Implementation Methods for the European Day-Ahead Electricity Market Integration

Anastasios Bakirtzis & Pandelis Biskas

Power Systems Laboratory, Aristotle University of Thessaloniki

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Presentation Overview

- **Introduction to the European Electricity Market**
  - EU Market Characteristics
  - Electricity Market Integration
  - The EU Internal Electricity Market
  - The EU “Target Model”

- **European Day-Ahead Market Integration**
  - Capacity Calculation
  - The Price Coupling Algorithm
  - Network Representation
  - Market Orders
  - Price Coupling Results

- **The “E-Market” Project**
  - Integration of Power Pools and Power Exchanges
  - Initial Results
  - Future Extensions

- **Concluding Remarks**
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EU Electricity Market Characteristics

- **Separation** of Market Operator (PX) and System Operator (TSO) roles. TSO owns transmission assets (in contrast to US ISO).

- **Zonal pricing**: Each market comprises a single price zone or a small number of price zones (in contrast to US nodal markets).

- **Bilateral trading** with voluntary participation in Power Exchange (PX) for Day ahead transactions.

- **Local Differences** do exist owing to uncoordinated restructuring initiatives in the 90’s:
  - Portfolio Offers (e.g. France) vs. Individual Unit Offers (e.g. Italy)
  - Piecewise Linear (e.g. France) vs. Stepwise Orders (e.g. Netherlands)
  - Centralized Pool Day Ahead Markets (Greece, Ireland)
Electricity Market Integration

Two ways of **Cross-Border Transmission Capacity Allocation**:

- **Explicit**: via dedicated cross-border transmission capacity auctions (yearly, monthly, daily)
  - Keeps local markets separate, but inefficient
- **Implicit**: within the energy market clearing process (optimal) → **Market Integration**

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**Market Integration Approaches**

- **Market Coupling**
  - **Decentralized** Approach (>1 PXs)
  - **Volume Coupling**: Determination of optimal exchanged quantities
  - **Price Coupling**: Determination of optimal exchanged quantities and market clearing prices

- **Market Splitting**
  - **Centralized** Approach (1 PX)
  - Simultaneous determination of cleared quantities/prices
The EU Internal Electricity Market

1st Energy Package
- Directive 1996/92/EC

2nd Energy Package
- Directive 2003/54/EC
- Regulation 1228/2003

Common rules for the Internal Electricity Market (IEM)

3rd Energy Package
- Directive 2009/72/EC

Regulation (EC) 713/2009

Regulation (EC) 714/2009

Top Down (centralized) approach → Integration of existing regional initiatives

“Implementation Methods for the European Day-Ahead Electricity Market Integration”
The EU “Target Model”

- **Target Model** ("Florence Forum" 2009) → Defines the requirements for the creation of the internal electricity market

- **ACER**: Target Model → Framework Guidelines
- **ENTSO-E**: Framework Guidelines → Binding Network Codes [CACM]

**Target Model**

**Implicit allocation of cross-border capacity**

**Capacity Calculation**

- **Forward Market**
- **Day-Ahead Market**
- **Intraday Market**
- **Balancing Market**

**Single price coupling algorithm**
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Capacity Calculation (1/3)

- Each TSO defines:
  - Local Grid Model \(\rightarrow\) Topology, load flow parameters
  - A set of **Critical Branches** (N,N-1 condition) and relevant remedial actions
  - Generation Shift Keys \(\rightarrow\) Translate Net Exports (Net Positions) of each bidding zone to individual unit injection in %
Each TSO defines:

- **Local Grid Model** $\rightarrow$ Topology, load flow parameters
- A set of **Critical Branches** (N,N-1 condition) and relevant remedial actions
- **Generation Shift Keys** $\rightarrow$ Translate Net Exports (Net Positions) of each bidding zone to individual unit injection in %
Capacity Calculation (2/3)

- 2 available approaches: Coordinated **ATC** or flow-based (**FB**)  
  - Both start from the Common Grid Model (CGM) and Critical Branches (cb)

**ATC approach**

- Bilateral Exchanges
- Transportation model

**FB approach**

- Physical Flows (KVL)
- PTDF (DC load flow)
The Coordinated Capacity Calculator calculates the Cross Zonal Capacity:

- ATC-based model
  - **Output**: ATC values constraining Bilateral Exchanges (BEXs)
- Flow Based model:
  - **Output**: Flow Based Parameters (FB matrix)
    - Power Transfer Distribution Factors (PTDF)
    - Remaining Available Margin (RAM) : MW remaining for DAM use

\[
PTDF_{cb}^{Z} = \frac{\Delta Flow_{cb}}{\Delta NEX_{Z}}
\]

* Only non-redundant Critical Branches / Critical Outages (pre-solve)
EU Day-Ahead Price Coupling

✓ Price Coupling of Regions (PCR) project (June 2012)
✓ 7 Power Exchanges (APX, Belpex, EPEXSPOT, GME, Nordpool Spot, OMIE, OTE)
✓ Development of tools for European Price Coupling

❖ Basic characteristics:

- One price coupling algorithm
- Fair and transparent algorithm
- Decentralized operation
- Robust operation, anonymous data sharing
- Decentralized governance
- Individual accountability
DA Market Price Coupling Algorithm

- **EUPHEMIA** (Pan-European Hybrid Electricity Market Integration Algorithm) → Price Coupling Algorithm

- **Maximizes** the pan-European DA Market welfare

\[
\max \sum_{z \in Z} \sum_{b \in B} \sum_{t \in T} (P_{zb}^t \times Q_{zb}^t \times x_{zb}^t)
\]

- **Power Balance Constraints**

\[
\sum_{z \in Z} (NEX_{zt}^t) = \emptyset
\]

\[
NEX_{zt}^t + \sum_{b \in B} (Q_{zb}^t \times x_{zb}^t) = \emptyset
\]

**Symbols**

- **z ∈ Z**: Bidding area
- **t ∈ T**: Trading Period (hour)
- **b ∈ B**: Offer/Bid
- **Q_{zb}^t**: Bid/Ask Quantity (Q<0: supply, Q>0: demand)
- **P_{zb}^t**: Bid/Ask Price
- **x_{zb}^t**: Cleared Quantity (pu)
- **NEX_{zt}^t**: Net Position (Export)

**Decision Variables:**

\[
\emptyset \leq x_{zb}^t \leq 1
\]
EUPHEMIA Input Data

- Ramping Data
- Network
  - Network Constraints (ATC, FB)
  - Tariffs & Losses
- EUPHEMIA
  - Orders
    - Hourly Orders
    - Complex Orders
    - Merit and PUN Orders
    - Block Orders

TSOs

- PXs

“Aristotle University of Thessaloniki
Power Systems Laboratory”
"Implementation Methods for the European Day-Ahead Electricity Market Integration"
Network Constraints (1/2)

Network Representation

\[ NEX^t_z + \sum_{z' \in Z} (BEX^t_{z,z'} - BEX^t_{z',z}) = \emptyset \quad \emptyset \leq BEX^t_{z,z'} \leq ATC^t_{z,z'} \]

Flow Based

\[ \sum_{z \in Z} (PTDF^z_{cb} \times NEX^t_z) \leq RAM_{cb} \]

For all significant critical branches, \( cb \)

Combination of ATC and FB – Hybrid model

✓ Some bidding areas use the FB model → the remaining use the ATC
Network Constraints (2/2)

- In the Flow Based method **non-intuitive** situations may appear

- High price area may export to a low price area (dumping)

**Intuitiveness Constraint**

\[(MCP_Z^t - MCP_{Z'}^t) \times BEX_{zz'}^t \leq 0\]

**Intuitive Patch**

- Iterative heuristic
- For each congested critical branch (active line)

\[\sum_{z \in Z} \sum_{z' \in Z} \left[ \max \left( PTDF_{cb}^z - PTDF_{cb}^{z'}, \emptyset \right) \times BEX_{zz'}^t \right] \leq RAM_{cb}\]
EUPHEMIA Input Data

- **TSOs**
  - Ramping Data
  - Network Constraints (ATC, FB)
  - Tariffs & Losses

- **EUPHEMIA**
  - Orders
    - Hourly Orders
    - Complex Orders
    - Merit and PUN Orders
    - Block Orders

- **PXs**
  - Network
Simple Hourly Orders

✓ EUPHEMIA supports a variety of orders currently submitted in CWE, Nordpool, MIBEL and GME

**Piecewise Linear**

**Stepwise**

**Mixed Curve**
Block Orders (1/2)

- Different quantity $Q_h$ in each period $h$
- Acceptance based on **volume weighted average** market clearing price (Average MCP)
- Partial acceptance → 0 or Minimum Acceptance Ratio $\leq$ Cleared Quantity $\leq$ 1

Accept order if it is “in-the-money”: $P < \text{Average MCP}$ (supply)

Reject order if it is “out-the-money”: $P > \text{Average MCP}$ (supply)

(Partially) Accept/Reject order if it is “at-the-money”: $P = \text{Average MCP}$ (supply)
Block Orders (2/2)

- Same quantity $Q_h$ in each period $h$
- **Fill-or-kill** constraints (no partial acceptance)

![Diagram showing block orders with a common price $P$, quantity $Q$, and time intervals from 10:00 to 14:00.](image)
Block Orders (2/2)

- Regular Block Orders
- Linked Block Orders
- Exclusive Block Orders

- Same quantity $Q_h$ in each period $h$
- Fill-or-kill constraints (no partial acceptance)
- The acceptance of a block order (child) is dependent on the acceptance of another block order (parent)

![Diagram of block orders]

- Child Block
- Parent Block
Blog Orders (2/2)

- Regular Block Orders
- Linked Block Orders
- Exclusive Block Orders

- **✓** Same quantity $Q_h$ in each period $h$
- **✓** *Fill-or-kill* constraints (no partial acceptance)
- **✓** The acceptance of a block order (child) is dependent on the acceptance of another block order (parent)

- **✓** Set of block orders $\Rightarrow$ Trading of different production patterns
- **✓** The total acceptance ratio must be less than one (1)

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**Linked Block Orders**

- Low price order
- Medium price order
- High price order

- $P_L \leq P_M \leq P_H$

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**Diagram Notes**

- Q [MW]
- T [h]
Block Orders (2/2)

Regular Block Orders
- Same quantity $Q_h$ in each period $h$
- Fill-or-kill constraints (no partial acceptance)

Linked Block Orders
- The acceptance of a block order (child) is dependent on the acceptance of another block order (parent)

Exclusive Block Orders
- Set of block orders $\rightarrow$ Trading of different production patterns
- The total acceptance ratio must be less than one (1)

Flexible Hourly Orders
- Participants submit only a price/quantity pair for all time periods $h$
- Only one order is cleared at most!
Complex Orders

✓ EUPHEMIA supports a variety of orders currently submitted in CWE, Nordpool, MIBEL and GME

- Maximum/minimum clearing in period h+1 depends on the clearing in period h

- Total daily revenue (TR) of an activated MIC order with cleared daily quantity q must cover a fixed (FT) and a variable (VT) cost term

\[ TR \geq VT \times q + FT \]
EUPHEMIA supports **PUN orders** (PUN=Unique National Price)

- Italian Power Exchange (**GME**)
  - Supply offers are settled at the zonal marginal price **BUT**...
  - Demand bids are cleared regardless of their location at the system price (PUN) $\rightarrow$ volume weighted average of zonal prices
✓ EUPHEMIA supports **PUN orders** (PUN=Unique National Price)
✓ Italian Power Exchange (**GME**)

- Supply offers are settled at the zonal marginal price **BUT**...
- Demand bids are cleared regardless of their location at the **system price** (PUN) $\rightarrow$ volume weighted average of zonal prices
EUPHEMIA Solution Algorithm

- EUPHEMIA utilizes an iterative algorithm
  - **Master problem** → Welfare maximization → Determines a good selection of block and complex orders using MIQP
  - **Price determination sub-problem** → Determines prices consistent to order acceptance rules → No paradoxically accepted orders (no out-of-the-money orders accepted)
  - **PUN search sub-problem** → Determines valid PUN volumes and prices
  - Constraints invoking both **primal** and **dual** problem variables

- EUPHEMIA output:
  - Price per bidding zone
  - Net position per bidding zone
  - Flows per interconnection
  - Matched energy for all types of orders
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The “E-Market” Project

- Funded by the General Secretariat of Research and Technology of Greece → February 2014 - July 2015

Step 1: Integration of Electricity Markets with significant diversity in their design

Step 2: Network model improvements (intra-zonal, AC-LF)

Step 3: Handling of order acceptance rules in a one-step model

*http://emarket.web.auth.gr/site/?lang=en
Initial Results

- **Integration of Power Pools and Power Exchanges:**

![Graph showing Average Execution Time vs. Total Number of Regular Block Orders](image)

42 bidding zones
59 AC and 12 DC lines
“E-Market” Ongoing Research

Network model improvements
- Both inter-zonal and intra-zonal constraints
- Incorporation of N-1 security constraints
- Modeling of remedial actions
- AC power flow computations

Handling of order acceptance rules (Paradoxically Accepted Block Orders, PUN Orders, MIC Orders) as an one-stage optimization problem:
- Minimization of Duality Gap, subject to:
  - Equilibrium Constraints (primal & dual problem constraints)
  - Integrality constraints
  - Additional Positive Profit constraints (Order Acceptance rules)
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Concluding Remarks

- Full integration of all DA markets is expected in the near future (end of 2014 most EU DA markets will be coupled)

- The task of implementing a DA market coupling across Europe is a considerable challenge in terms of algorithmic modeling, organization and harmonization

- Further research is required for the fine-tuning of the pan-European day-ahead electricity market

- Advances should be made in implementing the integration of the intra-day and balancing markets, which are important due to the increasing penetration of variable renewable energy sources
Thank you!

E-MARKET Research Program: http://emarket.web.auth.gr/site/?lang=en

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