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Transaction Based
Voltage Margin Allocations
for Deregulated Electric Markets

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De-Regulation
Deregulation or Restructuring denotes breaking up of the Vertically Integrated Utility (VIU) structure into Competitive Market Entities.
RESTRICTED ELECTRICAL INDUSTRY
SO is the Power System Operator and the Power Market Operator, which may include other entities depending on the market structure. SO, is independent of the other entities.
An Integrated Electricity Market

Power Commodity Markets

- Power Exchange Market (PX)
- Bilateral Contract Market (BCM/SC)
- Ancillary Service Market (ASM)

Transmission Capacity Markets

- New types of transmission directives (ISO, ISA, RTO)
- Long-term capacity access charge (LCC)
- Fixed transmission rights (FTRs)

Real-time Balancing Markets (RBM)

- To perform a security-constrained ED function
- To re-dispatch bilateral contracts
Power Commodity Market Components

- A **Power Exchange (PX)** establishes an auction market where energy offers/bids by the generators/consumers are matched anonymously based on volume and prices. The PX may operate a forward (a day-ahead) market as well as an hour-ahead spot market separately.

- A **Bilateral Contract** is defined as “the right to inject a certain amount of power at a delivery point \(i\) and remove it at another receipt point \(j\) at a specified price \(P_{ij}\).”

- **BCM/SC** market shields for pro-conservative market agents against risk of hedging of electricity price in the central spot market (PX) due to various strategic bids/offers.

- The **Ancillary Service Market** is responsible for procuring spinning reserve, non-spinning reserve, AGC, replacement reserves, voltage support and black start, to secure stable operation of the system.
Transmission Capacity Market Components

Within the context of Transmission Open Access (TOA) philosophy, the transmission entities continue to evolve towards new types of directives like:
- For-Profit TRANSCO
- Non-Profit Independent System Operator (ISO)
- Independent Scheduling Administrator (ISA)
- Regional Transmission Operator (RTO)

The **Capacity Connection Charge** (LCC), or power fee, is a long-term (say one year) charge per MW of connected capacity as a portion of the transmission tariff package.

The capacity charge could be same for all users connected to ISO, or can be related to the geographical location or based on other market designs related to congestion.

**Firm Transmission Right** is defined as “A financial contract that entitles the holder to a stream of revenues (or charges) based on the reserved level and hourly LMP difference across the specified transmission paths”.

FTR protects transmission customers from increased cost due to transmission congestion on the condition that energy trades are consistent with firm reservation.
The **Real-time Balancing Market** is a real-time energy balancing market performed by the ISO to revise the preferred schedules when there is any imbalance or transmission congestion.

- In the RBM, both generators and consumers in the PX can submit their incremental or decremental energy offers and bids to the ISO, who will select the least cost resources to meet the balancing requirements or to eliminate the congestion on a real-time basis.

- In the RBM, the ISO also can curtail the bilateral contracts whose sensitivity to the violated constraints is high, or call for new bilateral transactions resulting in a negative power flow effect on the congested lines.
Conventional Power Flow
Here all N buses fall into 3 categories: PQ bus, PV bus and one single slack bus \((V, \theta)\).

- Since power flow equation is in term of angle difference, a reference angle is assigned to the slack bus in advance, whereas generation of the slack bus is left open to account for imbalance between the total generation and load in the system.
NECESSITY & PROBLEMS WITH CLASSICAL SLACK BUS

NECESSITY

• Provides reference angle
• Accounts for energy imbalance
• Makes N power flow equations a consistent set

PROBLEMS

• Causes dependency of the PF solution on the slack bus when specified real power of N bus is inconsistent.
• Difficulty in determining loss responsibility for individual generators/loads/transactions.
• Causes PF sensitivity factors being slack bus dependent.
Nodal power balance equations (a) vs. nodal current balance equations (b).

\[
\begin{align*}
(P_{Gi} - P_{Di}) &= V_i \sum_{j \in i} (g_{ij} \cos \theta_{ij} + b_{ij} \sin \theta_{ij}) \\
(Q_{Gi} - Q_{Di}) &= V_i \sum_{j \in i} (g_{ij} \sin \theta_{ij} - b_{ij} \cos \theta_{ij}) 
\end{align*}
\]

Can we build a bridge between certain real power and particular nodal current?

\[P_i + jQ_i = V_i e^{j\theta_i} \times I_i^*\]
Note that $P$ and $Q$ are coupled with $I$ through associated phase angle and voltage magnitude, thus it is impossible to find the exact contribution of $P$ on $I$. Fortunately, transmission grids hold several characteristics like:

- R/X ratio and branch angle difference are small.
- Strongly Coupling relation between $P$ and $\theta$.
- Strongly Coupling relation between $Q$ and $V$.
- Strongly Coupling relations between $\text{Re}(I_{bus})$ and $\theta$, and between $\text{Im}(I_{bus})$ and $V$, provided nodal phase angle is small enough (say $|\theta_{max}| < \pi/9$).
Exact expression $P_i$ in terms of nodal current is

$$P_i = V_i \cos \theta_i \text{Re}(I_i) + V_i \sin \theta_i \text{Im}(I_i)$$

We make the following approximation according to the discussed basic facts:

$$\text{Re}(I_i) \approx \frac{P_i}{V_i \cos \theta_i}$$

assuming $V_i \sin \theta_i \text{Im}(I_i)$ is small.

The aggregated reactive power of the system takes care the remaining current components, including all $\text{Im}(I_i)$ terms and residual errors of $\text{Im}(I_i)$, which are

$$\text{Re}(I_i) - \frac{P_i}{V_i \cos \theta_i}$$
Main Features of The TBPF Analysis

- **Decompose** complex AC power flows directly into transaction components, in the light of Physical Laws.
- **Evaluate** interaction quantities of different energy transactions on particular power flows and losses.
- **Show** effect of reactive power scheduling on reactive loss and transmission losses.
- **Assure** satisfactory decomposition accuracy when realistic network conditions are satisfied.
- **Sustain** a simple and fast computation procedure.
TBPF APPLICATION SCOPES

- Transaction loss evaluations
- Parallel flow evaluation and compensation
- Congestion Management
- Conducting FTR purchase/sale and settlement
- Reactive power support charge for energy delivery
- Responsibility settlement of voltage stability
Transaction Based Voltage Margin Allocation
\[
[I \text{ bus}] = [Y \text{ bus}] * [E \text{ bus}]
\]
\[
\begin{bmatrix}
V_L \\
I_L \\
I_G
\end{bmatrix}
= H 
\begin{bmatrix}
I_L \\
V_G
\end{bmatrix}
= \begin{bmatrix}
Z_{LL} & F_{LG} \\
K_{GL} & Y_{GG}
\end{bmatrix}
\begin{bmatrix}
I_L \\
V_G
\end{bmatrix}
\]
\[
L_j = S_{j+} \cdot \frac{Y_{jj} + V_j^2}{S_{j+}}
\]
\[
S_{j+} = S_j + S_{jcorr}
\]
\[
S_{jcorr} = \left( \sum_{i \in L \atop i \neq j} \frac{Z_{ji} S_i}{Z_{ij} V_i} \right) V_{jj}
\]
\[
Y_{jj+} = \frac{1}{Z_{jj}}
\]
TRANSACTION BASED VOLTAGE MARGIN ALLOCATION (TB-VMA)
TB-VMA Application Scope

- Responsibility Settlement of Voltage Security
- Node-wise Voltage Stability Margin Utilization Evaluation
- Evolve Transaction Based Pricing Mechanism for Voltage Security
- A Tool to confirm whether a Transaction could be committed from voltage security margin viewpoint
- A Tool to decide which transaction if curtailed gives maximum effect in case of potential voltage collapse situation
CONCLUSION

- A Transaction Based Voltage Margin Assessment procedure has been formulated.
- The TB-VMA is able to evaluate voltage security margin utilization on a node wise basis with respect to individual transactions.
- TB-VMA has been effectively demonstrated using a composite market model containing both PoolCo type and Point-To-Point type transactions.
REFERENCES

- **Hongming Zhang**, “Transactions-based power flow analysis and its applications to a competitive power market” Ph.D dissertation submitted to Texas A&M University, June 2001


