Electricity Market Training – Part 2

Electricity Market Design, Implementation and Operation

Volta River Authority

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Part 2 – Outline

Part 2 centers on the following 3 topics:

I. Coordinating electricity supply and demand.
   A. What is dispatch?
   B. Why is it important?
   C. What are the options?
II. Dispatch based on Nodal (i.e. locational) prices.
   A. Basic overview.
   B. Key structural components.
   C. How it works.
III. Pricing and settlement in an LMP-based market.

Dispatch – Introduction

"Dispatch" refers to the methodology by which ***real time*** power supply and demand are balanced.

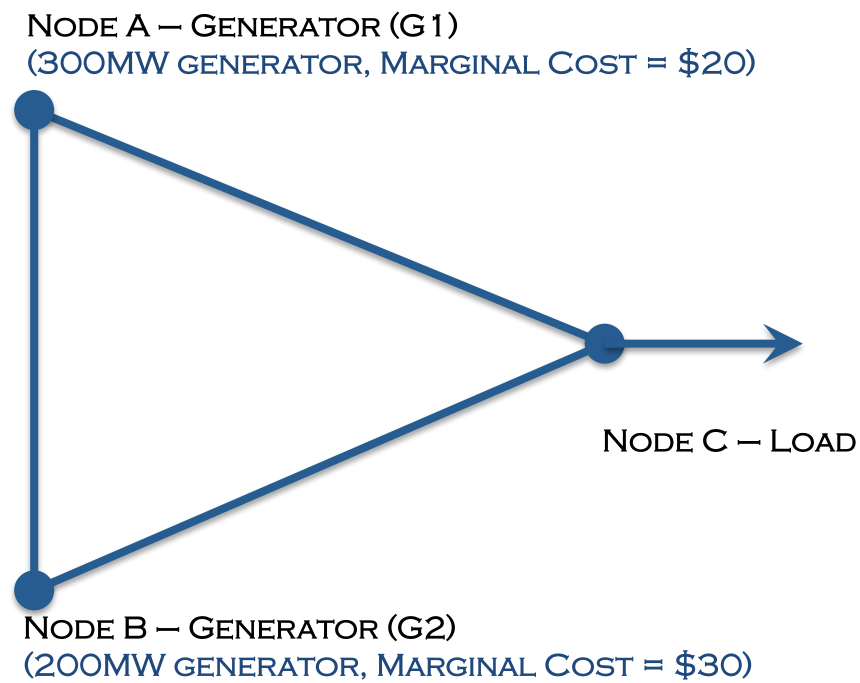
I. Electric power has unique characteristics that necessitate precise and constant coordination of supply and demand.
   A. Since large scale storage is not commercially viable, when physical supply exceeds physical load, frequency on the system will rise (unstable), similarly when physical supply is less than physical load, frequency will decay (unstable).
   B. Power flows according to the laws of physics, so all power flows must be coordinated, it is impossible to separate MWs purchased under bilateral contract from spot purchases.

II. The simple effect of these characteristics is that physical supply/demand must be kept within a tight range at every instant in time. If supply/demand are not balanced the entire electricity system will fail.
   A. Different than any other commodity.

Dispatch – Simple Example

Start with the simple 3-node example from Part 1.

I. Two generators, G1 and G2, at two separate nodes, A and B respectively.
   A. Assume G1 is a 300 MW capacity generator with marginal cost of $20.
   B. Assume G2 is a 200 MW capacity generator with marginal cost of $30.
II. One load node at C.
III. G1 and G2 are owned by the same company.
IV. Unlike Part 1, assume there is no constraint on line AC.



Dispatch – Simple Supply Curve

Continuing on with the simple (unconstrained) example.

I. Create a supply curve from the information regarding capacity and marginal cost for both G1 and G2.

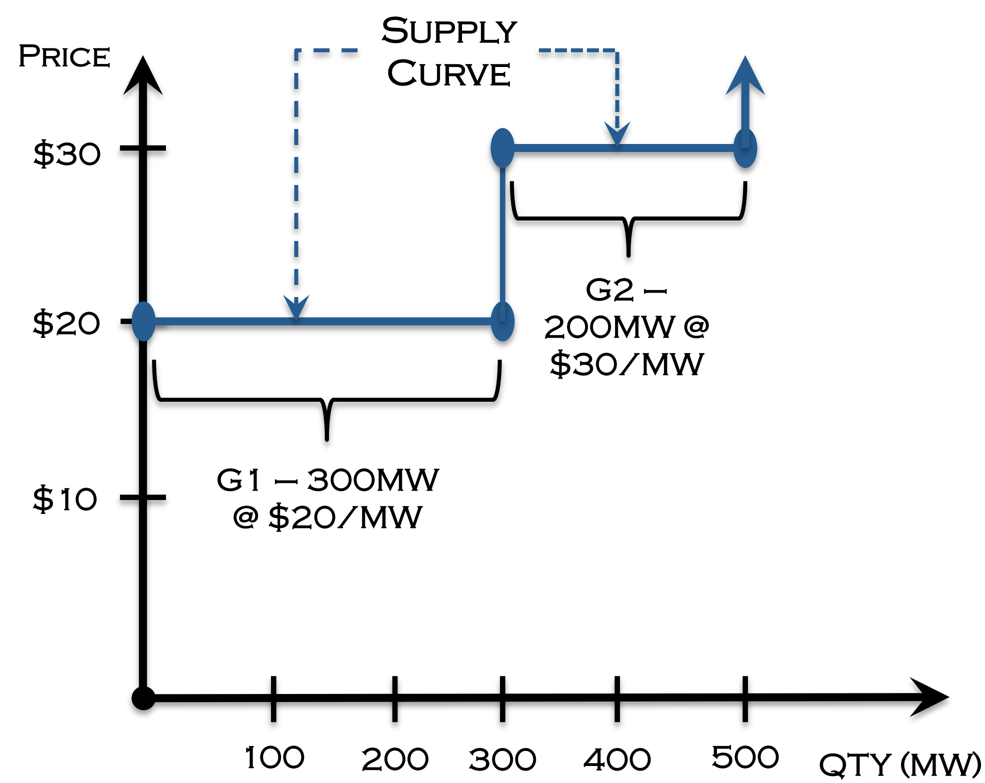
II. Using this supply curve:

   A. If 0 ≤ Load @ Node C ≤ 300MW, then G1 will supply all the power.

   B. If Load @ C is greater than 300 then incremental power will come from G2.

      1. If load is 320 MW then G1 will supply 300 MW and G2 will provide 20 MW.

III. Assumes no constraints!



The DEMR are based on the Simple Supply Curve

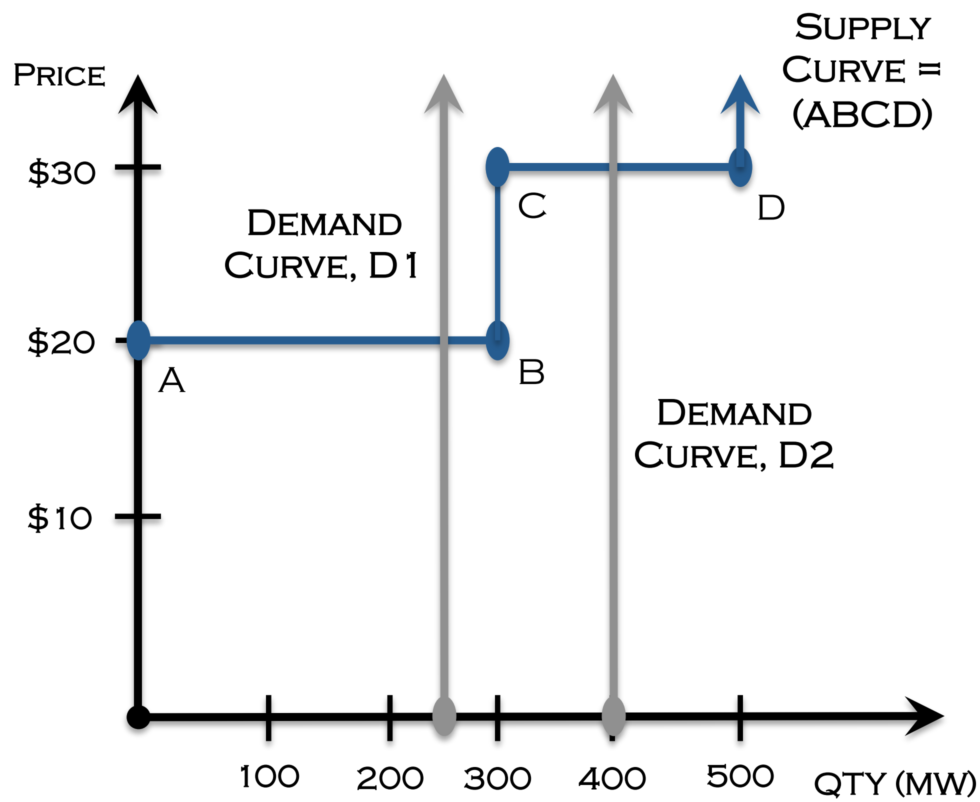
Coordinating supply in demand in this example is simple. For example:

I. If demand is 250 MW, i.e. D1, then supply = demand at $20 (the marginal cost of G1). All 250 MW will be produced by G1.

II. If demand is 400 MW, i.e. D2, then supply = demand at $30 (the marginal cost of G2). G1 will produce 300 MW and G2 will produce 100 MW.

III. When there are no constraints there is a single aggregate supply curve that applies to all nodes on the system.

IV. This simple unconstrained generation "stack" model is the basis for the Draft Electricity Market Rules.



Some Lessons from Unconstrained Dispatch – Supply

The unconstrained dispatch model from the previous slide highlights important aspects of market design:

I. How is the supply curve created?
   A. What information will the generators be required to give?
      1. Price per MW, i.e. an offer.
      2. Is it mandatory for generators to offer?
         - Does it matter how large, i.e. do generators less than 5 MW have to offer?
         - How is demand response treated?
      3. How many price/quantity pairs are allowed per offer, i.e. how many tranches?
      4. Are offers specific to individual generation facilities or are they aggregated by portfolio, zone, etc.?
      5. What is the time interval for each offer, i.e. is the offer for 5, 10, 15, 30 or even 60 minutes?
      6. How will ramp rates or other physical parameters be treated when creating the supply curve?
      7. How far in advance of real time will generators be required to offer?
      8. Once submitted, under what circumstances can an offer be changed?
      9. How will discontinuities in the supply curve be handled?

Some Lessons from Unconstrained Dispatch – Demand

The unconstrained dispatch model also highlights important aspects of market design regarding the demand curve:

I. How is the demand curve created?
   A. Presumably by forecasting expected demand for the period?
      1. Who has the authority for creating the forecast?
         - Who pays for inaccurate demand forecasts?
         - Is the dispatcher the "right" entity…what are their incentives?
      2. What forecasting tool will be used, e.g. regression, neural network model, etc.?
         - Who makes the decision about what methodology to use? On what basis is the decision made? Under what circumstances can it be changed?
      3. Is the forecast for expected load at the beginning of the interval, middle of the interval, end of the interval or average over the interval?
         - Regardless of the choice, this necessitates other decisions. For example, suppose the load forecast is for the end of the period…then what load forecast will the dispatcher use for the middle of the period?
      4. Will Market Participants be asked/required to provide their individual load forecasts? If so, how will that information be integrated into the forecast?

Some Lessons from Unconstrained Dispatch – Pricing

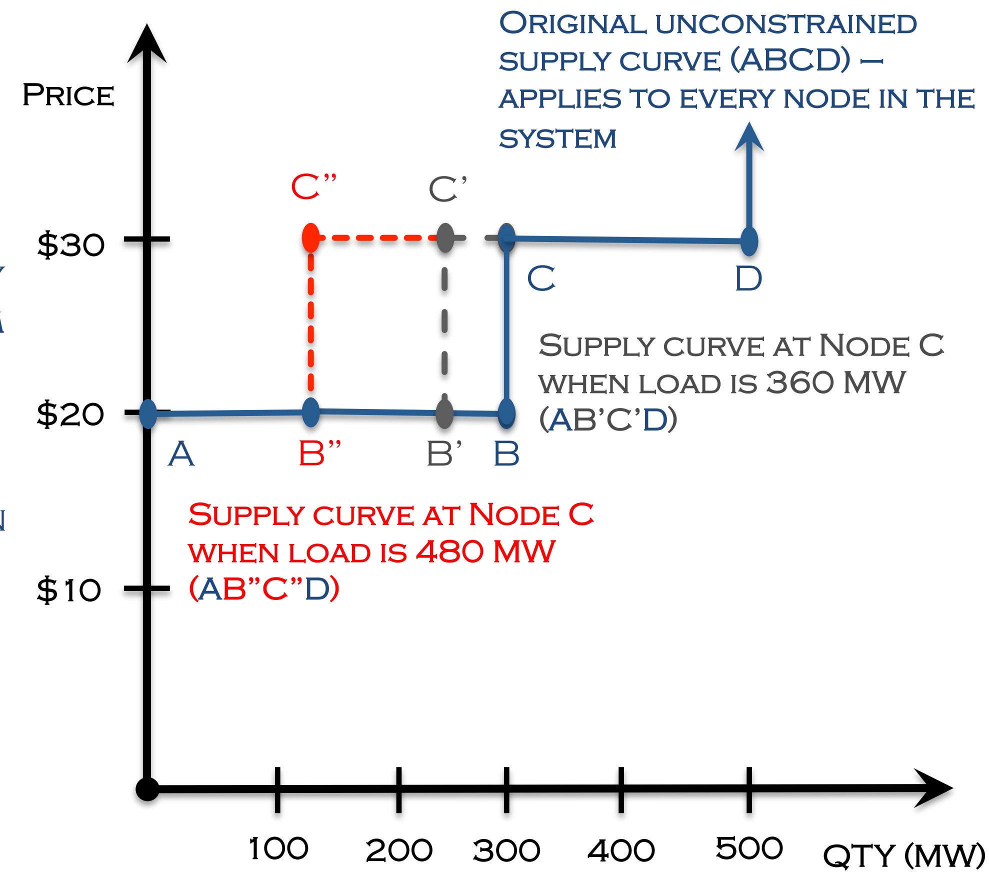
The unconstrained dispatch model leads to important questions regarding pricing:

I. How is the equilibrium price determined?
   A. Intersection of supply and demand? But which supply and demand concept?
      1. Should we use *ex ante* supply, i.e. the expected supply curve? But what if a generator fails to perform? That is, the expected and actual supply curves are different. Do we set price based on a generator that didn't actually produce or on a generator that shouldn't have produced?
      2. Alternatively should we use *ex post* supply, i.e. the actual supply curve? Should we let a generator who wasn't supposed to run set the price?
      3. Should we use *ex ante* demand, i.e. the forecast expected demand curve? But what if actual demand was greater or less than forecast demand?
      4. What if we use *ex post* demand, i.e. the actual demand for the period?
      5. Regardless of whether we use *ex ante* or *ex post* demand, which demand are we referring to, the load at the beginning, middle, end or the average over the period?
      6. What about a mix like *ex ante* supply and *ex post* demand which is the way New Zealand does it?
      7. Answers to all these questions will have pros and cons. The key is to understand the ramifications/implications of the choices.

Simple Model of Dispatch – With a Constraint

Things change when the line from A to C has a thermal limit of 200 MW (as it did in the original example in Part 1).

I. A single supply curve is only relevant when there are no binding constraints!
   A. Once a constraint occurs there is no longer a single aggregate supply curve…instead ***there is potentially a different supply curve at each node and for different levels of load.***
   B. For example let's look at Node C:
      1. At Node C if load is 360 MW, then the supply curve at Node C is given by AB'C'D, since the constraint on AC limits the output of G1 to 240 MW.
      2. However, if load is 480 MW then the supply curve at Node C is given by AB"C"D, since the constraint on AC limits the output of G1 to 120 MW.



Some Lessons from Constrained Dispatch

The constrained dispatch model leads to important conclusions:

I. The existence of a binding constraint necessarily means that (1) there is potentially a different supply curve at every node and (2) the supply curve at every node is dependent on the level of load.

II. This conclusion is not an "opinion". Rather it is physical reality.

III. There is no way for the dispatcher to ignore this reality and be reliable. That is, if the dispatcher assumes there is a single supply curve and issues instructions to generation based on this incorrect assumption, the system will fail.

IV. Binding constraints can change quickly and dynamically. This means the supply curve at each node is volatile.

V. In order to be reliable, the dispatcher must use a dispatch tool that accounts for this dynamic environment…and the tool must be unbiased and produce reliable operation of the grid.

Dispatch and Nodal Pricing

Nodal pricing is based on the notion that *place* and *time* are important characteristics of electricity.

I. Nodal pricing is a tool used by the dispatcher to provide reliable, least cost, non-discriminatory access, in real time, to competitive generation facilities.

II. Nodal pricing is based on the fact that energy delivered to a different place and/or at a different time is a different good and should be priced accordingly in order to achieve economic efficiency.

   A. An attempt to create a market at each "place" at different "times".

   B. Recognizes the effects of joint production of energy for delivery and energy for consumption.

   C. In its simplest form nodal pricing, is the "cost" of electricity at the generator bus and the cost of moving the electricity from the generator to the consumer.

      1. In practice things are a little more complicated, e.g., the energy price is set by the marginal generator, the cost of any constraints, and the cost of transmission losses.

Market "vs" Dispatch…the Need in Real Time for Centralized Coordination

Since electricity supply and demand must remain constantly in balance we cannot rely solely on "decentralized" processes like a market to find an equilibrium. The market process, i.e. finding a price which balances supply and demand, simply takes too long to be relied upon for reliable operation of the electricity system. Therefore, some amount of "centralized" decision making will be needed. This centralized decision making is the real time dispatch function. A key element of designing an efficient non-discriminatory open access structure, is to achieve the right balance between the dispatcher (i.e. centralized decision-making) and the market (i.e. decentralized decision making).

The Dispatcher as the Air Traffic Controller

In effect the dispatcher is akin to an air traffic controller at an airport. Both acquire information and, based on that information, unilaterally make decisions.

I. From a market design perspective the keys are not to get rid of the dispatcher but to (1) achieve the proper balance between the dispatcher and the market and (2) to provide the right incentives for the dispatcher to act in the best interests of the market participants.

II. Under nodal pricing, the dispatcher uses the same "tools" to match supply and demand that are used to establish prices.

   A. Thus there is a match between dispatch and prices or, put another way the market price provides a good indicator of what happened in the physical system.

   B. This minimizes the need for the dispatcher to manage the difference between what people thought would happen and what actually did happen.

Overview of Real Time Dispatch Based on Nodal Prices

Nodal pricing, also called locational marginal pricing or LMP, is an approach to balancing real time supply and demand by having the dispatcher operate a real-time energy market and pricing system that is based on the physics of electricity and uses economic incentives to provide non-discriminatory open access to the real time electricity grid.

I. There are three primary elements of an LMP-based dispatch system:
   A. It uses security constrained economic dispatch (SCED) based on the offers of Market Participants.
   B. It calculates market prices (LMPs) from this dispatch and uses them for energy market settlements.
   C. It offers energy balancing services to anyone willing to pay the energy market prices.

Definition: Locational Marginal Price

The marginal cost of supplying the next increment of electric demand at a specific location (node) on the electric power network, taking into account both generation marginal cost and the physical aspects of the transmission system.

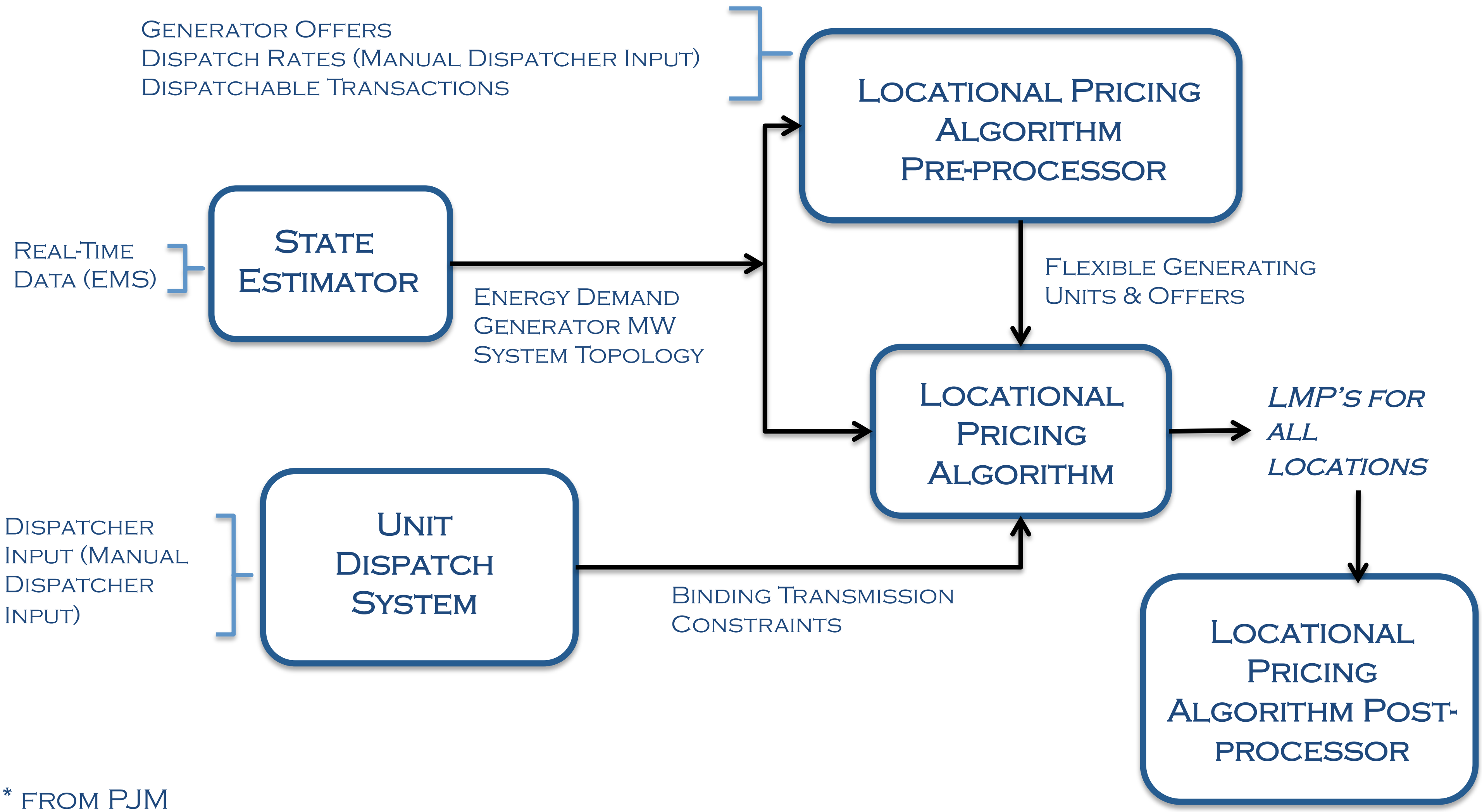
Dispatch Based on the Offers of Market Participants

LMP is based on the security-constrained dispatch of a coordinated energy market.

I. Dispatch uses voluntary market bids that can change (depending on the rules) anywhere from every five minutes to hourly or even daily.
   A. Generators can be scheduled based on bids.
   B. Loads can purchase energy at the market price.
      1. If allowable, dispatchable loads may submit bids based on willingness to pay.
   C. Participation in the energy market is voluntary:
      1. Generators can sell energy into the energy market, through bilateral transactions, or any combination of the two.
      2. Market Participants who serve load can buy energy from the market, through bilateral transactions, or any combination of the two.

II. Market participants obtain non-discriminatory grid access by submitting bids and schedules for the dispatch. Participants are not required to obtain transmission rights.

An Example of an LMP Model*



* from PJM

Locational Pricing Algorithm

There are three components to the locational pricing algorithm (LPA).

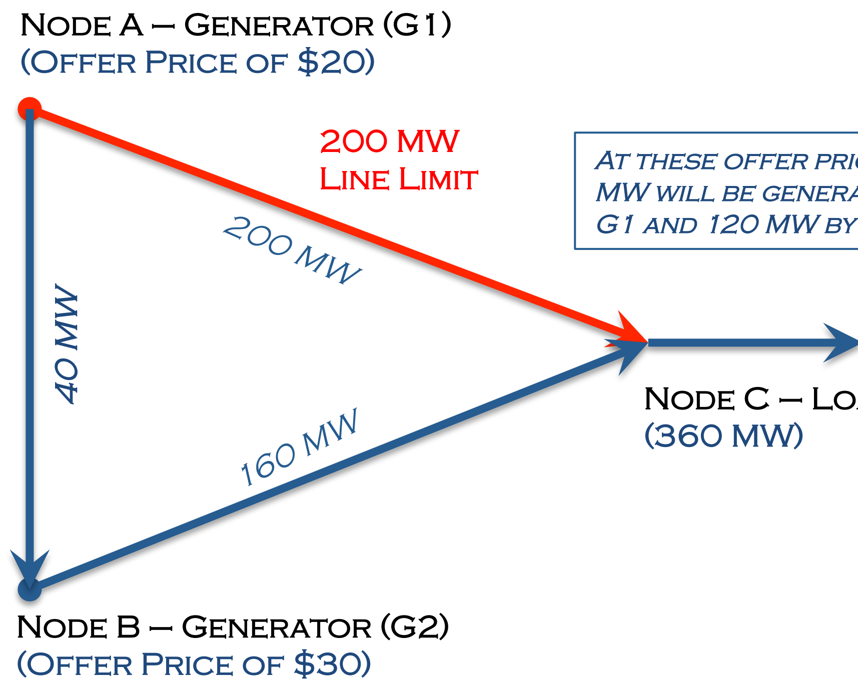
I. The LPA Pre-processor which screens for and determines the eligible units.
II. The LPA Engine or processor which calculates the LMPs at each generator, load, tie and external bus in the model.
III. The LPA Post-processor is comprised of several different programs which ultimately produce the settlement prices.

Dispatch and Congestion – The example from Part 1

I. Recall from Part 1 the example given in the diagram to the right.
   A. When load at Node C is 360 MW, efficient (i.e., least cost) dispatch requires that G1 produce 240 MW and G2 produce 120 MW.

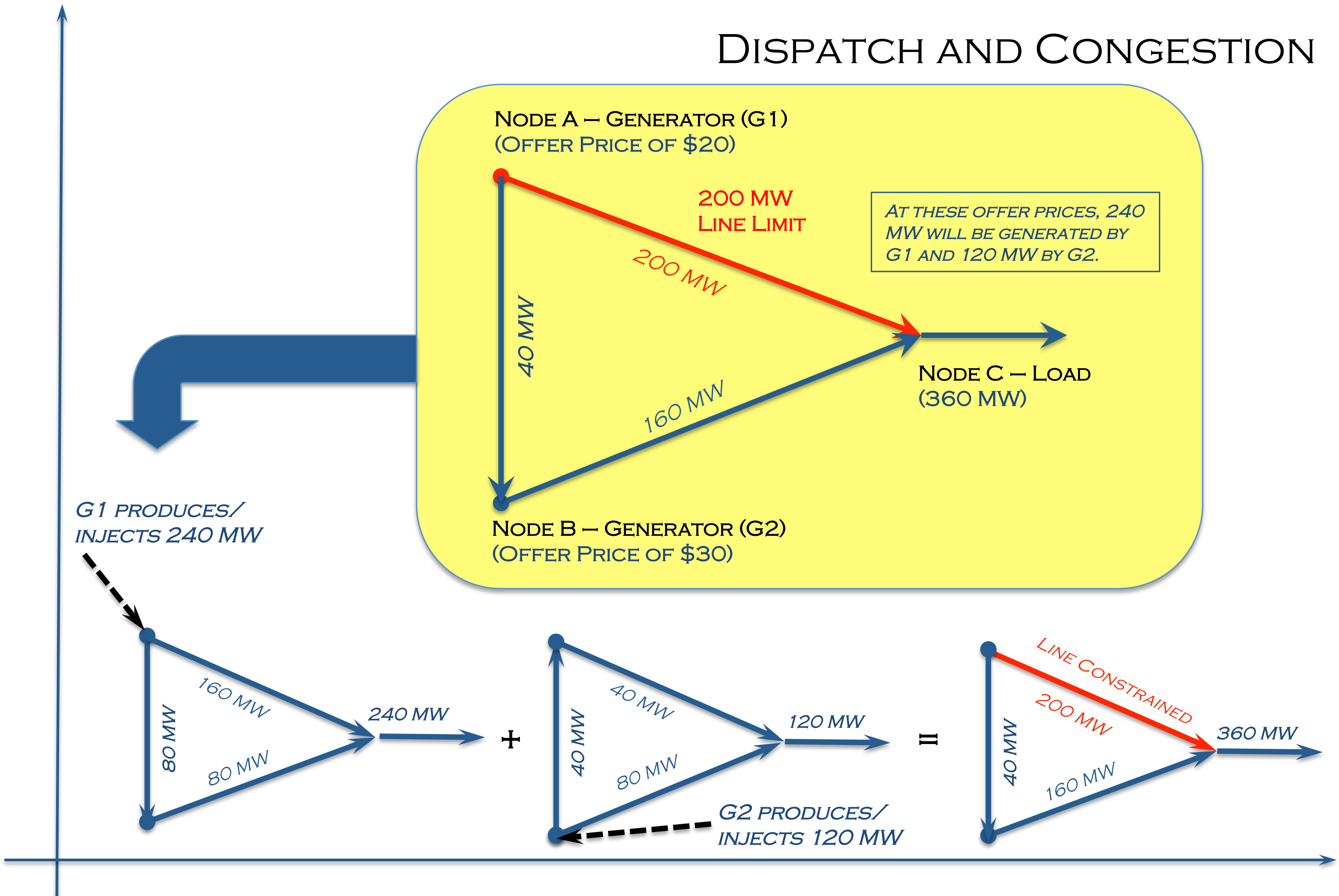
II. Even though it would cost less to have G1 produce 300 MW and G2 produce 60 MW that solution is not feasible since it would violate the constraint on AC:
   A. (300MW * $20) + (60MW * $30) = $7,800
   B. (240MW * $20) + (120MW * $30) = $8,400

III. What physically happens is shown on the next slide.



At these offer prices, 240 MW will be generated by G1 and 120 MW by G2.

Dispatch and Congestion



Dispatch and Congestion – Pricing

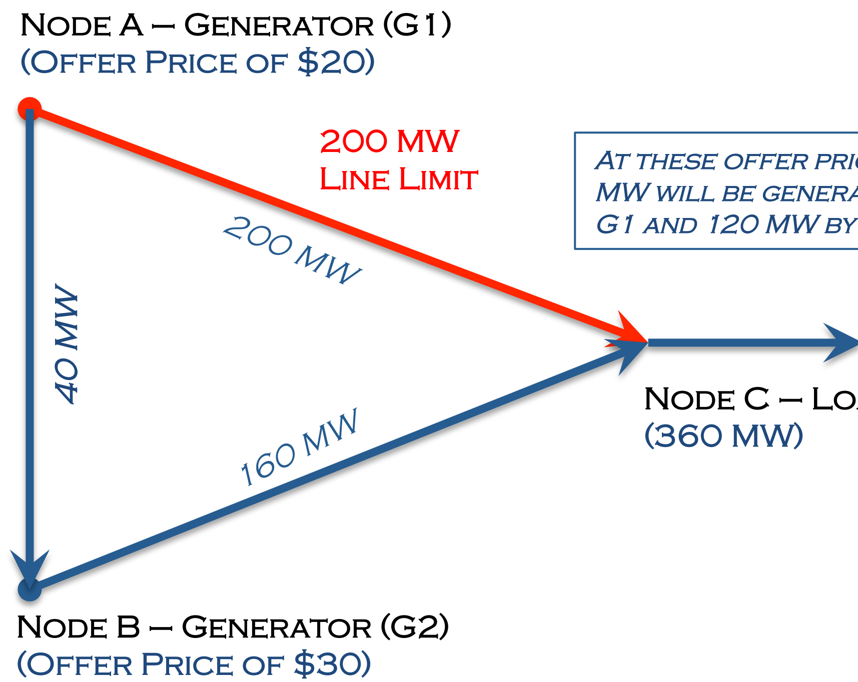
I. What are prices at each node for this load and dispatch?

II. The locational marginal price is the lowest cost of supplying an additional increment of load at every node.

III. So, if there was an additional increment of load at A, G1 would be used and since the energy would be consumed at A, no power would flow to the rest of the grid. Therefore, the LMPa = $20.

IV. At B even though it would be cheaper to use G1, the power from G1 would flow on AC and violate the constraint. So we have to use G2 and LMPb = $30.

V. What about C? If we tried to use G1 then 2/3 MW would flow along AC and violate the constraint. Likewise if we tried to use G2 then 1/3 MW would flow along AC and violate the constraint…so, what the dispatcher has to do is reduce G1 by 1MW and then increase G2 by 2MW (1MW to make up for the loss from G1 and 1MW for the extra increment). Therefore the price is LMPc = (-1 * $20) + (2 * $30) = $40



At these offer prices, 240 MW will be generated by G1 and 120 MW by G2.

Constraints, Congestion and the Price Spread

I. In the simple 3-node model, the reason why there are three different prices (at the given level of load) is due to the 200MW limit or constraint on the transmission line from AC.
   A. Anytime there is a binding constraint prices will separate (again, not taking into consideration the effect of losses).

II. Within a single dispatch region constraints "create" price spreads.

III. Good market design will largely eliminate incentives for market participants to artificially create or exacerbate constraints.
   A. Good market design, implementation and operation respects the actual (rather than expected or forecast) dispatch.
      1. Design from the real time market out...not a forward market in.
   B. Good market design is based on physics and reflects the actions of the dispatcher (i.e. uses market mechanisms to incentivize Market Participants to behave in a manner that is aligned with what the dispatcher needs/wants them to do).
   C. Bad market design creates incentives for Market Participants to do something other than what the dispatcher wants/needs.

Dispatch and Congestion – Settlement and the Creation of a Financial Surplus

Now that we know the locational marginal prices at each node we can show how the system clears and settles.

I. Under LMP dispatch generators are paid the LMP at their transmission bus for energy.
   A. In the 3-node example:
      1. G1, the generator at A will be paid $20 * 240MW = $4,800 from the pool.
      2. G2, the generator at B will be paid $30 * 120MW = $3,600 from the pool.
      3. The total dollars paid from the pool to generators = $8,400

II. Under LMP dispatch load pays the LMP at their location.
   A. In the 3-node example:
      1. Load at Node C will pay $40 * 360MW = $14,400 to the pool.
      2. The total dollars paid to the pool from the load = $14,400.

III. In this example, generators received $8,400 and load paid $14,400. There is a surplus of $6,000. What happens to this money?
   A. Have to give it back or the RTO will have an incentive to perform inefficient dispatch.
   B. This is covered in Part 3 of the training.

Locational Marginal Pricing as the Basis for Dispatch – Summary

I. The physical characteristics of electricity mean that there needs to be an "air traffic controller" charged with balancing real time supply and demand.

II. The key task is to design the market such that Market Participants are incentivized to behave the way the dispatcher needs in order to maintain reliability while minimizing the costs.

III. An LMP-based dispatch system is a mechanism that provides non-discriminatory open access while at the same time minimizing costs and operating reliably.

   A. There are three cornerstones of an LMP-based dispatch system.

      1. It uses security constrained economic dispatch (SCED) based on the offers of Market Participants.
      2. It calculates market prices (LMPs) from this dispatch and uses them for energy market settlements.
      3. It offers energy balancing services to anyone willing to pay the energy market prices.

IV. LMP-based dispatch is the only known way to align the physics of electricity with the economics of the system.