Valuation of Congestion Revenue Rights based on Power Market Simulation Models

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Outline

- Motivation
- Congestion Revenue Rights (CRRs)
  - FTRs and FGRs
- An AC Power System Model
  - Loads and transactions
  - Quadratized power-flow formulation
- Valuation of CRRs: numerical examples
  - Visualization of spot prices
  - Statistical modeling
- Future Work
Transmission Pricing and Congestion Management

- Postage Stamp Transmission Pricing
  - Simple to implement
  - No economic signal provided for efficient congestion management or for location of generation & load.

- Nodal pricing/FTRs
  - Efficient congestion management through centralized economic dispatch (first best under perfect information).

- Parallel markets for energy and link-based transmission rights (e.g., FGRs)
  - Efficient congestion management through trading rules set by the ISO and dual market equilibrium.
Key Concepts

- **Congestion Charge (Revenue)**
  - Marginal congestion component of energy purchases or transmission usage charges
  - Reflecting the increased cost resulting from dispatching a transmission system to respect transmission system constraints

- **Congestion Revenue Right (CRR)**
  - A property right that entitles and/or obligates the holder of the right to receive specified congestion revenues.
  - Ownership not limited to transmission users
Flow-gate

- A transmission facility (such as a transmission line, a transformer or some other components of an electrical network) or a group of facilities (e.g., an interface).

Flow-gate Right (FGR)

- A Congestion Revenue Right specified by a portion of the total MW capacity over a particular transmission flow-gate in a specified direction
- Right to collect congestion revenue associated with the specified MW flow over the identified flow-gate in the specified direction
Congestion Revenue Rights: Obligation vs. Option

● Four Types
  - Receipt-point-to-delivery-point congestion revenue right obligation
    ● Implemented in PJM, NY and NE
  - Receipt-point-to-delivery-point congestion revenue right option
  - Flow-gate congestion revenue right obligation
  - Flow-gate congestion revenue right option

● Difference between obligation and option
  - CRR obligation must pay the amount of the congestion rent to the System Operator
  - CRR option would not be exercised
Role of CRRs

- Assist in providing assurance of adequate and reliable supplies of electric energy at just and reasonable wholesale prices
  - To provide price certainty for a subset of transmission customers who purchase open access transmission service.
  - To provide a subset of transmission customers with a non-price vehicle for “buying through” transmission congestion regardless of the value of congestion (VOC).
Issues with CRRs

- Availability of CRRs
  - Total quantity
  - Eligible transmission customers for initial allocation

- Allocation of CRRs
  - Simultaneous feasibility
  - Initial allocation auction and secondary market trading

- The length of time that a CRR could be hold
  - One year: good liquidity
  - Multi-year: important reliability enhancing role in SMD
Secondary Market for CRRs

- **Rationales**
  - Load patterns change over time
  - Some LSEs with CRRs drop off the transmission network, and their CRRs may have to be re-distributed to the remaining LSEs if CRR auctions are not in operation
  - New CRRs created by transmission investment that need to be distributed

- **Trading Mechanisms**
  - Bilateral transactions
  - CRR resale auctions
Transmission Risk Management: CRRs

- Yearly CRRs, Forwards on CRRs, and Call/Put options on CRRs
  - Lower price to hedge uncertain congestion charges
- Perspective from different players
  - LSE (regulated utility): CRR call options
  - Independent Transmission Provider: CRR put options
Our Objectives

- **Electricity Spot Price Behavior in a Reliability Constrained System**
  - Visualization

- **Transmission Rights and Asset Valuation**
  - Implications of reliability constraints on the valuation of CRRs and transmission assets
  - Component reliability premium

- **Compensation Scheme for Transmission**
  - Incentives for transmission investment and risk management under reliability constraints
Day Ahead Sequential Simulation
(Important Sample Generation)

- Proposed methodology
  - Day-ahead operating scenario generation
  - Rare events postulation

- Formulation
  - Non-conforming load model
  - Quadratized power flow
  - Rare events
    - Hybrid contingency selection methods using multiple performance indices

- Public Information
  - ATC, Other
Animation and Visualization Approach

• Generate a Visual Representation of Spot Prices, FTRs, and FGRs
• Vary System Operating Conditions and Update the Visual Representation
  ➢ Electric load variation
  ➢ Contingencies
• Update the Visual Representation
  ➢ Solve power flow
  ➢ Compute spot prices, FTRs and FGRs
• Computational Speed is Very Important
Literature Review — Market Simulation

- Issues Investigated by Simulation
  - Full-fledged market operation simulation
  - Bidding strategies
  - Generation scheduling and investment planning

- Selected Reported Market Simulators
  - STEMS/LTPMS EPRI
  - MAPS GE
  - PROSYM Henwood Energy Services Inc.
  - MARKET EPRI and Iowa State University
  - PowerWeb UIUC/ Cornell University
  - EDSPOT Italy
Market Signals Modeling

- Simulate system conditions and market operation to get prices
- Model the stochastic behavior of market prices from historical data and fundamental analysis
Multilateral Transaction Model

\[
\{(i,p),(j,\rho),(\gamma, P_w)\} = \left\{ \left( i_1, p_1, \gamma, P_{w1} \right), \left( i_2, p_2, \gamma, P_{w2} \right), \ldots \right\}
\]

where:

- \(i\) a vector for bus numbers where power producers are connected. \(i = [i_1, i_2, \ldots, i_n]\).
- \(p\) a vector for wheeling participation factors for generators at the buses.
- \(j\) a vector for bus numbers where power consumers are connected. \(j = [j_1, j_2, \ldots, j_m]\).
- \(\rho\) a vector for wheeling participation factors for loads at the buses.
- \(\gamma\) a transmission loss sensitivity due to the transaction.
- \(P_w\) total real power of the transaction.
- \(p_k\) a wheeling participation factor for the generator at bus \(k\).
- \(\rho_k\) a wheeling participation factor for the load at bus \(k\),

\[
\sum_{k=1}^{n} p_k = 1, \quad \sum_{k=1}^{m} \rho_k = 1
\]
Non-conforming Load Model with Flexible Contracts

\[ P_L = P_0 P_0 + P_1 P_1 v_1 + \sum_{k=2}^{m} P_k P_k v_k \]

where:

- \( P_L \) is an n-vector of random variables representing the bus electric loads.
- \( n \) is the number of load buses.
- \( P_0 \) is the valley value of system load.
- \( P_0 \) is a vector of bus valley loads in percent of system valley load.
- \( P_1 \) is the peak minus valley value of system load.
- \( P_1 \) is a vector of bus peak minus valley loads in percent of system peak minus valley load.
- \( v_k \) is a set of independent random variables.
- \( P_k \) is the total load w.r.t. random variable \( v_k \).
- \( P_k \) is a vector of bus loads in percent of \( P_k \).

If \( m \geq 2 \), then the above model becomes a nonconforming load model.
Non-Conforming Electric Load Model

\[ S_i = P_i (1 + j \beta_i) \]

\[ P_i = P_{io} + \alpha_{i1} v_1 + \alpha_{i2} v_2 + \ldots \]

Where: \[ v_j = [-1.0 \text{ to } 1.0] \]

If only one \( v \) variable \( \Rightarrow \) Conforming Load
Spot Market Model

\[ J \equiv \text{Min} \sum_j c_j \Delta P_{gj} + \sum_k \sum_i c_{ki} p_{ki} (1 + \gamma_k) \Delta P_{k,w} \]

s.t.
\[ \sum_j \Delta P_{gj} + \sum_k \sum_i p_{ki} \Delta P_{k,w} = dP_L + \beta + \alpha^T \Delta v + \sum_k \sum_l \rho_{kl} \Delta P_{k,w} \]
\[ P_n^o + \sum_j [PTDF]_{n,j} \Delta P_{gj} + \sum_k \sum_i [GPTDF]_{n,ki} p_{ki} (1 + \gamma_k) \Delta P_{k,w} \]
\[ + \sum_m [PTDF]_{n,m} \Delta v_m \leq \tilde{P}_n \quad n \in \text{binding constraints} \]
\[ \Delta P_{gj}, \Delta P_{k,w} \geq 0, \quad \forall j, k \]

where:
- \( \Delta P_{gj}, \Delta P_{k,w}, \Delta v \) are incremental values of \( P_{gj}, P_{k,w} \) and \( v \).
- \( dP_L \) is an incremental load change at the load for the transaction \( P_{g} \).
- \( \beta + \alpha^T \Delta v \) is the amount of total real power of the load of the transaction \( P_{g} \).
- \( \rho_{kl} \) is the participation factor for the load at bus \( l \) of the transaction \( P_{k,w} \).
- \( P_n^o \) is the present loading of transmission line \( n \).
- \([PTDF]_{n,j}\) is the change of power flow on a transmission line \( n \) for the incremental real power injection at bus \( j \).
- \([GPTDF]_{n,ki}\) is the change of power flow on a transmission line \( n \) for the real power injection due to the transaction \( \Delta P_{k,w} \).
- \([PTDF]_{n,m}\) is the change of power flow on a transmission line \( n \) for the real power injection due to the value of \( \Delta v_m \).
Spot Price Computations via QPF

Min \[ J = \sum_{i=1}^{n} f_i(P_{gi}) \]

Subject to:
\[ G(x,w) = 0.0 \]
\[ |\tilde{T}_{km}(x,w)| \leq \bar{T}_{km} \]
\[ 0 \leq P_{gi} \leq \bar{P}_{gi}, \quad i = 1,2,...,n \]
\[ \Delta P_{gi} = P_{gi} - P_{gi}^0 \geq 0, \quad i = 1,2,...,n \]

Electric Load \( w(1+j\alpha) \) at Bus \( k \)
\[ \tilde{I}_{dk} = w(1+j\alpha)\tilde{V}_k + u_1 w(1+j\alpha)\tilde{V}_k \]
\[ 0 = u_2 + u_1 u_2 - 1 \]
\[ 0 = u_2 - V_k^2 \]

Spot Price \( (SP) = \frac{dJ}{dw} \)

Computation Procedure
- Linearize Around Operating Point (LP)
- Linear Program Provides Derivative
Financial Transmission Right (FTR) between i and j

\[ FTR_{ij} = SP_i - SP_j \]

Flowgate Right (FGR) of Flowgate k

\[ FGR_k = \frac{dJ}{dT_k} \]
Visualization of Spot Prices, FTRs & FGRs

Example System: IEEE RTS 24 Bus System
Visualization of Spot Prices, FTRs & FGRs: Example System: IEEE RTS 24 Bus System
Snapshot of Spot Prices
Snapshot of Spot Prices
Example 6-Bus System

- **Admittances**
  \[ B_{12} = B_{13} = B_{25} = B_{45} = -j10.0 \]
  \[ B_{16} = B_{46} = -j5.0 \]

- **Circuit Loading Limits**
  \[ T_{1-2\text{ Limit}} = T_{1-3\text{ Limit}} = T_{2-5\text{ Limit}} = T_{4-5\text{ Limit}} = 3.0 \]
  \[ T_{1-6\text{ Limit}} = T_{4-6\text{ Limit}} = 1.0 \]

- **Unit Generation Cost**
  \[ f(P_{G1}) = 17.8 + P_{G1}/3.0 \]
  \[ f(P_{G3}) = 18.0 + P_{G3}/4.0 \]
  \[ f(P_{G4}) = 22.0 + P_{G4}/5.0 \]
  \[ f(P_{G5}) = 22.2 + P_{G5}/6.0 \]

- **Random Loads**
  \[ P_{L2} = 3.00 + 1.04v_1 \]
  \[ P_{L6} = 2.64 + 2.40v_2 \]
  \[ v_1, v_2 \sim Uniform(0,1) \]

- **Generation Limit**
  \[ P_{LimitG1} = P_{LimitG1} = P_{LimitG1} = P_{LimitG1} = 10 \]

- **Unit Bases Values**
  - Power: 100MW
  - Voltage: 110kV

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Varying Flowgate Right Value (1 to 6 over 1-6)

- The FGR value increases with V2
- V1 has no significant effect on this FGR Value
Probabilistic Distribution of FGR Values 1 to 6 over 1-6

Probability Function of Flowgate Right Value (1 to 6 over 1-6)

- No Contingency
- Loss of Circuit 1-2
- Loss of one Circuit 2-5
- Loss of one Circuit 5-6
- Loss of Circuit 5-6
- Loss of Circuit 4-5

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Probabilistic Distribution of FGR Values 4 to 6 over 4-6

Probability Function of Flowgate Right Value (4 to 6 over 4-6)

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Future Work

- **Visualization**
  - Improve visualization tools via user feedback
  - Exploiting the QPF for fast repeat solutions

- **Volatility of the spot price and CRR value distributions**
  - CRR forwards
  - CRR call/put options

- **Influential factors for the FTR and FGR distributions**
  - VAR constraints
  - Voltage support problems
Future Work (con’t)

- Market-based reliability analysis
  - Value of active electric load (e.g., TLR)
  - Reliability of circuits
  - Availability of generators and circuits