative of a single representative matrix of factors would be an approximation that, under most conditions, would necessarily tend to be conservative.

- The iterative market clearing algorithm at the heart of the FMC process remains to be specified in detail. ETSO representatives maintained that it was important that transmission-feasible solutions (i.e. schedules compliant with the inter-regional constraints) were produced by each iteration, so that operationally viable inter-regional schedules would be available in the event of non-convergence or 'time-out'. EuroPEX representatives were concerned that such solutions could violate block constraints and may not exhibit sufficient price convergence to gain acceptability by users.

Outstanding issues

The work described in this report is itself incomplete, and will need to be revised and extended in the light of feedback and comments received. In addition, it has not attempted to address a number of outstanding issues. These include the following:

- The approximations introduced by the simple transmission model (i.e. single-price areas represented as electrical nodes) remain to be quantified.

- The algorithms for generating the simplified transmission model and updating its parameters (bottleneck capacities and flow factors) have yet to be put in place.

- The algorithms for co-ordinating the day-ahead markets need to be developed, with particular reference to the non-convexities introduced by block constraints. The specific need to provide feasibility with respect to both transmission constraints and block constraints should be addressed.

- Performance measures for both TSOs and power exchanges should be sought, together with regulatory or commercial incentives.

- The specific steps necessary to evolve from current arrangements to FMC will need to be identified. These will be different in different Member States.

- Contractual/regulatory issues remaining to be addressed include: settlement timescales and cashflow, managing changes to the rules, accession of new regions, intellectual property rights, legal jurisdiction, credit risk, and organisation of common activities.

Future work

The above outstanding issues suggest that the joint ETSO-EuroPEX work should continue. The future workplan might then contain the following:

- Revision and further development of the topics contained in this report, taking into account responses from the Rome Regulators' Forum and comments and contributions from other parties.

- Development of the processes required to define a suitable transmission model and to update its parameters (a TSO responsibility, possibly reported to the JWG).

- Development of the processes required to clear the co-ordinated day-ahead market in the presence of block bids and offers. This is likely to require mathematical definition of the algorithms to be used, and an analysis of their convergence properties (a power exchange responsibility, possibly reported to the JWG).

- Resolution of the regulatory/contractual link between TSOs and power exchanges.

- Development of inputs for possible adoption by the EU Comitology procedure.

- Development of advice for local development projects.

Conclusions

The ETSO-EuroPEX Joint Working Group has reached agreement on an approach to cross-border congestion management, called Flow-based Market Coupling (FMC), that in their view best meets the needs of both the market and system operation. In so doing, they have achieved a balance between the requirements for effective congestion management (notably an accurate transmission model) and those for efficient energy trading (notably market liquidity). The result is a model with regional price areas, with inter-regional trading facilitated by market coupling subject to simplified transmission constraints.

The FMC model describes arrangements for day-ahead trading. This needs to be part of a broader set of arrangements including, on one side, effective opportunities for participants to hedge price risk and, on the other side, complementary adjustment

and balancing arrangements. FMC is compatible with price risk being hedged via a variety of forward physical or financial markets.

The minimum set of regulatory/contractual arrangements necessary to implement FMC has been identified. Some issues concerning the status of power exchanges in some Member States remain to be resolved, particularly regarding the designated nature of the proposed day-ahead market.

The transmission modelling and market co-ordination processes remain to be specified in technical detail. Both should be as transparent as reasonably possible, and the latter is likely to be an iterative process, introducing the possibility of convergence issues.

Subject to the response to this interim report from other parties, ETSO and EuroPEX agree that the FMC concept should be developed further. Eventual deliverables should include inputs for consideration under the EU Comitology procedure, and advice for consideration by local implementation projects.

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APPENDIX A

Flow-based Modelling

'Flows' and 'commercial exchanges'

The word 'flow' should be used only for the physical power flows that can be measured on a set of electrical transmission lines. Power flows are currently managed by each Transmission System Operator acting in his own 'control area'.

Conversely, the expression 'commercial exchange' should only be used to describe programs of exchange scheduled from one market to another one as a consequence of market activity or cross-border bilateral trading.

For a given control area, it should noted that (under the approximation that a program of exchange scheduled with a neighbour instantaneously takes effect):

Algebraic sum of flows on interconnections = algebraic sum of commercial exchanges = balance of the control zone.

For example, a control area which has commercial exchanges amounting to a net export of 1000 MW towards other control areas also has a net export flow of 1000 MW through its physical interconnection ties with all its neighbour control areas.

'Bottlenecks' and 'bottleneck capacities'

The expression 'bottleneck' has been introduced to describe links between nodes in the simplified transmission model used in FMC. They provide an approximate representation of the transmission circuits, or sets of circuits, which tend to become congested in the presence of significant commercial exchanges. They are therefore subject to careful monitoring by TSOs as part of the congestion management process.

A 'bottleneck capacity' designates the value (expressed in megawatts) of the maximum flow that can be accepted through a particular bottleneck. It is assessed in relation to the capacities of the lines included in the bottleneck, and of the security criteria used by system operators for flow management.

Relationship between flows and commercial exchanges

The flows describe the physical state of the system. For a given real-time pattern of inputs and outputs on the grid, there is a unique pattern of flows on the lines. These can be summed over all the lines crossing a given border to yield a 'border flow'.

Commercial exchanges describe the contractual situation. They refer to 'paper' linkages between generators, traders and consumers.

There is no unique relationship between the flows and the commercial exchanges. This can be seen from the following observations:

- For a given set of imbalances of the different control areas (i.e. a given set of net exports and imports), there is an infinity of possible generation and load schedules for each area. These different schedules are not the responsibility of TSOs. They are only notified of the results of market

participants' decisions, in a manner that depends on the legislation in each Member State.

- Symmetrically, a given flow pattern can be the result of different commercial exchange patterns so long as each maintains the generation and load schedules of each area. For example, a closed chain of commercial exchanges (e.g. A to B, B to C, and C to A) can be added to an existing exchange pattern without affecting the flows at all.

- In general, border flows (say the sum of the flows on power lines between control areas A and B) do not coincide with 'border commercial exchanges' (the net sum of traded products between markets in A and B). In fact, it is very common on the UCTE grid to have a significant border flow in one direction, while the border exchange is in the other direction.

The relation between the flows can be simplified through linearisation, so that the flows on a specific bottleneck can be expressed as a linear combination of the area balances. If these areas coincide with market areas ('regions'), this relation can be used to link the physical and commercial domains. ETSO has proposed such a model, using a matrix of 'flow factors', as a relatively simple means of representing physical flows within commercial or market processes.

Basically, this model sets out the relation between:
variations of balances of each area (Delta B), and
variations of flows on each bottleneck (Delta F).

The prefix 'Delta' refers to variations from the reference state around which the model is linearised. The relation can be written mathematically as:

Delta F = Matrix* Delta B

The matrix is called the 'flow matrix'. It contains the flow factors mentioned in the body of the report.

Summary of the flow-based model

In the proposed FMC model, variations of balances (Delta B) are economically optimised while respecting the bottleneck capacity limits, i.e.

Maximise an objective function of delta B	(1)
With Delta F = Matrix* Delta B	(2)
While F_0 + Delta F < BC	(3)

where the F_0 are the reference state flows for each bottleneck, and the BCs are a corresponding set of bottleneck capacities.

In the FMC model under study, the following quantities are evaluated by the system operation processes S1 and S6 (see Fig. 1):
-the reference flows F_0
-the bottleneck capacities BC, and
-the flow matrix.
The optimisation [FMC process M3, corresponding to equations (1) (2) (3) above] is a market operation process.

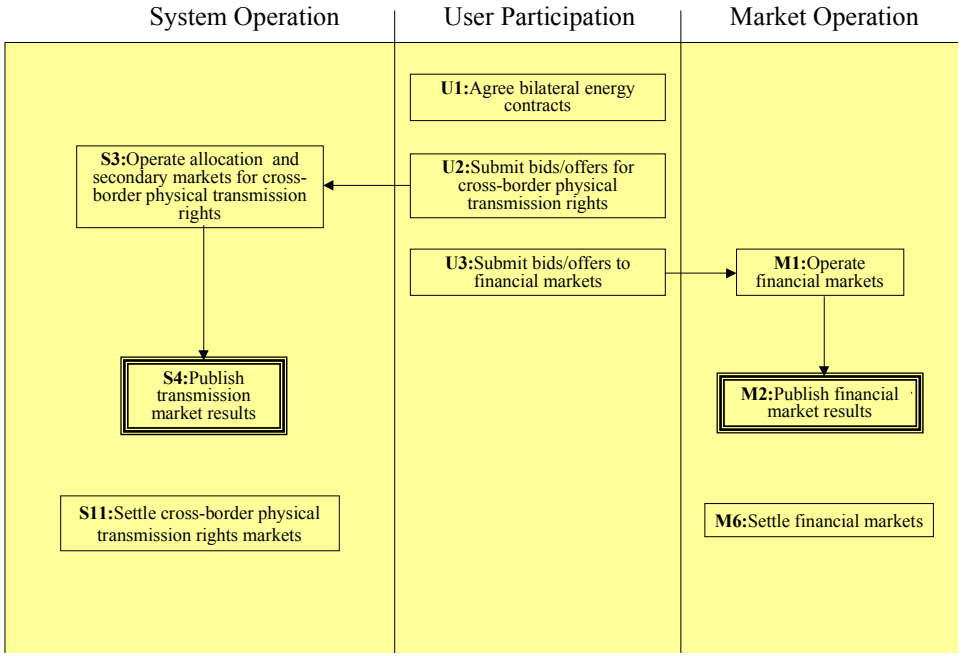
APPENDIX B

Tabular Description of the FMC Model

Alternative forward markets

FMC can coexist with several forms of forward market arrangements. These provide opportunities for users to hedge cross-border price risk that they would otherwise face in the day-ahead market. Alternatives could include participation in electricity related financial markets and/or participation in explicit auctions of forward transmission rights. These arrangements would operate independently from the day-ahead FMC. A general presentation of the main processes is included below. The processes related to the different alternatives for physical or financial forward markets are presented in italics in tabular form.

FMC model: Alternative forward markets



1. Users[1]

Process		Time	Input	Method	Output	Comments
U1	***Agree bilateral energy contracts***	*Unrestricted*	--	*Unrestricted*	*Regional trading location and contracted energy volume for each market (settlement) period.*	
U2	***Submit bids/offers for cross-border physical transmission rights***	*In accordance with published rules for allocation and trading*	--	*In accordance with published rules for allocation and trading*	*Accepted bid/offer prices and volumes*	
U3	***Submit bids/offers to financial markets***	*In accordance with published financial market rules*	--	*In accordance with published financial market rules*	*Accepted bi/offer prices and volumes*	
U4	***Notify exercise of cross-border physical transmission rights***	*Early in day-head (e.g. by 09:00)*	--	*In accordance with published rules*	*Notification of cross-border physical transmission rights volumes*	*For operational purposes, TSOs must be able to assume that transmission rights are firm*
U5	**Submit regional price bids/offers**	In accordance with the day-ahead market rules	--	In accordance with published market rules	Regional bid/offer prices and volumes	Users with no transmission rights and users with transmission rights can all bid in these markets
U6	**Submit inter-regional price difference bids/offers**	In accordance with the day-ahead market rules	--	In accordance with published market rules	Inter-regional bid/offer prices and volumes	Users with no transmission rights and users with transmission rights can all bid in these markets
U7	**Submit intra-day and/or balancing bids/offers**	In accordance with published rules	--	In accordance with published rules	Bid/offer prices and volumes	

[1] The processes related to the different alternatives for physical or financial forward markets are presented in italics.

2. System operation[2]

Process		Time	Input	Method	Output	Comments
S1	**Forecast inter-regional bottleneck capacities and flow factors**	Prior to operation of forward markets (e.g. annually, monthly, …D-2)	Transmission system electrical parameters; Estimate of transmission system availability and connectivity; Estimate of loadflow conditions	In accordance with published rules	Bottleneck capacities and Flow factors for each period	
S2	**Publish forecast bottleneck capacities and flow factors**	Prior to operation of forward markets	Bottleneck capacities and flow factors from S1	Display on TSO websites, with links from ETSO website	Published bottleneck capacities and flow factors	
S3	***Operate allocation and secondary markets for cross-border physical transmission rights***	In accordance with published rules*)*	*Bids/offers for cross-border physical transmission rights from U2* *Bottleneck capacities and flow factors from S1*	*Co-ordinated explicit auctions in accordance with published rules.*	*Purchase/sales volumes of accepted bids/offers.* *Market prices for cross-border physical transmission rights*	*The volume of products available in forward auctions may be restricted to some fraction of BC. If so, these fractions will be published*
S4	***Publish transmission market results***	*Immediately following each allocation of transmission rights*	*Purchase/sale volumes and market prices from process S3*	*Display on TSO websites, with link from ETSO website*	*Published transmission rights volume allocations and prices*	*Holders of transmission rights could be identified by name (in the interests of market transparency) or not (in the interests of commercial confidentiality)*

[2] The processes related to the different alternatives for physical or financial forward markets are presented in italics. Processes involving data publication to users are highlighted in grey.

S5	**Estimate network physical flows**	Morning day-head	Allocated volumes from process S3. Historical flow data. Other known social events (e.g. holidays)	Regional forecasting techniques	Estimated network physical flows. Estimated inter-regional physical flows	
S6	**Calculate day-ahead inter-regional bottleneck capacities and flow factors**	Morning day-head	Day-ahead network conditions. Estimated network flows from process S5. *Notifications from users on the exercise of cross-border physical transmission rights from U4*	Update previous estimates. *Subtract notified transmission rights from estimates*	Day-ahead inter-regional bottleneck capacities and flow factors	No capacity specifically held back for intra-day mechanisms.
S7	**Publish day-ahead inter-regional bottleneck capacities and flow factors**	Morning day-head	Day-ahead bottleneck capacities and flow factors from S6	Display on TSO websites, with links from ETSO and PXs website	Published day-ahead bottleneck capacities and flow factors tables	
S8	**Consolidate firm transmission schedules**	In the afternoon one day-head	Operational day-ahead market schedules from process M3	Update foreseen network flow conditions based on firm schedules. Plan operation	Firm physical schedules. Day-ahead operational plan	
S9	**Balance the system in real time**	Continuously	Operational plan from S8; Measured system conditions; Short-term operational forecasts; Intra-day Market results from M4; Bids and offers into intra-day balancing/adjustment mechanisms	Utilise balancing, adjustment and ancillary products as made available in country/regional mechanisms, including control of cross-border flows	Secure system operation	
S10	**Settle balancing mechanism (in some regions)**	Ex-post	Settlement prices plus inputs from S9	In accordance with published rules	Settlement of balancing mechanism	
S11	**Settle cross-border physical transmission rights markets**	Ex-ante or ex-post, depending on the contractual rules	Transmission rights held by each user	In accordance with published rules	Settlement of physical transmission rights	

3. Market operation[3]

Process		Time	Input	Method	Output	Comments
M1	***Operate financial markets***	*In accordance with published rules*	*bids/offers to financial markets from U3*	*In accordance with published rules*	*Purchase/sales volumes of successful bids/offers*	
M2	***Publish financial market results***	*In accordance with published rules*	*Purchase/sales volumes of successful bids/offers. Financial market prices from M1*	*In accordance with published rules*	*Publication of financial market results*	
M3	**Operate co-ordinated day-ahead market**	Common day-head time	Day-ahead inter-regional bottleneck capacities and flow factors from S6 Regional price bids/offers from U5 Inter-regional price difference bids/offers from U6	(See the detailed description of the operation of the day-ahead market)	Compile schedules and prices for relevant publication and notification	
M4	**Operate intraday-markets (where they exist)**	Continuously or at the specified times	Bid/offer prices and volumes	In accordance with published rules	Compile schedules and prices for relevant publication and notification	
M5	**Settle markets (including balancing in some regions)**	Ex-post	Settle prices plus inputs from S9	In accordance with published rules	Settlement of markets (including balancing in some regions)	
M6	**Settle financial markets**	Ex-ante or ex-post, depending on the contractual rules	Financial products purchased by each user	In accordance with published rules	Settlement of financial markets	

[3] The processes related to the different alternatives for physical or financial forward markets are presented in italics. Processes involving data publication to users are highlighted in grey.

3.1 Operation of co-ordinated day ahead market

Process	Inputs	Method	Outputs	Comments
M3.1	- Regional bids/offers from participants (U5); - Inter-regional flow estimates from S5	A daily Auction	- Aggregate bid/offer curves including activated block bids	- Inter-regional flow estimates may be used or any other method to define the initial net surplus considered.
M3.2	- Outputs from M3.1 or - Output fromM3.6 iteration i-1		Import/export curves for iteration i	Merely a transfer of initial regional results (M3.1) in a format understandable for the inter-regional Market Coupling process in M3.4
M3.3	- Price-difference bids/ offers from U6; - Regional information regarding participants;	Confirmation of acceptance by both systems	Valid price-difference bids/ offers.	
M3.4	- Import/export curves from M3.2; - Valid price difference bids/offers from M3.3; - Day-ahead bottleneck capacities and flow factors from **S6**	Linear program or other mathematical formulation	- Net surpluses for each region; - Price-difference bids schedules.	
M3.5	- Timeout: current number of iterations/ computation time; - Convergence: depends on the criterion used.	Test	Yes/No	Several convergence criteria possible (ex: net exports unchanged)
M3.6	- Regional bids/offers from participants (U5); - Net surpluses from M3.4	Auction	- Aggregate bid/offer curves including activated block bids	
M3.7	- Yes signal from M3.5; - Net exports from M3.4.		- Final market prices; - Individual participants (hourly and block) schedules.	
M3.8	- Yes signal from M3.5; - Selected price-difference bids from M3.4.		Individual participants schedules for price-difference bids	
M3.9	Schedules from M3.7 and M3.8.		Data to be published and notified (including participants and S8).	

APPENDIX C

Minimum Set of Harmonisation Requirements

System Operation (SO) processes

Process	Inputs from	Outputs to	Harmonisation
S1	Other regions		Methodology
S2			Publishing format
S5	Other regions		Format & timing
		Reg. MO (M3.1)	Format & timing
S6	Other regions		Methodology
		Inter-reg. MO (M3.3)	Format & timing
	UP (U4)		
S7			Publishing format
S8	Reg. MO (M3.9)		
S9	UP (U7)		
S10		UP	

User Participation (UP) processes

Process	Inputs from	Outputs to	Harmonisation
U4		SO (S6)	
U5		Reg. MO (M3.1)	
U6		Inter-reg. MO (M3.3)	Bid/offer format
U7		SO (S9) Reg. MO (M4)	

Market Operation (MO) processes

Process	Inputs from	Outputs to	Harmonisation
M3.1	UP (U5) SO (S5)		
M3.2		Inter-reg. MO (M3.4)	Format & timing
M3.3	UP (U6) SO (S6)		Format & timing Format & timing
M3.4	Reg. MOs (M3.2)		Format & timing
M3.5		Reg. MO (M3.6,M3.7)	Format & timing
M3.6	Inter-reg. MO (M3.5)		Format & timing
M3.7	Inter-reg. MO (M3.5)		Format & timing
M3.8		Reg. MO (M3.9)	Format & timing
M3.9	Inter-reg. MO (M3.8)	SO (S8)	Publishing format Format & timing Schedule feasibility
M4	UP (U7)		
M5		UP	

APPENDIX D

Minimum Set of Relationships for the FMC Model

Multilateral between TSOs

- Methodology for forecasting inter-regional bottleneck capacities and flow factors
- Format for publishing inter-regional bottleneck capacities and flow factors
- Data exchange for estimating network flows
- Methodology for calculating day-ahead bottleneck capacities and flow factors
- Format for publishing day-ahead bottleneck capacities and flow factors

Multilateral between PXs

- Transfer of import/export curves
- Transfer of inter-regional iteration results
- Settlement of inter-regional electricity transfers
- Collection of congestion rent

Regional between TSO and Regional Users

- Regional balancing operation
- Regional balancing settlement (in some Member States)

Regional between PX and Regional Users

- Day-ahead market bid/offer rules
- Acceptance of regional price bids/offers
- Regional day-ahead and intra-day market operation
- Regional day-ahead and intra-day market settlement
- Regional balancing settlement (in some Member States)

Multilateral between PXs and Inter-regional Users

- Submission of price difference bids/offers
- Acceptance by PXs of inter-regional price difference bids/offers

Multilateral between TSOs and PXs

- Transfer of estimated network flow data from TSOs to PXs
- Transfer of day-ahead bottleneck capacities and flow factors from TSOs to PXs
- Feasibility and transfer of schedules from PXs to TSOs