Hybrid Congestion Management Systems: Flow-based versus Point-to-point Transmission Rights

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Overview

- Context: RTOs and congestion management
- Definitions: Flowgates, Commercially significant flowgates (CSF)
- How are CSFs priced
- Market settlement example
- Comparison of flow-based and point-to-point transmission rights

Objective: To Discuss -

- Flow-based transmission rights
  - Commercially significant flowgates and flowgate rights, FGRs
  - Mathematical source of flowgate pricing
- Hybrid congestion management systems
  - 'Hybrid' because they combine aspects of both flow-based and point-to-point transmission rights systems
- Assuming familiarity with nodal pricing and LMP

RTOs and Congestion Management

- Congestion management systems (CMS)
  - RTO proposals must include a market mechanism for managing congestion
  - This implies a need to allocate transmission capacity when it is constrained, *i.e.,* scarce
  - Which implies a need for a process to define transmission rights

Options for Transmission Rights: Flow-Based Transmission Right, FGR

- A right to flow power on a specific transmission facility or flowgate
  - Market participants can buy rights on commercially significant flowgates, CSFs
  - Experience and simulations identify which ones are commercially significant
  - NERC Security coordinators and control area operators define and use flowgates

Options for Transmission Rights: Point-to-Point Transmission Right, FTR

- A right to inject power at one node (or point) and withdraw the same amount at a second node
- No specific transmission facilities are associated with the right
- *Every* node has a 'nodal price'
  - Differs from flow-based which has relatively fewer facilities on which to buy rights

Options for Transmission Rights: Hybrid Model

- Flow-based - designed to have a more liquid forward market
- Nodal - defined to be more accurate in real time
- Hybrid model
  - Introduces an interface between a forward market with flow-based pricing and real-time operations with nodal pricing
  - *Ex-post* settlement combines forward market schedules, with nodal pricing for imbalances

RTOs and Flow-Based Transmission Rights

- The second wave of RTO filings include many proponents of flow-based systems
  - Alliance
  - Desert Star
  - ERCOT
  - Florida
  - ITC (Midwest)
  - Midwest ISO
  - RTO West
  - SPP
- TCA is involved with most of these regions

Mechanics of Flow-Based Transmission Rights

Question One:

How are the relevant facilities identified?

Definition: Flowgate

- A modeled transmission line or transformer that can become limiting during system operation and for which representation is made in the NERC security coordinator model.
- A flowgate may consist of the total interface between control areas, a partial interface, an interface within a control area that consists of a single line or transformer, or a defined set of any of these facilities.
- Flowgates are defined through NERC processes

Three Assumptions for Commercially Significant Flowgates, CSF

1. There is a set of transmission facilities, *i.e.* flowgates, that are the flow limiting elements in the system.
2. The transfer capability across a flowgate can be calculated in advance of operations
   - This quantity is relatively stable over time, subject only to significant, electrically close, outages in the transmission system.
3. Only a subset of the operator identified flowgates has commercial significance
   - Related to the cost of redispatching generating units to relieve the constraint

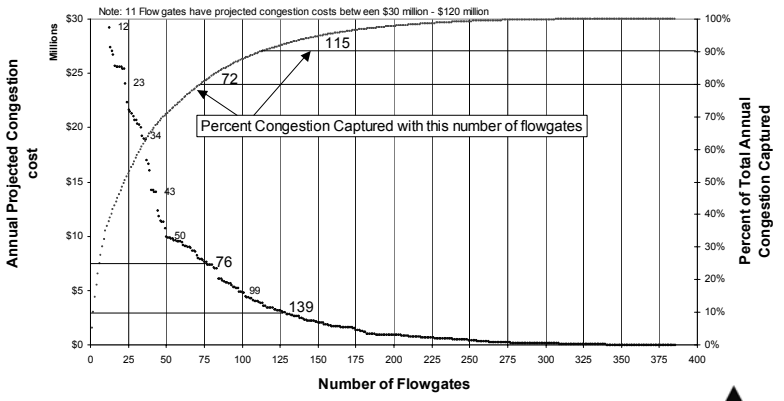
Three Steps for Defining CSFs

1. Identify all potentially congested flowgates and their transfer limitations
   - This task is the same as identifying all operational flowgates, which is routinely performed by system operators and security coordinators
2. Simulate the operation of the transmission system and competitive wholesale market to project congestion costs
   - Simulate for a variety of system conditions, load levels
   - Obtain the expected cost from congestion on each flowgate

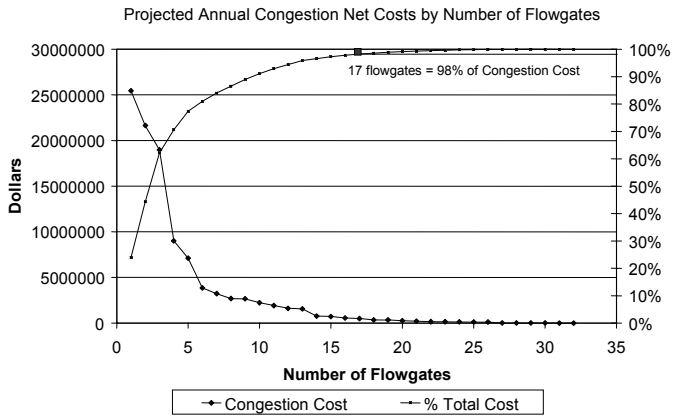
Three Steps for Defining CSFs

3. Develop a commercial significance "threshold"
   - Rank, or cumulate the expected costs, by flowgate, from the highest to the lowest
   - Those flowgates that account for a specified percentage of the costs (*e.g.,* 98%) are defined to be commercially significant for the purpose of defining flowgate transmission rights.

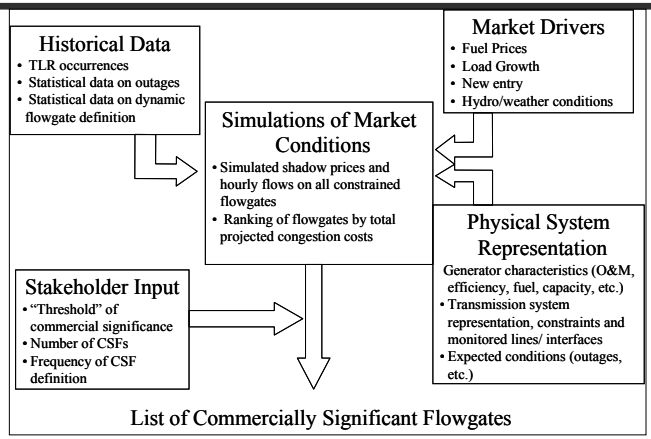
Projected Annual Net Congestion Costs (2003) by Number of Flowgates in Eastern Interconnection



Midwest CSFs



CSF Determination Methodology



Question Two:
How is the Theoretical Price
for a CSF Determined?

Mathematics of Transmission Pricing

- Starting point: Linear programming equations for the power system
  - Formulate the objective function
    - Serve load at least cost
  - Subject to system constraints
    - Nodal energy balance
    - Transmission facility flow limits
    - Generator output limits
  - Formulate Lagrangean and solve for energy and transmission shadow prices

Definitions of Variables

p_{gi} = price of generation
g_i = generation at node i
d_i = demand at node i
f_j = flow on facility j
f_{ik} = flow between nodes i, k
F = total number of flowgates
N = total number of nodes
G = total number of generators
xi_n = Power injection to node n from reference node
xw_n = Power withdrawal from node n to reference node
$GSF_{n,j}$ = Generation Shift Factor from node n on facility j

Standard Simplified Economic Dispatch

minimize $\quad \text{Cost} = \sum_i^G c_{gi} g_i$

subject to $\quad \sum_i^N g_i = \sum_i^N d_i$

$$f_{ik} \le \text{FlowLim}_{ik}, \quad \forall \text{ lines } i,k$$

Lagrangean $\quad \text{L} = \sum_i^G c_{gi} g_i - \lambda \left(\sum_i^N g_i - \sum_i^N d_i \right)$

$$- \rho \left(f_{ik} - \text{FlowLim}_{ik} \right)$$

Standard Simplified Economic Dispatch

- 🖱 is defined to be 'System Lambda' - the energy price
  - The system 🖱 becomes a nodal 🖱 when there is congestion
- Typically, 👎 has not been recorded or utilized in pricing methodologies
  - 👎 is the price associated with constrained transmission facilities

Focusing on Transmission Pricing

- Objective Function

$$\text{minimize Cost} = \sum_{i}^{G} p_{gi} g_i$$

- Subject to system constraints

$$(1)\ \left(g_n + xw_n\right) = \left(d_n + xi_n\right), \qquad \forall n \quad n = 1 \ldots N$$

$$(2)\ \sum_{n}^{N} \left[xi_n \cdot GSF_{n,j} - xw_n \cdot GSF_{n,j}\right] \le \text{FlowLim}_j, \quad \forall j \quad j = 1 \ldots F$$

$$(3)\ \ \text{minGen}_i \le g_i \le \ \text{maxGen}_i, \qquad \forall i \quad i = 1 \ldots G$$

Focusing on Transmission Pricing

- Lagrangean

$$L = \sum_{i}^{G} p_{gi} g_i - \sum_{n}^{N} \left[\lambda_n \left(\left(g_n + xw_n\right) - \left(d_n + xi_n\right)\right)\right] - \sum_{j}^{F} \left[\rho_j \left(\sum_{n}^{N} \left(xi_n \cdot GSF_{n,j} - xw_n \cdot GSF_{n,j}\right) - \text{FlowLim}_j\right)\right]$$

Interpreting the Shadow Prices

- Nodal energy prices, 🖱
  - Equation (1) – nodal energy balance
  - Shadow price on equation (1) is the value to the objective function of injecting 1MW at the node
  - This is the nodal energy price, LMP
- Flowgate transmission price, 👎
  - Equation (2) – Flow limits on physical transmission facilities
  - Shadow price on equation (2) is the value of relieving a flow limit by 1MW
  - This can be interpreted as the price of using the constrained flowgate

Summary of Electricity Pricing Method

- Typically only shadow prices from equation (1), nodal energy balance, are used
- Flow-based transmission pricing relies on using shadow prices from equation (2), the flow equation, as well
- The equations and mathematical theory are identical for both systems
  - More information is utilized for flow-based pricing

Question Three:

What is the Interface Between Forward and Real-Time Markets?

Time Frames for Market Operations

- Forward market
  - Determine and submit schedules
  - Schedules can include energy source, sink and associated transmission use (CSF purchases)
  - ➢ *Need price certainty in the forward market*
- Real-time operations
  - Implement schedules
  - Balancing and system operation by RTO
- Ex-post settlement

Hybrid System: Integrating Markets and Operations

- Forward market sets the prices for congestion at the expected values of transmission
- Real-time operations determine actual values, and uses on nodal prices
- Discrepancies between forward expectations and real-time system conditions
  - Allocation of congestion costs from flowgates not defined as CSFs
  - Discrepancies resulting from outages or other changes in system topology

Hybrid System: Integrating Markets and Operations

- Markets need a mechanism to reconcile the differences between the expected and the actual congestion and prices

➢ ***Hybrid Congestion Management System***

Question Four:
How is Settlement Implemented?

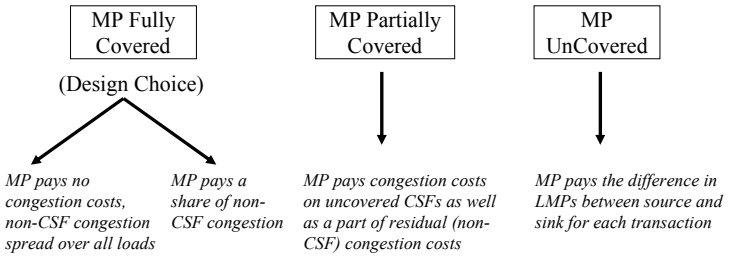
Purchasing CSFs

- Use posted shift factor matrix to determine how many rights to buy on which flowgates
  - Generation shift factor – the percentage of power from a transaction that flows on a given flowgate

  ⇨ Use GSF matrix ⇨ select CSFs ⇨ buy FGRs
- Purchase some or all of the indicated FGRs in annual and/or monthly auctions
- Use the FGRs:
  - To hedge congestion costs when scheduling transactions
  - To resell in the secondary market or monthly auctions

Hybrid System Settlement Logic

- Combines forward market FGRs with real-time LMP



MP = Market Participant
Covered = all necessary FGRs are held

Hybrid System Settlement Logic

- Recall the transmission pricing discussion
  - 🖱 is the shadow price for nodes, buses
  - 👆 is the shadow price on transmission facilities

MP Pays: $$\sum_{\forall Transactions(i)} (\lambda_{POW} - \lambda_{POI}) * Q_i - \sum_{\forall CSFs(j)} \rho_j * Q_j$$

- In words, MPs will be charged the sum over all transactions of LMP prices multiplied by transaction quantity less the credit for held FGRs based shadow prices. (Q_j = MW purchased/held on CSF_j)

Hybrid Settlement for Portfolios

- Settlement accounting can be vastly simplified for a portfolio with this approach
- Each market participant pays the real time cost of delivery minus total FGR credit

$$\sum_{\forall Transactions(i)} \boldsymbol{\lambda}_{POW} * \mathbf{Q}_{POW} - \sum_{\forall Transactions(i)} \boldsymbol{\lambda}_{POW} * \mathbf{Q}_{POI} - \sum_{\forall CSFs(j)} \boldsymbol{\rho}_j * \mathbf{Q}_j$$

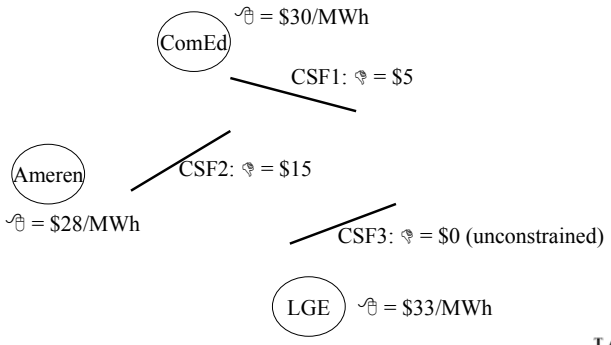
Example: Hybrid Settlement for Portfolios

- MP has portfolio of transactions and FGRs
  - 100 MW from Gen 1 in Ameren to LGE
  - 100 MW from Gen 2 in ComEd to LGE

	GSF Requirements		MP FGR Requirements
Flowgates	Amrn to LGE	ComEd to LGE	
CSF1	2%	20%	22 MW
CSF2	6%	20%	26 MW
CSF3	6%	10%	16 MW

Example: Hybrid Settlement for Portfolios

- RTO calculates shadow prices for nodes and for CSFs



SP = Shadow prices

Example: Hybrid Settlement for Portfolios Market Participant is Fully Covered

Congestion Cost:

Amrn->LGE *ComEd->LGE*
($33-$28)*100MW + ($33-$30)*100MW = $800

Credit for CSFs:

CSF1 *CSF2*
$15*26MW + $5*22MW = $500

Discrepancy: = $300

Note: The example is designed to highlight possible discrepancies

Example: Hybrid Settlement for Portfolios Market Participant is Partially Covered

Flowgates	MP FGR Requirements	MP FGR Held
CSF1	22 MW	22 MW
CSF2	26 MW	20 MW
CSF3	16 MW	16 MW

Amrn->LGE *ComEd->LGE*
MP Charge: ($33-$28)*100MW + ($33-$30)*100MW = $800 (congestion cost)

CSF1 *CSF2* *CSF3*
MP Credit: $15*20MW + $5*22MW + $0*16MW = $410 (credit for CSFs)

MP Obligation: = $390

Hybrid Settlement Options

- Fully covered market participants
  - If rules exempt these MPs from all congestion charges, the $300 would be paid from a 'kitty'
    - 'Insurance' payments from all participants (see Chao and Peck papers)
    - FGR auction revenues
    - Net revenue from LMP charges
  - Rules could require these MPs to pay residual congestion
- Partially covered market participants
  - Pay the discrepancy or obligation, as identified on previous slide

Flexibility with Flow-Based Transmission Rights

Flexibility of Flow-Based Rights

Type of Right	FGR	FTR
Designate POI and POW	Flexibility after purchase of rights to select POI and POW to best match actual conditions	No flexibility. POI and POW fixed at time of purchase
Change in transaction portfolio	Partially uncovered transaction. Can sell or buy incremental rights as needed	Little flexibility. Only able to sell or buy bundled right with fixed POI & POW
Major change in portfolio	Can sell separate rights or bundled package to other West-East transacting MPs.	No flexibility. Only able to sell or buy bundled right with fixed POI & POW

POI = point of injection
POW = point of withdrawal

FGRs Facilitate Forward Markets

- Flexible product
  - Holders of FGRs can use them for a variety of transactions (variety of POI and POW)
- Liquid and efficient secondary market and
  - There are likely to be many interested buyers and sellers for the unbundled FGRs
- Price certainty in forward market
  - Flexibility and price certainty of FGRs facilitate large trading volumes in the forward market

Summary: Limitations of LMP/FTR System

- Less flexibility for trading transmission rights in forward markets
  - ➢But, in order to hedge volatile spot energy prices *there must be a forward market*
- Very large number of nodal prices hinders forward market liquidity (thousands of nodes)
- Less accurate identification of which transmission facilities are constrained (hinders system expansion)

Summary: Limitations of Flowgate System

- Concern over discrepancies between forward market projections of congestion and real-time system conditions
- Less experience, use in the industry

➢**Hybrid model** addresses limitations in each system
- ➢Facilitates forward market development, and
- ➢Reconciles discrepancies for *ex-post* settlement

Footnotes

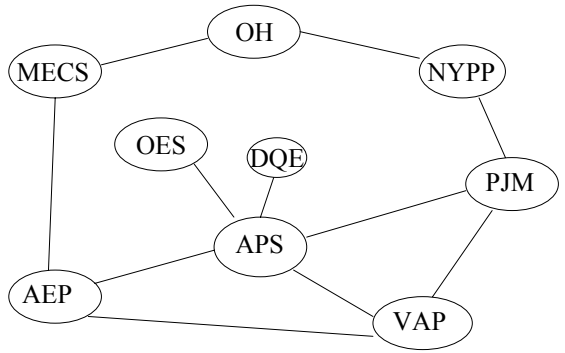
Definition: Generation Shift Factor

- GSF: A generation shift factor, GSF (similar to a power transfer distribution factor (PTDF)), is the percentage of the power, due to a power transfer between any two generators on the system, that flows on the flowgate of interest. GSFs allow system operators and market participants to determine the loading on each flowgate (critical transmission element).

Flowgates and GSFs

- Each flowgate has a *set* of GSFs associated with it – one for each transaction (represented by a pair of nodes) of interest to a market participant.
- Each generator has a different set of GSFs for each transaction, representing the distinct impact of that transaction on each flowgate.

Example: APS to PJM Transfer



Example: PTDFs for Transfer

Flow Gate	*Factor*
APS - PJM	0.70
APS - AEP	0.21
APS - VAP	0.08
AEP - VAP	0.05
VAP - PJM	0.16
AEP - MECS	0.08
MECS - OH	0.07
OH - NYPP	0.07
NYPP - PJM	0.12

In general, for a given transfer:

- Factors out of APS sum to 1.0
- Factors into PJM sum to 1.0

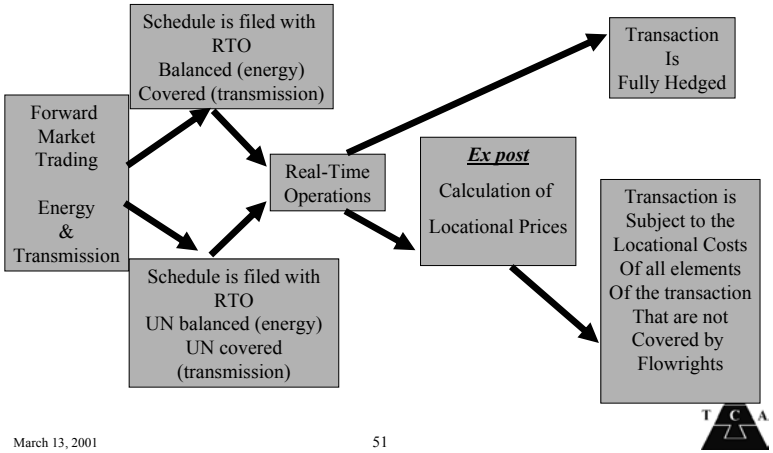
** Note that not all factors are shown in this table **

Hybrid System Time Line Example

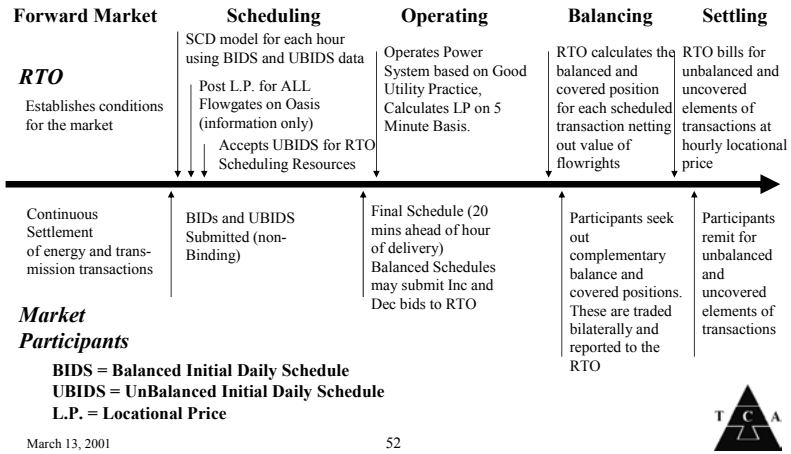
Year Ahead	Monthly	Scheduling	Real-time	Settlement

• Define CSFs
• Define ATC
• Auction FGRs
	• Auction additional/ incremental FGRs	• Submit energy schedules with or without associated FGRs
		• May be day ahead or hour ahead scheduling
			• Schedules hold
			• Resources available to the RTO for real time operations and balancing are:
			  • Incs and Decs
			  • Bids and Asks
				• Imbalances are traded in *ex post* market
				• Net imbalances and uncovered transactions assessed at LMP

Integrating Forward Market and Real Time Operations



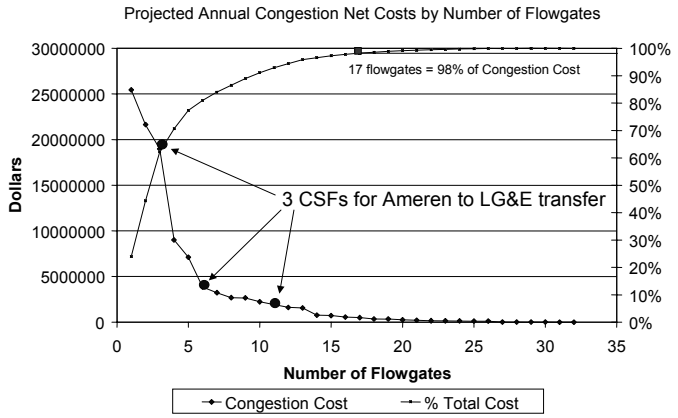
Tariff Operational Timeline



Ameren to LGE Example

- Commercial analysis identifies 32 commercially significant flowgates for the region, 17 of which capture 98% of all congestion costs
- Only 3 of these 17 CSFs are affected by a potential transfer from Ameren to LG&E

Ameren to LGE Example



Ameren to LGE Example

- A Market Participant expects to have multiple, simultaneous transactions from Ameren to LG&E during the next month
- Operationally
  - These transactions are anticipated to impact about 350 facilities, accounting for all flowgates with a GSF ≥ 2% for these transactions
- Commercially
  - These transactions will impact only 3 CSFs (continuing from previous example)

Ameren to LGE Example

- The market participant has 5 possible sources in Ameren and 3 possible buyers in LG&E
  - MP desires flexibility to designate POI and POW closer to real-time, but wants to purchase transmission rights now
- Month or year ahead:
  - With FGRs, MP buys rights on the 3 identified CSFs, but leaves POI and POW un-designated
  - Note that if there were FTRs rather than FGRs, MP would be required to designate in advance which generators and which buyers would be involved

Flexibility of Flow-Based Rights

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