Architecture of Power Markets

Momoh, James, and Lamine Mili, eds. *Economic market design and planning for electric power systems*. Vol. 52. John Wiley & Sons, 2009.

Christie, Richard D., Bruce F. Wollenberg, and Ivar Wangensteen. "Transmission management in the deregulated environment." *Proceedings of the IEEE* 88.2 (2000): 170-195.

Wilson, Robert. "Architecture of power markets." *Econometrica* 70.4 (2002): 1299-1340.

Sergey Alexeev
sergeyvalexeev.com

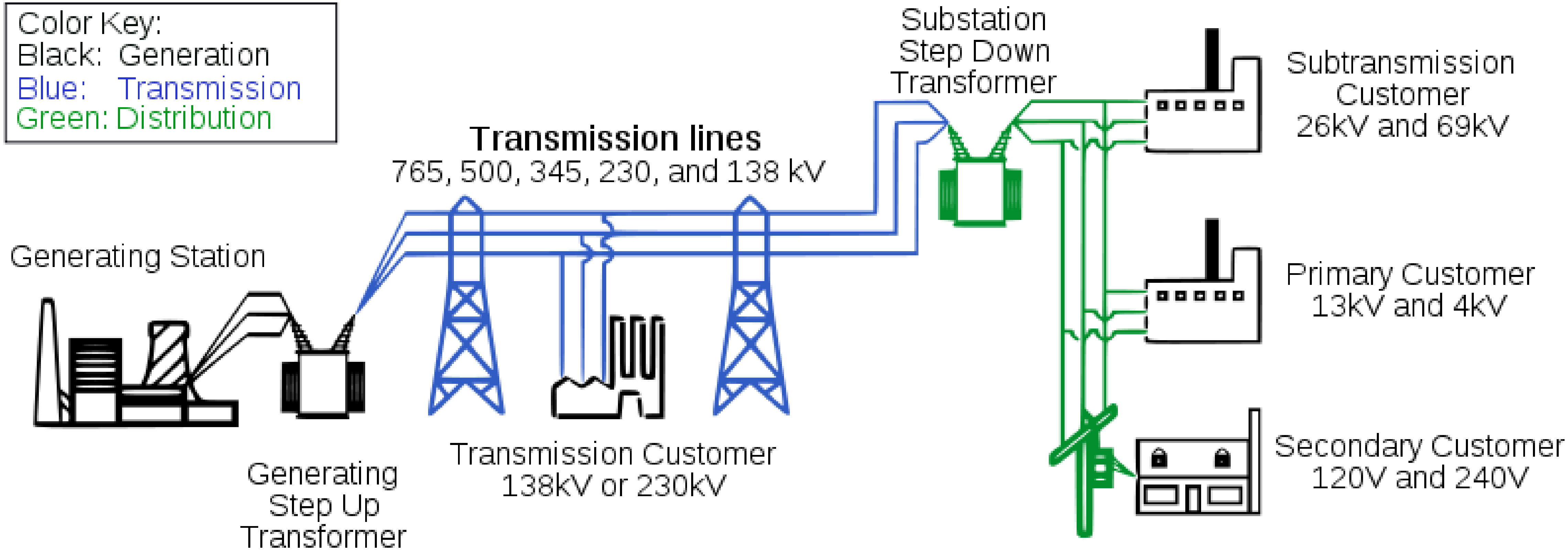
University of Technology Sydney
2016

Introduction

- In 1988 one controlling authority (the utility) generates, transmits and distributes electricity
- Doubts about efficiencies
  - Deregulation examples of telecommunication and airline
  - Friendly political climate
  - Changing technologies
  - Especially in developing countries
- UK was the first to create a competitive environment to sell electricity
  - Then was Norway, Australia and New Zealand
- Restructuring typically starts from introduction of spot market for generation
  - Transmission remain regulated to keep open access and facilitate new investment
- A massive natural experiment is underway

Three Main Elements Of Electricity Market

macrostructure



Volts times amps equals watts and wires are sized based upon their ability to carry amps
Networks – typical case of natural monopoly

Standard economic theory viewpoint

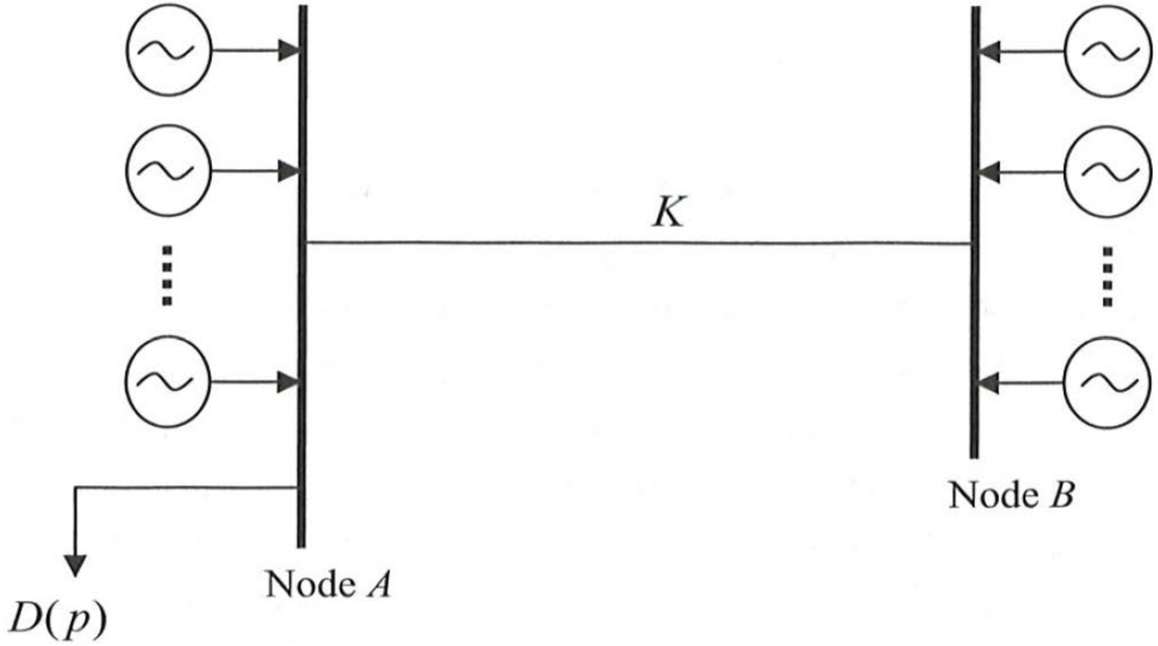
fridge

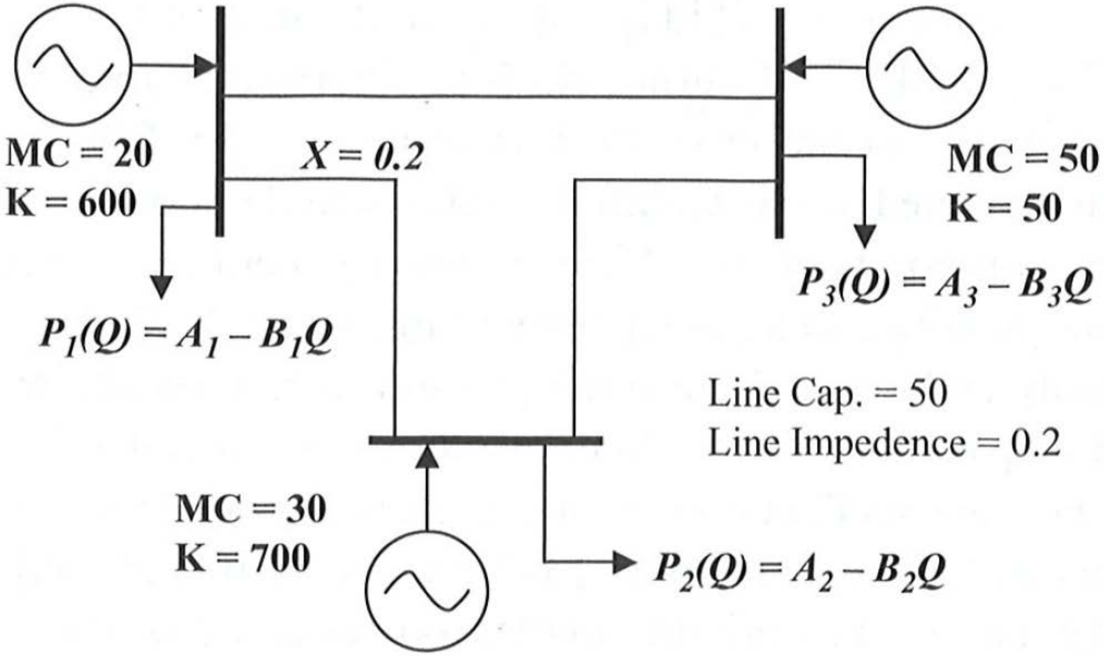
- Power is a flow
  - Cannot be monitored perfectly and stored in significant amount
  - Universally adopted compromise
    - Large daily and seasonal variation in demand is not matched with flexible spot pricing
    - No forward constrains and crude pricing for retail customer
    - A right to inject power that is paid the spot price
- Imperfectly competitive
  - Economies of scale, entry barriers, oligopolistic ownership
  - Supply side rigidities and intertemporal demand mismatches
- Power transformation issues dwarf problems above

Power transformation

- Economics of network assume free choice among alternatives and ability to store at the nodes
- Externalities (Kirchhoff's Law)
  - Losses and "Loop flows"
  - No titles
  - Absence of point-to-point transmission
- Continuous requirements for balancing the transmission system
  - Vulnerability to instabilities
  - Reliability calls for auxiliary markets
    - Creates different markets for otherwise homogenous product
- Both creates complementarities and localized market power

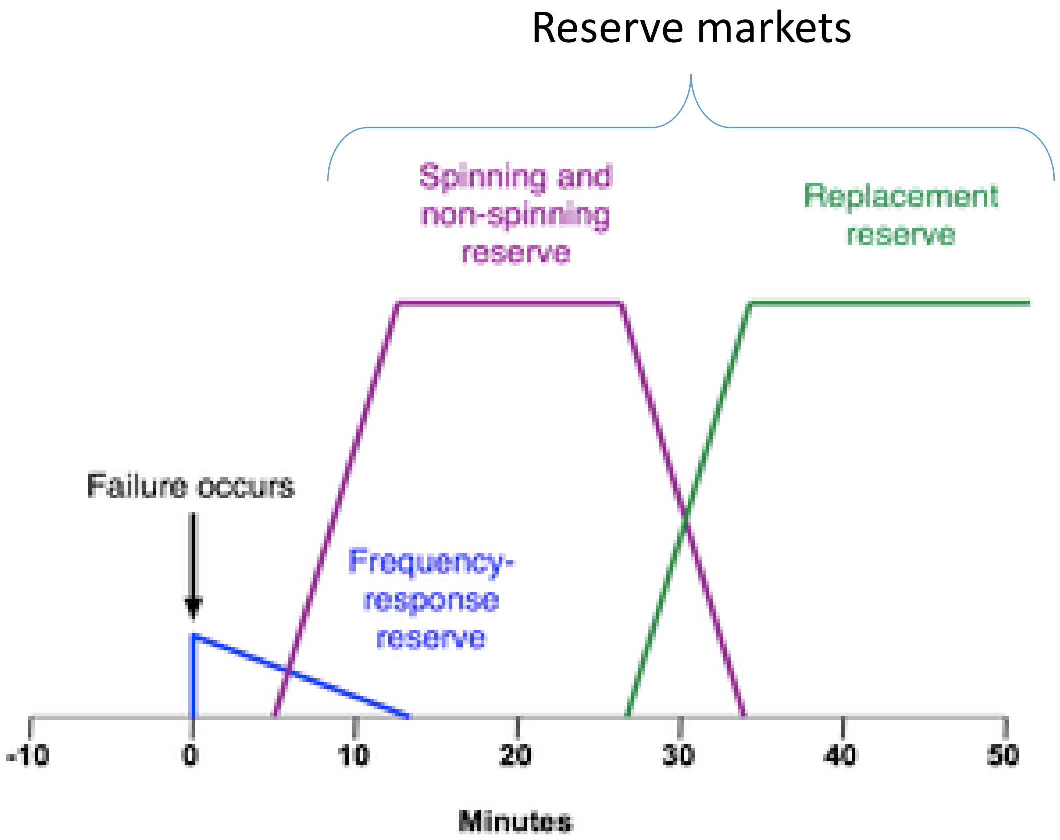
The Basic Structure of a Market for Electricity





No single marketplace, congestion rent, power flow, Kirchhoff's Voltage Law, no bilateral contracts

System integrator (SO)
Spot and Reserved Markets



- Continues operation
- Momentary imbalances
  - “Regulation”
  - Work automatically and provide cushion
- Incompleteness calls for reserves
  - Illiquid spot market
  - Transmission constrains
- Within category options used in merit order
- SO absorbs the costs of options exercised out of merit order or out of market to maintain reliability
  - Systems contrast
  - If SO limited to only buy options it will be act precariously

[Market for reactive power]

Integrated systems

- Long-term relational contracts
  - Sanctions and reciprocal obligations
    - Demanders' obligation to obtain options on installed capacity
    - Suppliers mandatory participation including obligation to offer all operable capacity
  - Market test of SO's decisions and prices is ruled out
- Smart market for overall optimization of operational decisions
  - Day-ahead optimization of all generation, transmission and reserves
    - Including constraints on ramping rates and other intertemporal costs
    - Indicative, since plans are re-optimized hour-ahead and in real-time
  - Pricing and settlement are based on system-wide opportunity costs as measured by shadow prices on system constraints

The Locational Marginal Pricing System

$$Minimize\ f(P_S, P_D) = C_S^T P_S - C_D^T P_D$$

$subject\ to$

$$g(x, u, P_S, P_D) = 0\ \ (Power\ balance)$$

$$Q_G^{min} \leq Q_G \leq Q_G^{max}\ (Gen\ Q - Limits)$$

$$V^{min} \leq V \leq V^{max}\ (Bus\ voltage\ limits)$$

$$\left|P_{ij}(x)\right| \leq P_{ij}^{max}\ (Thermal\ limits)$$

$$\lambda_C \leq \lambda_{C_0} (Stability\ loading\ at\ "critical\ points")$$

$$0 \leq P_S \leq P_S^{max}\ (Supply\ bids)$$

$$0 \leq P_D \leq P_D^{max}\ (Demand\ bids)$$

Role of SO is still much like “single buyer”
-better pricing
-minimizing costs for given demand

If none binding then market clears at all nodes according to merit order

On Incentive of Integrated systems

- Participant can retain capacities or claim higher costs, thus increasing shadow prices
  - False operational constrains in UK in 1999
- Cost minimization is a fiction if bidding is not incentive compatible
  - System rely on regulation
    - Market Surveillance Committee in New Zealand
  - Reputation
- Unbundled systems emphasize incentive effects
  - Argue that SO should only focus on real-time balancing and minimum intrusion into forward markets only to ensure physical feasibility
- Integration make sense only in context of vigorous competition where the gain from tight coordination exceed the gain from stronger incentive
- Essentially it is an attempt to mimic Walrasian equlibrium when bidders are not price takers and outcome is NE in distorted reports of cost
- SO’s planning doesn’t allow detailed private information to schedule private buses better

Forward Contracting of Output

- $\Pi_i(q_i, q_J) = \mathrm{P}(q_i + q_j)q_i - cq_i$
- $\Pi_i(q_i, q_J) = \mathrm{P}(q_i + q_j)(q_i - x) - cq_i + \tilde{p}x$

$$if\ q_i = x\ then$$

$$\Pi_i(q_i, q_J) = (\tilde{p} - c)x$$

- $NE\text{:}\ q_i^* = q_j^* = \frac{1}{3}\alpha(\bar{p} - c) + \frac{x}{3}$
- $P(q_i^* + q_j^*) = \frac{1}{3}\bar{p} + \frac{2}{3}(c - \frac{x}{\alpha})$

$$if\ x = \frac{D - \varepsilon}{2}\ then$$

$$P(q_i^* + q_j^*) = \frac{1}{3}\bar{p} + \frac{2}{3}\left(\mathrm{c} - \frac{D - \varepsilon}{2\alpha}\right) = \frac{2}{3}\left(c + \frac{\varepsilon}{\alpha}\right)$$

The spot market is structurally a residual market settled after all the forward transactions of energy and transmission rights are closed.

B. Allaz and J. Vila, "Cournot Competition, Forward Markets and Efficiency," Journal of Economic Theory.

Unbundled system

- No central scheduling/dispatching entity (UK has one), only a central power exchange (Nord Pool, CalPX) and SO's (usually owns most of grid)
  - Scheduling and dispatch is on individual profit maximizing companies
- One could see this as miracle
  - Sequential and independent clearing of energy, transmission and reserves markets
    - E.g. bides are submitted before the prices of transmission and reserves status are known
  - Intertemporal costs are internalized
    - Might be unhappy to supply and have to sell or buy a replacement
    - Ramping and start-up constrains of thermal generators in California and Australia
  - Markets are repeated constituting sort of a "rational expectation" and outcome is NE in bidding st.

Unbundled system

- Spot market is settled at noon for 24h
  - Individual bids are aggregated by SO to form supply and demand curves
- The reserved market (first approximation)
  - Supply bids with info on duration, magnitude and price
  - In real time SO picks the cheapest available from the merit of order
  - Thus price on reserves is settled ex post
- The future market
  - Purely financial market
  - More liquid on short duration
  - Not binding because physical scheduling can be adjusted in later markets
  - This aspect contrasts sharply with integrated systems
    - All commit for optimized plan and deviation are penalized. Shift towards "re-declaring"
- Bilateral trade is still allowed (everything except these managed by CPE)

California's case in 2001

Summary Comparison

- Unbounded market is essentially a dual of optimization used by integrated systems
  - Were everything complete and perfect solutions would be identical
  - Implicit and explicit incompleteness in both cases
- Bundled start from idea that actors are bound and employ exclusive manager for all market (spot, forward, energy, transmission)
  - Tight coordination in daily operations, however incentives to cooperate are undermined
  - Words great in competition or amply powered regulation or cartel
- Unbundled starts from opposite idea that cooperation is volunteer
  - SO manages the only public good – transmission, can intervene only to increase reliability. Complete and efficient forward market is essential
- The chose depends on what system would approximate the competitive and complete markets better

Forward Market for Reserves

- Centrally optimized systems use supplier’s day-ahead bids to assign reserve status
- In unbundles systems SO procure sufficient amount in each category in a series of auctions

Complications:

1. Unidirectional substitutability
    - Market should be cleared simultaneously
    - In California an attempt to minimize costs to for all reserves with single-party bidding washed away all participant in “regulation”
2. Single-party bidding doesn’t allow to state true preferences
    - No-load (reservation price) and start-up costs are declared. Even three in smart markets
3. Ultimate solution is a greater reserve options on the demand-side
    - Distributors almost never participate in reserve market

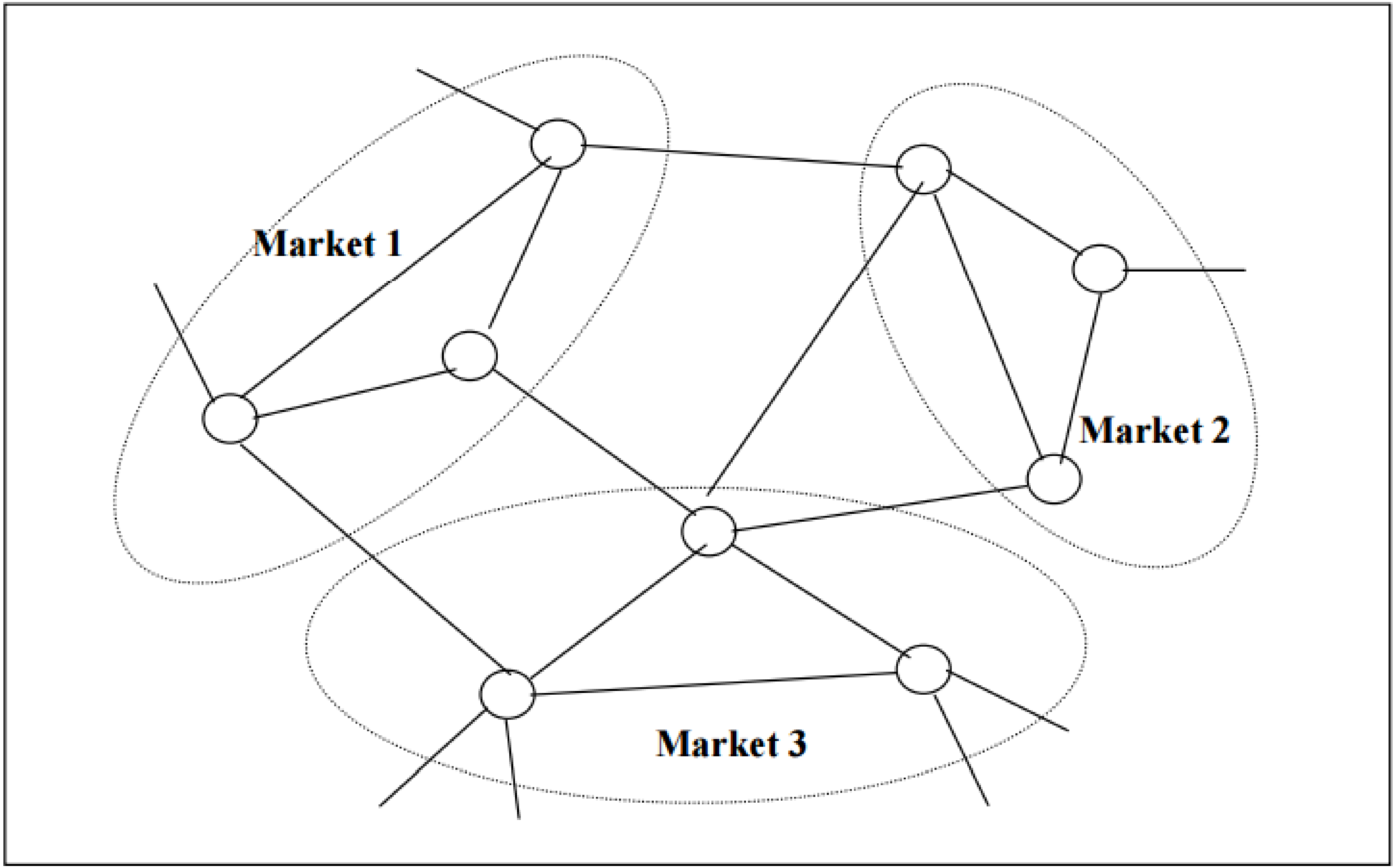
Forward Market for Transmission

Nord Pool (Norway, Sweden, Finland, Denmark) context

- Usual structure with market participants (SO including)

1. Tariffs
    - All busses and networks (national, regional, local) pay point tariffs (investment, energy and capacity parts)
    - In Sweden (Finland, UK) power flow always goes from north to south
    - Philosophy is that the transmission system should not affect the market resolution
    - Capacity charge is high and load is less in northern part of the country
2. Price areas (day-ahead market) (cf. nodal pricing)
    - In Norway areas with excess generation will have lower prices, and areas with excess load higher prices. Market income from this price difference is paid to the SO and is used to reduce the capacity fee
    - Dec game in California
3. Buyback (postmarket schedules)
    - Main instrument in Sweden, rarely used in Norway

3Q at P in day ahead
Wait for p* to supply 2Q
(P-p*)2Q


Market 1
Market 2
Market 3