Market Clearing in Market Management Systems: State-of-the-art, Challenges and Opportunities

Kwok W. Cheung, Ph.D., PE, FIEEE
Director, Global Market Management Solutions
GE Grid Software Solutions

Confidential. Not to be copied, distributed, or reproduced without prior approval.
Outline

- Introduction
- State-of-the-art of Electricity Market Clearing in the United States
- Challenges and Opportunities for Energy Market Management
- Vision of the Next Generation of Market Management Systems (MMS)
- Final Remarks
What is GE Digital?

Our mission is

To bring simplicity, speed and scale to your digital transformation with modular software applications that better help you to operate, analyze and optimize your business processes.

$1.2B Industrial SWS Business

4000+ Employees, T&D foundational

- Electric Utilities and Telecommunications
- Power generation (gas, steam, and related plant operations)
- Oil & Gas industry and related adjacent markets
- Select manufacturing applications and digital transformation projects
Advanced Energy Management: Market + EMS + DMS

Unprecedented Opportunity to Leverage Value Across the Eco-system
DIGITAL ENERGY

Market Product Solutions and Deployment

Market
Solution for the Global electricity markets.

Market ENTSO-E
Solution for the European electricity markets.

Settlements
Settlement package for market participants and transmission system operators. Manages multiple products simultaneously.

Commit
Security-constrained resource scheduling and commitment program designed for competitive markets:
- Forward capacity markets
- Capacity allocation and nominations
- Financial Transmission Rights
- Day-ahead market and scheduling
- Forward reliability analysis
- Real-time balancing market
- Real-time look ahead commitment & dispatch
- Settlements

Multiple market models
- US-model
- EU-model (ENTSO-E)

Runs 70% of the generation capacity installed in the US ISO/RTO footprint

Transmission MMS Customers
22 MMS

GE - CONFIDENTIAL - Not to be copied, reproduced or distributed outside of GE without prior approval.
Electricity Markets: US Model

In North America, Regional Transmission Organization (RTO) or Independent System Operator (ISO) is responsible for:

- Operate a power grid securely with minimum costs
- Schedule and dispatch resources to satisfy market demand with economic efficiency
- Purchase ancillary services for the benefit of grid reliability
- Disseminate open market information to participants

PJM and MISO are some of the world's largest Market Operators using GE’s Digital Energy Market
Digital Energy

Standard Market Design (SMD) in the US

• In late 90s and early this century, FERC pushed for a common market design framework called **Standard Market Design**

• **Multi-Settlement System**
  - Day-ahead Market
  - Real-time Market

• **Locational Marginal Pricing**
  - Market-based Congestion Management
  - Financial Transmission Rights

• **Co-optimization of Energy and Ancillary Services (A/S)**

• **Reliability Assurance Business Processes**
  - Reliability Unit Commitment (DA, Intra-day)
  - Look-Ahead Commitment and Dispatch
Reliability Functions and Market Design

Utility Business Processes before Restructuring:

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Activities</th>
<th>Functions</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-5 years</td>
<td>Long Term Planning</td>
<td>Investment in generation and transmission</td>
<td>Production planning program</td>
</tr>
<tr>
<td>3-6 months</td>
<td>Resource Adequacy</td>
<td>Secure generation to serve loads and set long term maintenance schedule</td>
<td>Reliability analysis</td>
</tr>
<tr>
<td>1-2 weeks</td>
<td>Operations Planning</td>
<td>Coordinate short term maintenance schedule and long lead time generation</td>
<td>Load flow, transient stability, voltage stability</td>
</tr>
<tr>
<td>12-24 hours</td>
<td>Day Ahead Scheduling</td>
<td>Security constrained unit commitment using energy bids</td>
<td>Security constrained unit commitment program based on forecast load</td>
</tr>
<tr>
<td>5-180 minutes</td>
<td>Real Time Commitment and Dispatch</td>
<td>Real-time security-based balancing of generation and load</td>
<td>Security constrained unit commitment program based on real-time load</td>
</tr>
</tbody>
</table>

RTO Market Business Processes:

- Forward Capacity Market
- Long-Term Financial Transmission Rights
- Day-Ahead Market (DAM)
- Reserve Adequacy Assessment (RAA)
- Security Constrained Reliability Analysis (SCRA)
- Intra-Day Reliability Commitment (IDRAC)
- Intra-Day SCRA
- Look-Ahead Commitment and Dispatch (LAC/LAD)
- Real-Time Market (RTM)
Consistent dispatch signals and price signals based on

- Security constrained economic dispatch (SCED)
- Locational Marginal Pricing (LMP)

Market Clearing Applications

- Support for multiple markets:
  - Day-ahead
  - Real-time
  - Hour-ahead
  - Look-ahead
  - Re-play/Study Mode

- Support for various problems:
  - Balance Scheduling
  - Unit Commitment
  - Dispatch
  - Security Constraint
  - Re-pricing
OPF Evolution for Electricity Pricing

\[
\begin{align*}
\min f(u_P, u_Q) \\
\text{subject to} \\
(\lambda) & \quad g(u, x) = 0 \\
(\mu) & \quad h(u, x) \leq 0 \\
& \quad u^\text{min} \leq u \leq u^\text{max}
\end{align*}
\]

where

\[
u = [u_P, u_Q]^T \quad \text{Control variables, such as generation real and reactive power output}
\]

\[
f(u, x) \quad \text{Objective function represented with total production cost}
\]

\[
x = [x_\theta, x_Y]^T \quad \text{State variables, such as voltage angles and magnitudes}
\]

\[
g(u, x) = [g_p(u, x), g_Q(u, x)]^T \quad \text{Equality constraints of bus real and reactive power balance}
\]

\[
h(u, x) = [h_P(u, x), h_Q(u, x)]^T \quad \text{Inequality constraints of branch and voltage magnitude limits}
\]

\[
\lambda = [\lambda_P, \lambda_Q]^T \quad \text{Shadow prices of bus real and reactive power balance constraints}
\]

\[
\mu = [\mu_P, \mu_Q]^T \quad \text{Shadow prices of grid security constraints}
\]

\[
u^\text{min} = [u_P^\text{min}, u_Q^\text{min}]^T \quad \text{Minimum limits for control variables}
\]

\[
u^\text{max} = [u_P^\text{max}, u_Q^\text{max}]^T \quad \text{Maximum limits for control variables}
\]
Decoupled OPF Formulation (Real Power)

\[
\begin{align*}
\text{min } f(u_P) \\
\text{subject to} \\
(\lambda_P) \quad g_P(u_P, x_\theta) &= 0 \\
(\mu_P) \quad h_P(u_P, x_\theta) &\leq 0 \\
\quad u_P^{\text{min}} &\leq u_P \leq u_P^{\text{max}}
\end{align*}
\]

- Real and reactive problems are only loosely coupled
- Reactive power problem is highly non-linear; the real power problem is very linear
- Decoupled OPF - most commonly used optimization framework for SCED
SCED Algorithm for Market Clearing

• Reformulation of the decoupled OPF

• Advantages of SCED algorithm
  – Solved with state-of-the-art linear programming (LP) techniques
  – Simple and robust
  – Unlimited capability to handle many constraints
  – Both base and contingency grid security constraints can be handled
  – Participant bid data model accurately reflected
  – Ancillary Services (AS) can be incorporated
  – Unified framework for market clearing of energy, AS, and FTR

• Successfully applied to large-scale grid models in USA
  – PJM: 20,000 buses
  – Midwest ISO: 40,000 buses
Market Clearing Engine (MCE) Functional Characteristics

The MCE formulates the problem of clearing bids and offers as a constrained optimization problem

- Minimization of objective function: the cost of bid-price times bid-quantity, cleared to meet all requirements.
- A set of decision variables: the quantity to be cleared for each bid. Bids exist not only for energy but also for different types of ancillary service commodities in the market.
- A set of linear constraints
  - Equality-type constraints: power balance...
  - Inequality-type constraints: reserve requirement, technical limits, network security constraints ...

Able to deal with nodal / zonal / system models

- Unconstrained and constrained clearing & pricing managed through the market clearing engine models configuration
Co-optimizes clearing of energy, regulation/reserve, transactions, and dispatchable demand

- Different / additional offer formats depending on the market rules
  - e.g. start-up offers, full MW range offers, upward / downward offers
- Variable sized blocks based on specific market rules
  - e.g. min up time constraint, min cleared quantity
- Support of multiple markets and simultaneous solutions

Constrained optimization enforces limits on:

- Individual resource offering one or more products (e.g. energy offer, FCR offer, FRR offers, RR offers)
- Resource capacity and ramp rate (e.g. unit-based MW limit, energy constraints)
- Transmission assets (e.g. security constraints received from MKTNET)
- Conflicting constraints with prioritized violations
Market Clearing Engine (MCE) Functional Characteristics (Cont’d)

Support general function found in major electricity markets
• Constraint relaxation and scarcity prices
• Regulation Group commitment, regulation up and regulation down clearing
• Transmission constraints and branch flow penalty curve
• Tie-breaking model for energy & A/S
• Emergency logics in different study mode
• Special resources like Energy Limited Resources, Advanced Storage Model, Aggregated Combined Cycle and Configuration based Combined Cycle etc.

Support fuel-based non-market system
• Fuel cost
• Heat Rate Curve
What about **Tomorrow**...?

*Climate change is the biggest challenge of our generation*

Profound societal transformation that cannot wait any more

*Information precedes action*

Understand the climate impact of your decisions

*Together*

Open community to change the world

**Tomorrow** ([https://www.tmrow.com](https://www.tmrow.com)) – Get TMROW apps – in touch with the founder *Olivier Corradi*
Twin transformation

Renewable penetration combined with Electrification of sectors to drive emission reduction

86% of Electricity produced from renewable energy

60% from Variable Renewable Energy (VRE)
Energy Market **Disruption** from **Variable Renewable Energy**

- **Reduction in MWh**
  - wholesale price down for each VRE % added

- **Displacement of conventional generation**
  - leads to scarcity in capacity

- **New Bodies**
  - in Electricity Value Chain

- **Integration costs of renewable**
  - not counted in basic price

- **Demarginalization**
  - What about the current market design?

- **Performance limits**
  - Reduction in time slots and multitude of energy services

**DISRUPTION**
Grid Modernization Challenges and Opportunities

• Global energy & environmental movement
  − Emphasis on low carbon energy mix and Demand Response (DR)
  − Increasing presence of renewable power
  − Increasing presence of Distributed Energy Resources (DER), storage, PHEV

• Smart Grid Transformation
  − From centralized to more decentralized generation and control architecture
  − Bi-directional flow of energy (‘‘Prosumers’’)
  − Automation of distribution management
  − Retail electricity market and gas/electricity market coordination
  − Situational awareness for grid visibility/predictability becomes critical
  − New apps/services based on new equipment and more active network
  − **Optimization: larger footprint and deeper in the T&D hierarchy**
  − **Operational challenges: Uncertainty management**

• Unrelenting complexity in business & technical decision process
  − Smart devices/resources with distributed intelligence
  − Coordinated decision making
  − Big Data/AI/ML

• MMS customers is undergoing enormous “3D” transformation
  − **Digitalization, Decentralization, Demarginalization**
Digitalization: Digital Utility Reference Architecture

Decentralization: Emerging Retail Markets

How will new business models evolve to value and incent sustainable DER growth?

How can DER go beyond Net Energy Metering?
  - dLMP (vary by time and location)
  - Providing essential reliability services
    - Volt/var support
    - Fast frequency response (FFR)
    - Regulation reserves

How will retail markets coordinate with the wholesale markets?
  - Interfacing between ISO and DSO (MMS/EMS/DMS)

How will retail markets be formed?
  - Distribution system operator (DSO)
  - Aggregator vs. Local Utility
  - Peer-to-peer
De-marginalization: Energy Price Formation

- Approaching almost zero marginal cost of electricity
- Generating resources are differentiated less by incremental cost but more by physical/operational attributes
- The locational marginal pricing (LMP) approach in its “purest form” might not be sufficient to allow generators to fully recover costs - “missing money”
- Leading to the issue of revenue sufficiency
- The missing money problem will also directly result in a negative impact on resource adequacy and long-term system reliability
- Developing correct price signals that reflect the cost of serving load is fundamental
A New Vision: Advanced MMS

Performance and Scalability
- Re-engineering the Market Clearing Engine for superior performance
- Micro services ecosystem
- Advanced messaging and data transfer infrastructure
- Highly scalable architecture for diverse system footprints

Flexibility
- Modular applications easily configured to meet rapidly changing business requirements
- Solution framework allows for an easy integration of the needed business modules and interface with external systems

Advanced Capabilities
- Complex modeling
- Regional balancing and reserve sharing
- Energy price formation
- Congestion management leveraging world-class Network Apps

Advanced Analytics
- Leveraging Big Data and AI for business returns
A new toolset for a fragmenting world

Solutions need to adapt to a fragmenting and decentralized ecosystem
Advanced MMS
Next Generation Market

Solution Highlights

Solution for global electricity markets
- Finer market interval
- Shorter market clearing time
- Gas market coordination
- Advanced combined cycle, storage & demand
- Model-predictive scheduling and dispatch
- Handling millions of renewable DERs
- Adaptive model management
- Flow and topology control
- Scalable market footprints
- Retail market extension, integration & dynamic pricing
Final Remarks: Recent R&D and Implementation Trends for MMS

- Energy price formation
- Convergence of reserve market design and implementation
- Flexibility products
- Integration of energy storage
- Configuration-based combined cycle
- Topology control and transmission switching
- FACTS optimization
- Multi-day markets
- Integration of distributed energy resources/VPP
- Risk-based market clearing and stochastic optimization
- Retail Market - Distributed System Platform