# Transmission Congestion: *why it occurs and causes locational differences in energy prices*

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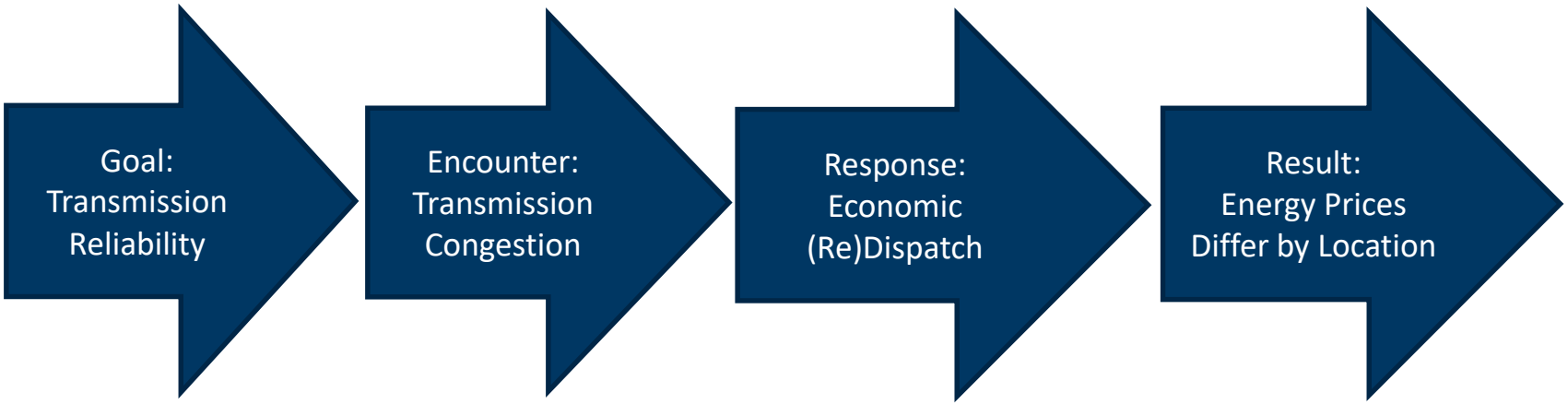
***WebEx***

# RELIABLE TRANSMISSION OPERATION → CONGESTION




| Driven by physical properties of grid | Natural consequence of least-cost reliable operation due to | Adjustments to maintain a reliable dispatch | Locational Marginal Prices (LMPs) for energy and congestion pricing |
|---|---|---|---|
| Parallel Flow<br><br>Transmission Constraints<br><br>Contingency Analysis (not addressed here) | Parallel Flow and Transmission Constraints<br><br>Changing Levels of Load, Imports/Exports<br><br>Changing Availability of Supply and Grid Resources | Based on Supply Offers and Load Bids<br><br>• Could be for full economic dispatch or for balancing dispatch<br><br>• Could be incs or decs | Arise from economic dispatch to maintain transmission reliability<br><br>Differences between LMPs at two locations is the difference in the value of energy due to transmission congestion |

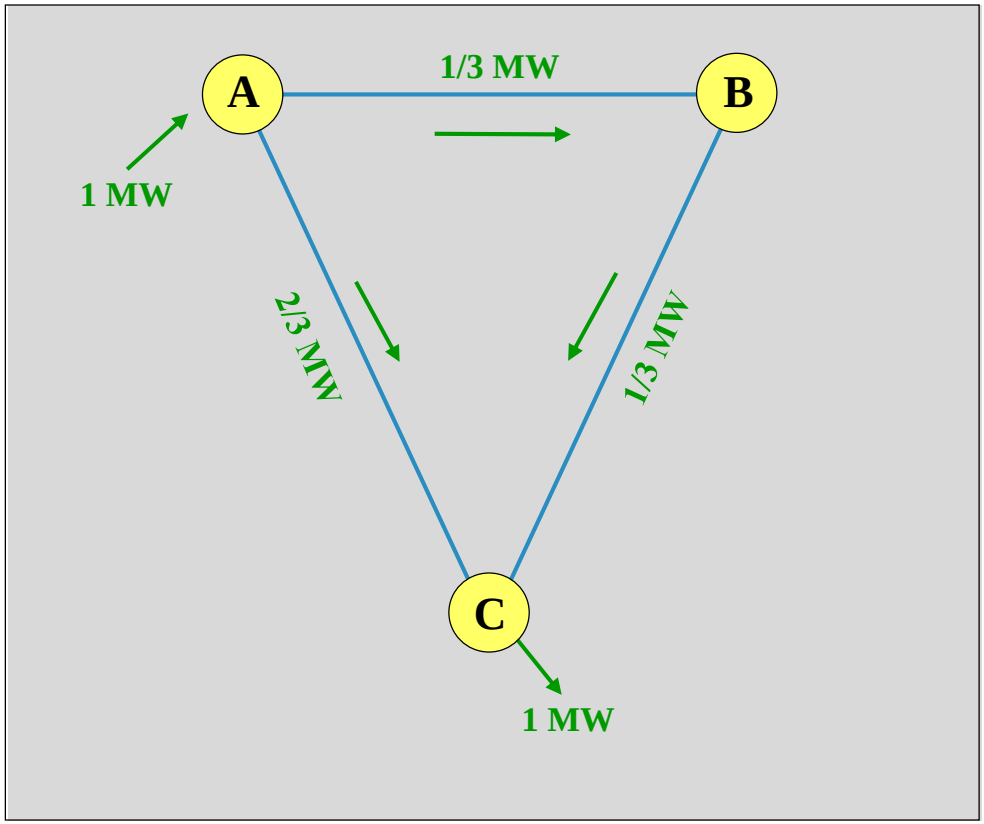
# TRANSMISSION OPERATION: PARALLEL FLOW

**Parallel flow means that electricity will flow over all interconnected lines between source and sink**

**Electricity flows do not follow contract paths**

For simplicity, all lines in this example have equal impedance

The flow on each parallel path between source (A) and sink (C) is inversely related to the relative impedance of each path



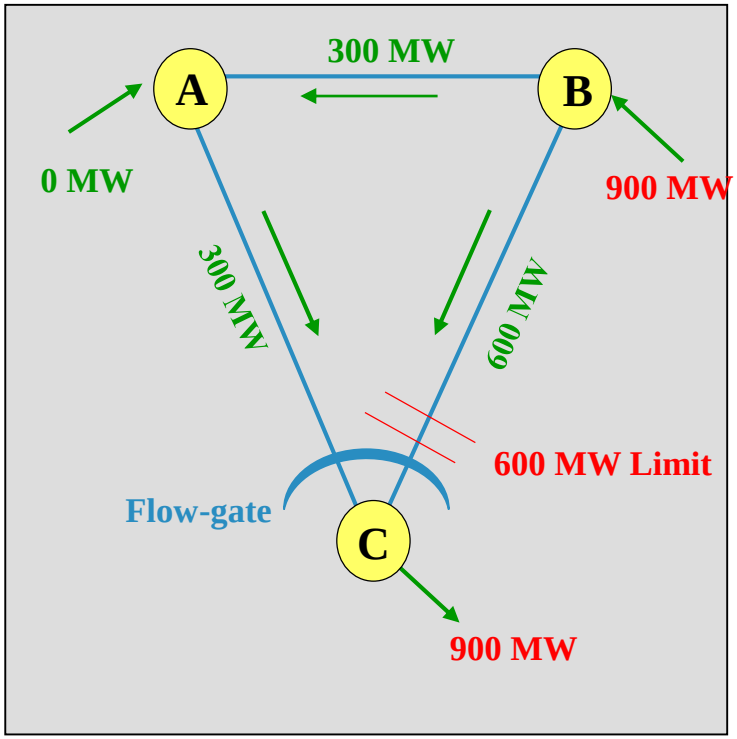
# TRANSMISSION OPERATION: PARALLEL FLOW

Parallel flow means that the transmission capacity between two locations

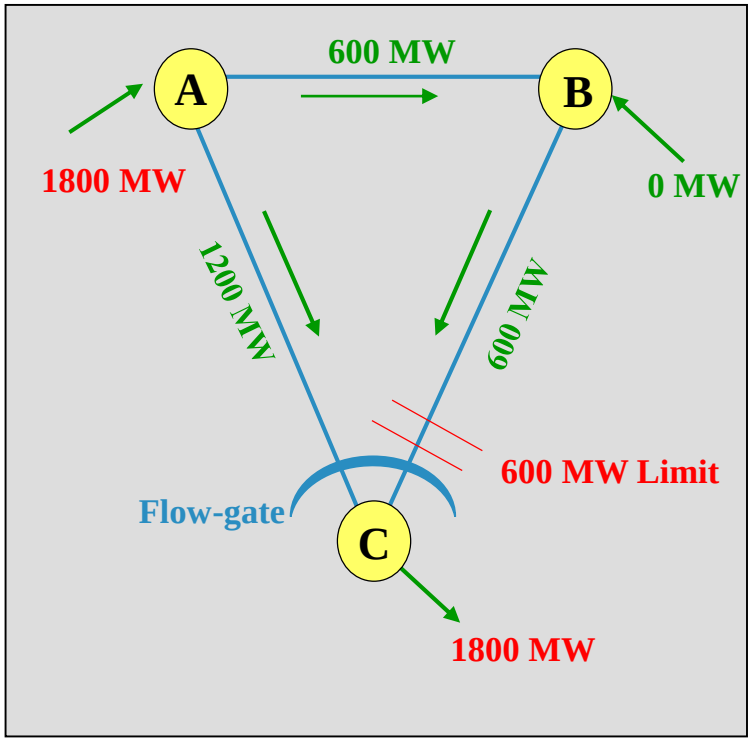
-- or across an interface or flowgate --

is not fixed

The quantity of energy that can flow depends on the locations of injections and withdrawals, even when all transmission elements are in service




**ATC to C is 900,**
**if all injections are at B**




**ATC to C is 1800,**
**if all injections are at A**

# TRANSMISSION OPERATION: LIMITS AND CONTINGENCIES

**Limits observed during reliable operation:**

***Thermal Limits*** –on conductor temperature

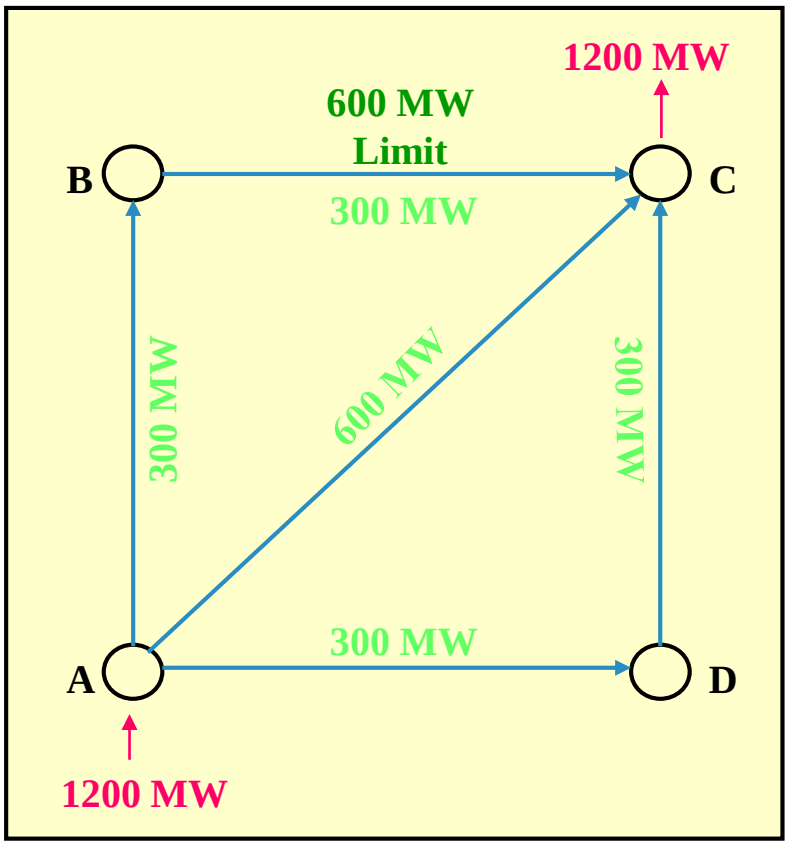
***Voltage Limits*** –on the voltages at busses

***Stability Limits*** –on the ability of the system to stabilize following a contingency

**The nature and speed of electric transmission failures require operation on a contingency-constrained basis**

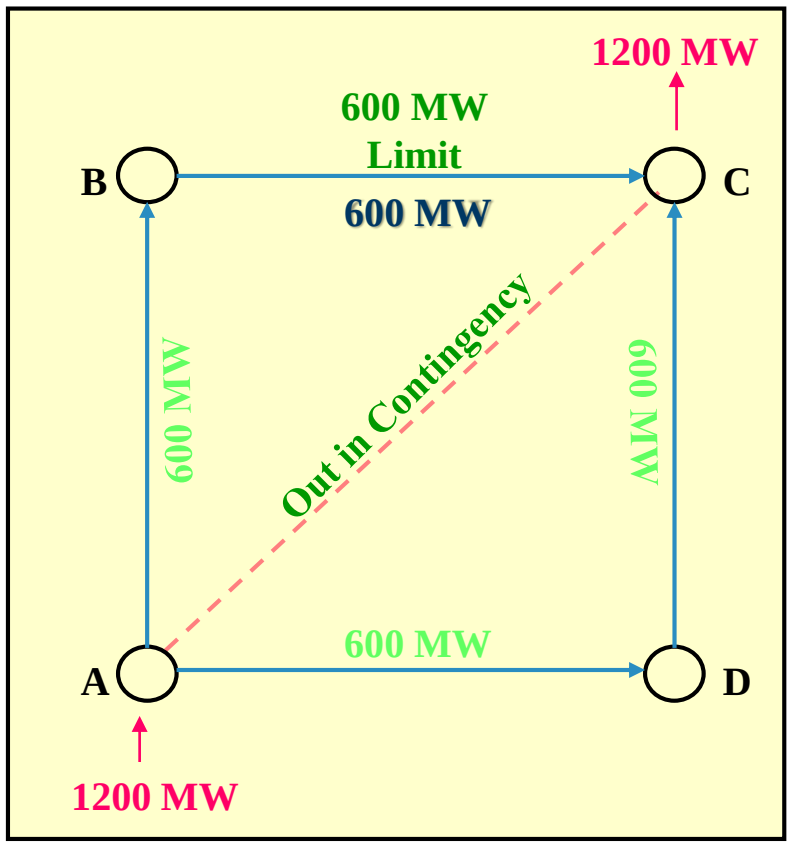
**Emergency rating limits respected when a major failure occurs**

## PRE-CONTINGENCY




Under 600 MW Limit

## POST-CONTINGENCY




At 600 MW Limit

# TRANSMISSION CONGESTION

**This grid will be used to illustrate:**

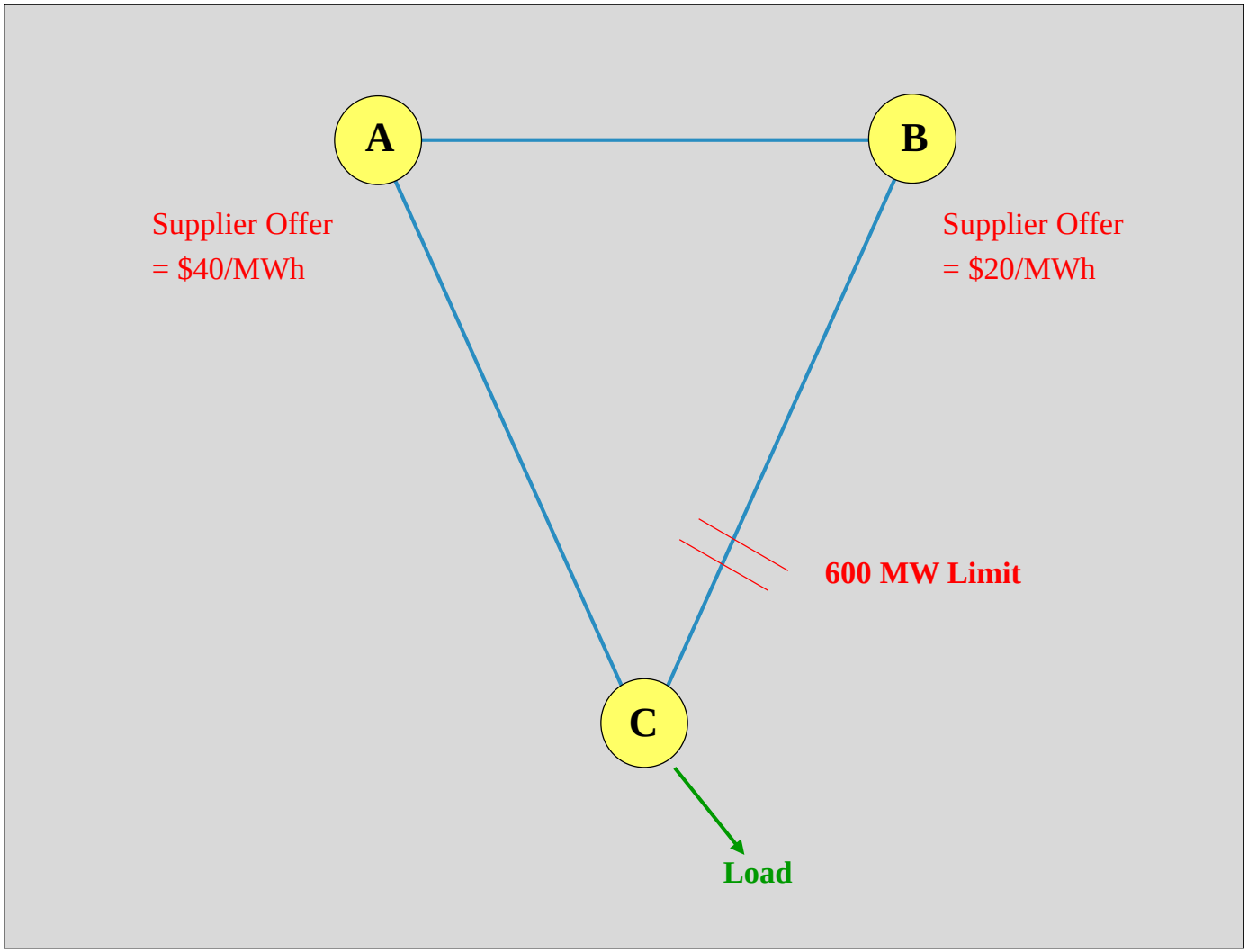
How transmission congestion occurs

Security-constrained economic (re)dispatch

How LMP prices are calculated from the security-constrained dispatch

For simplicity, all lines in the example have equal impedance

Dollar figures are the supplier offers at each bus



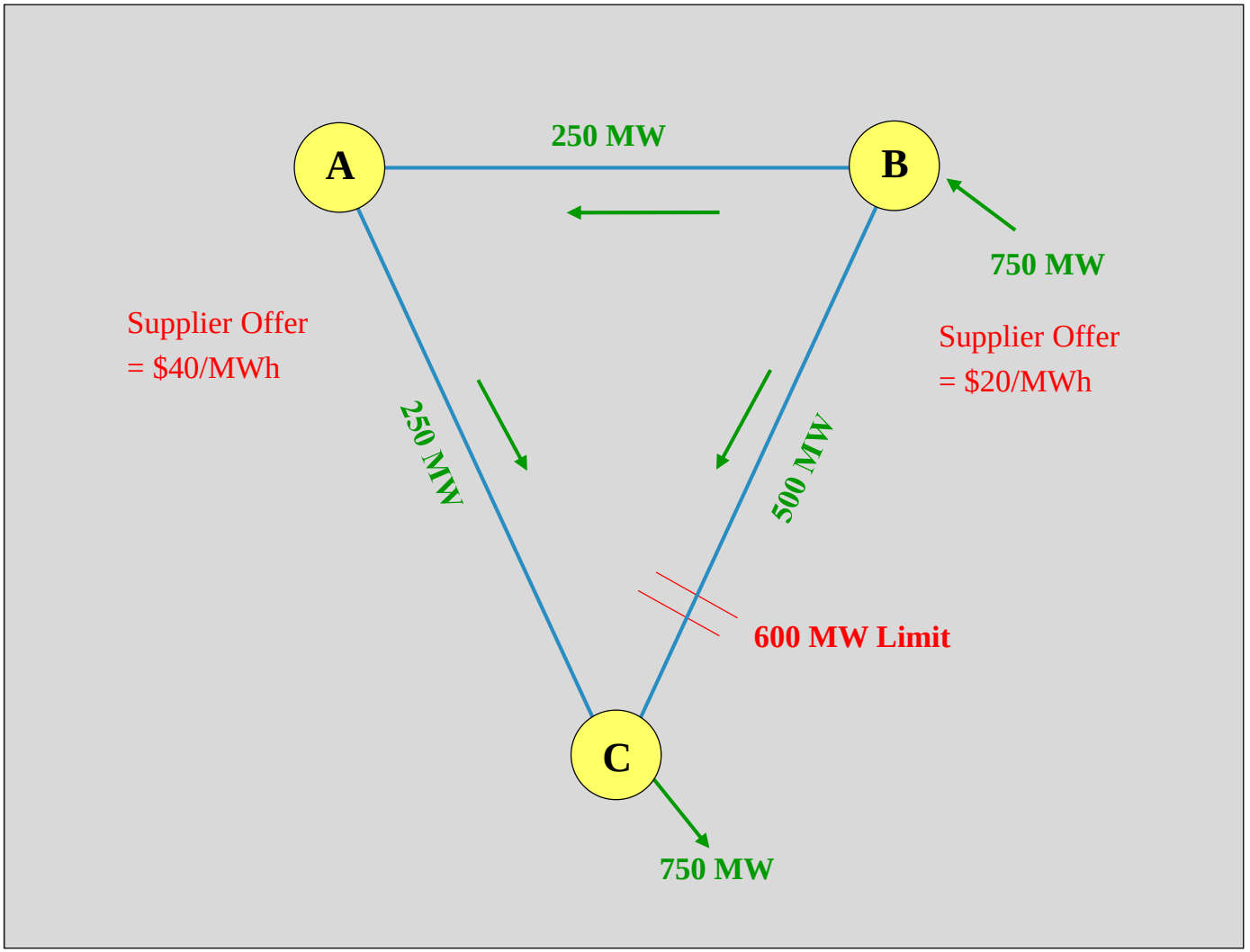
# TRANSMISSION CONGESTION: UNCONSTRAINED DISPATCH

**If the load on this system were 750 MW at C, it could all be met at least cost with the $20/MWh supplier at B**

Flow on the line B-C is 500 MW, below the 600 MW limit

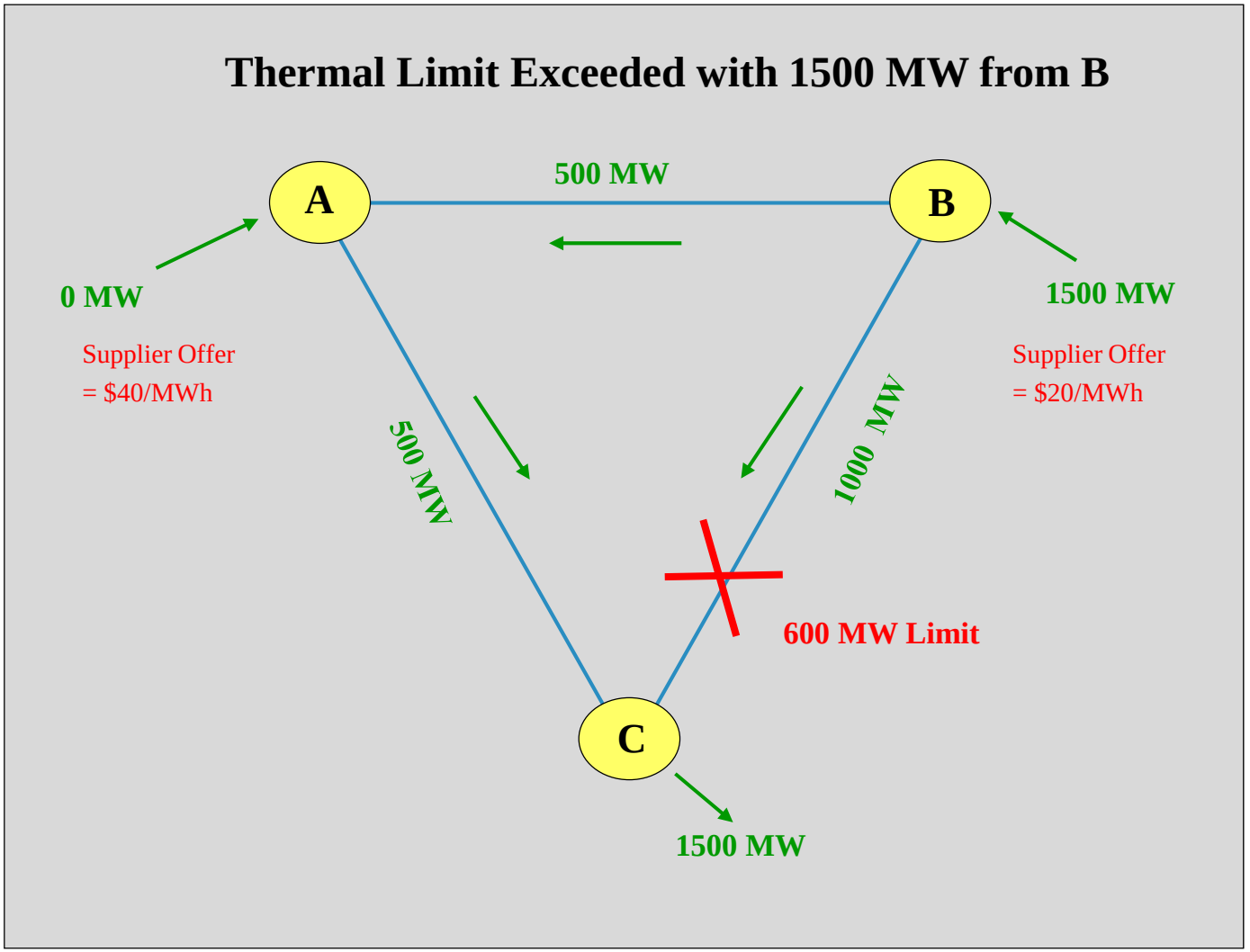
Not all of the energy injected at B flows to C on the B-C line (parallel flow)

There is no transmission congestion



# TRANSMISSION CONGESTION: CONSTRAINED DISPATCH

**If load at C increased to 1,500 MW, then it could not be met exclusively with the low offer-cost supplier at B without exceeding the limit on the line B-C.**

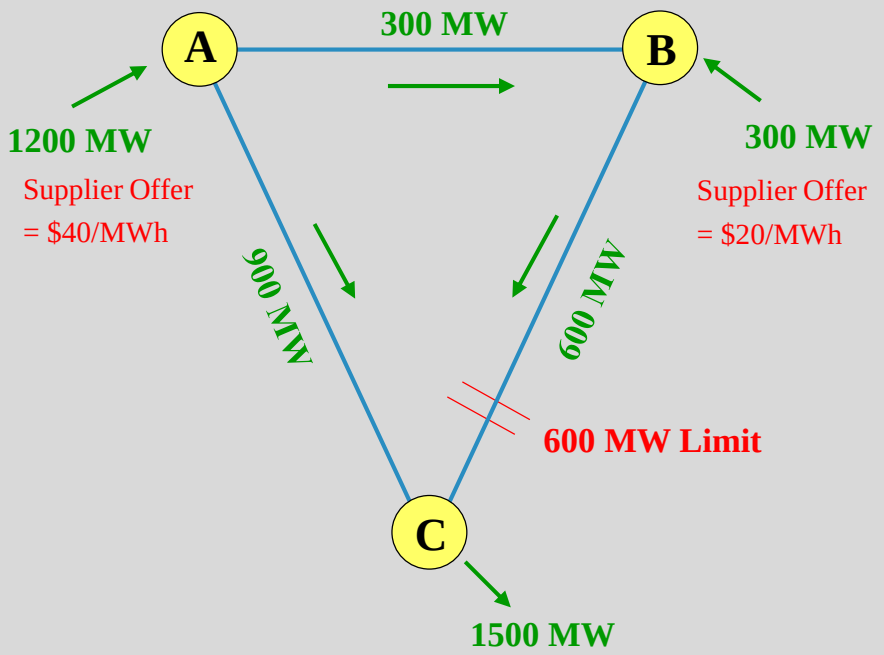


# (RE)DISPATCH AT LEAST COST

**If load at C increased to 1,500 MW, at most 300 MW could be supplied from B**

Higher offer-cost supplier at A meets 1200 MW of load

## Thermal Limit Respected with 300 MW from B




**A to B Flow = 400 from gen A - 100 from gen B = 300 MW**
**A to C Flow = 800 from gen A + 100 from gen B = 900 MW**
**B to C Flow = 400 from gen A + 200 from gen B = 600 MW**

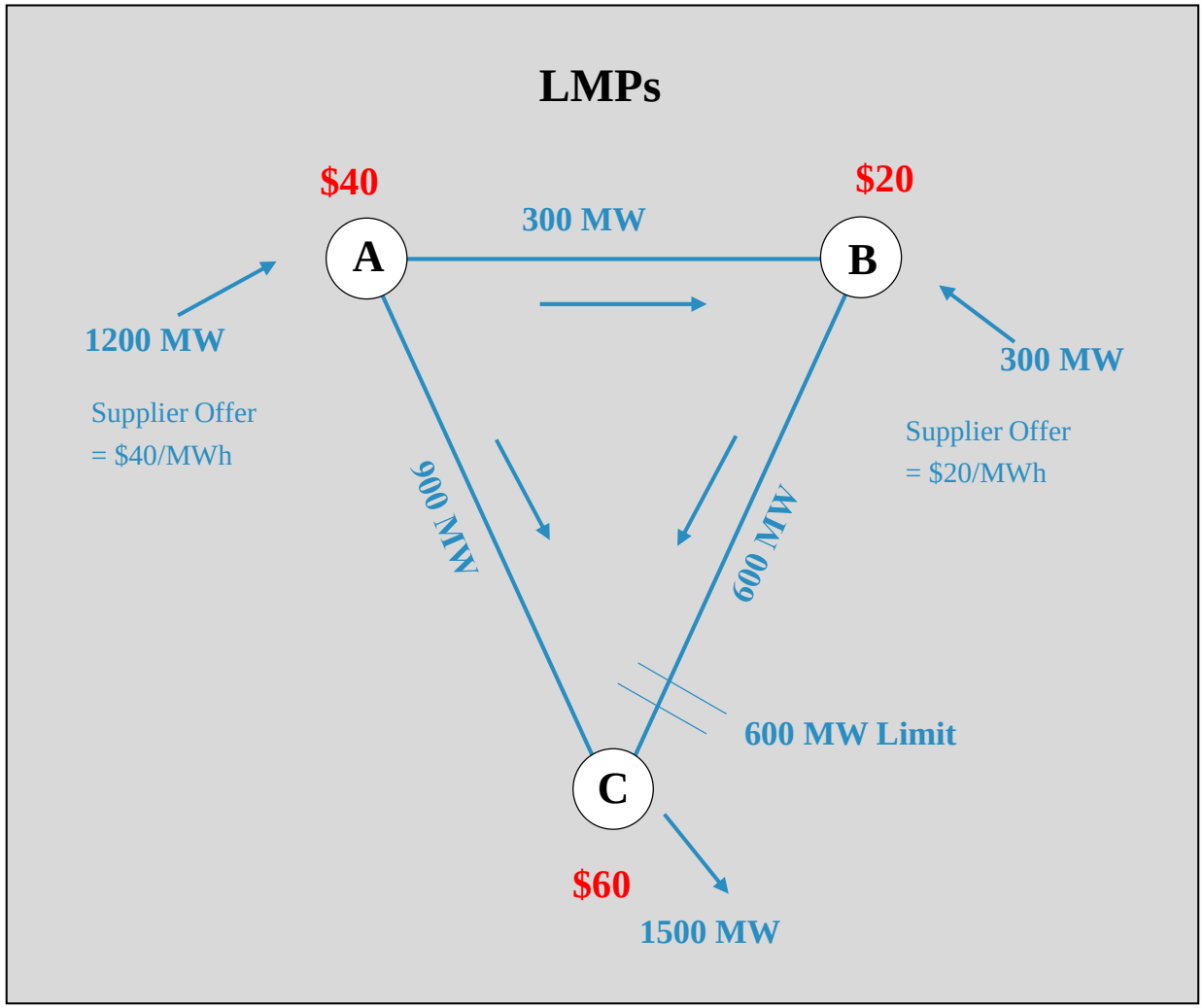
# (RE)DISPATCH AT LEAST COST

**When there is transmission congestion:**

- The least-cost (based on offers) mix of suppliers cannot be used to meet load
- (Re)dispatch is necessary to serve additional load at C
- Small increases in injections at some locations (B) rather than at other locations (A) would cause a transmission limit to be exceeded
- The market value of incremental supply at location B must be less than at locations A and C

# ENERGY PRICES (LMPs) FOR CONGESTED LEAST-COST DISPATCH

**The LMP is the lowest (re)dispatch cost (based on bids and offers) of supplying energy to the next increment of load at a specific location on the transmission grid, while observing all security limits**

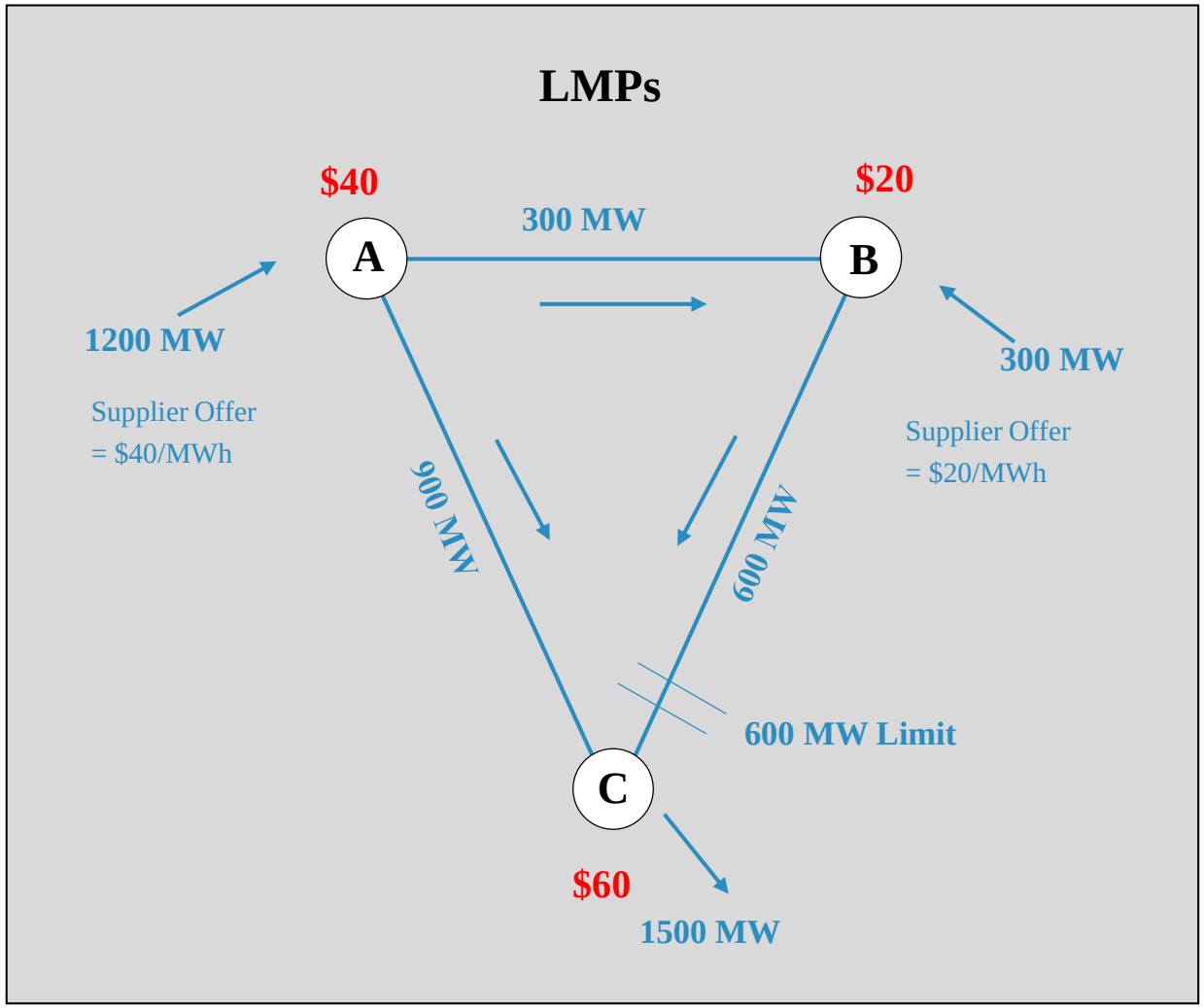


# LMP DERIVATION AT LOCATIONS A AND B

**LMP at B is $20/MWh.** An increment of load can be met at lowest cost by the $20 supplier at B

**LMP at A is $40/MWh.** An increment of load at A can be met at lowest cost by the $40 supplier at A

Incremental supply at B cannot serve load at A, because some of it would flow on the line from B to C, violating the limit on this line

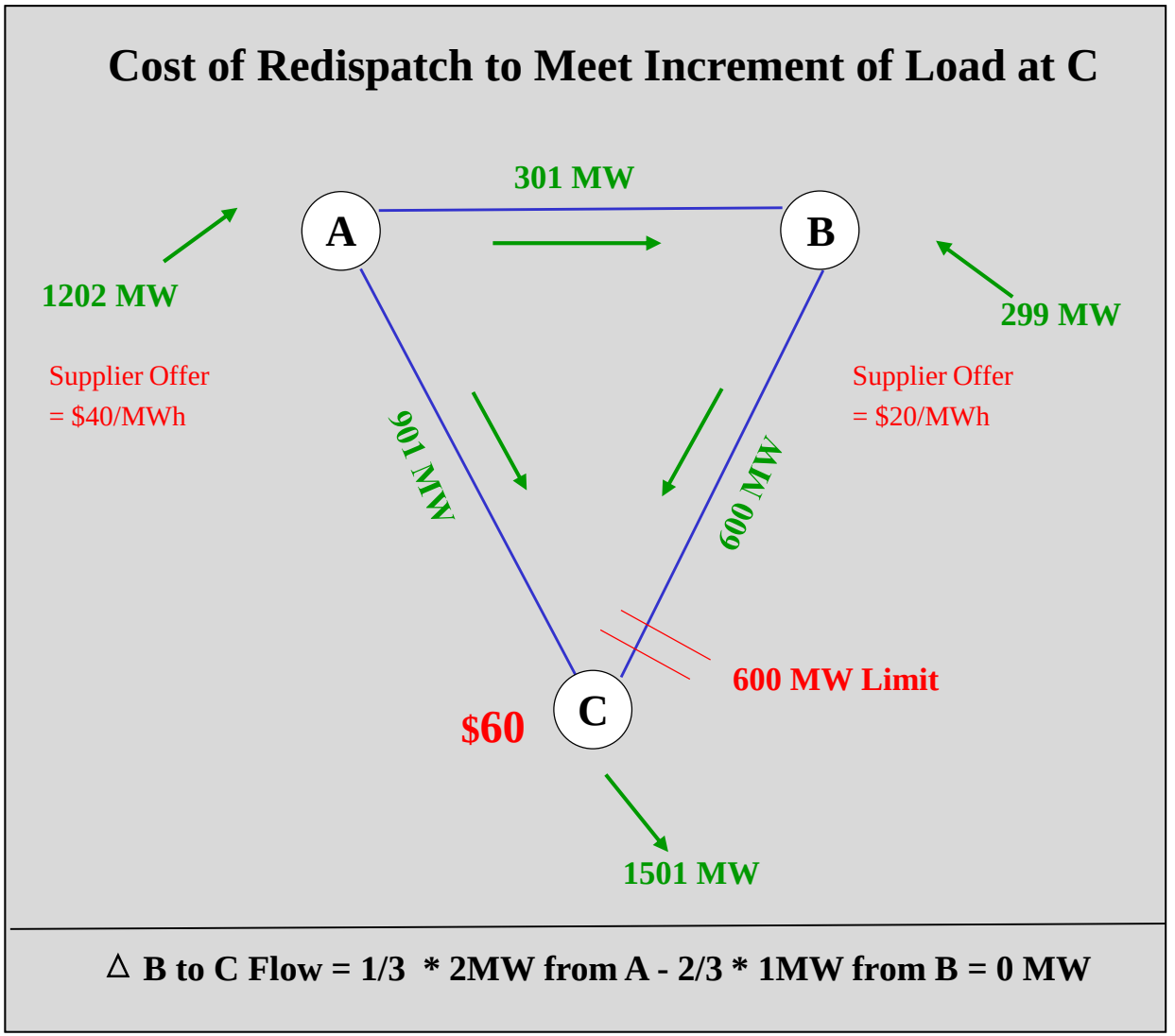


# LMP DERIVATION AT LOCATION C

**LMP at C is $60 because an increment of load is met by:**

- 2 MW increased injection at node A, plus
- 1 MW *decreased* injection at node B
- 2MW *$40 – 1MW * $20 = $60

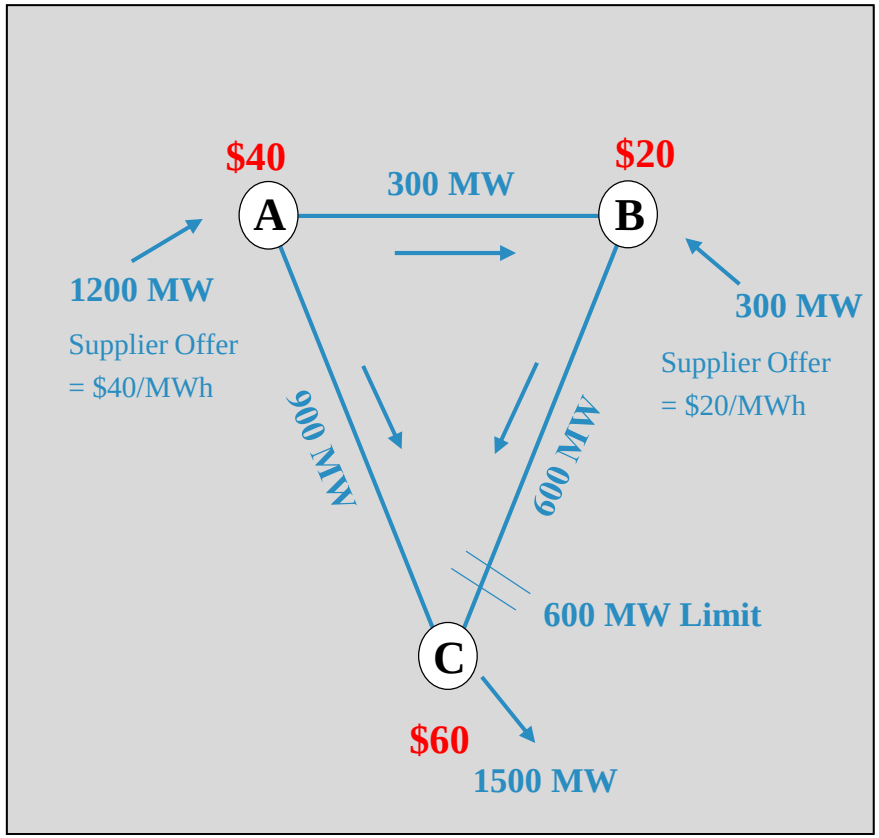
This is the least-cost (re)dispatch to meet an increment of load at C without violating the 600 MW thermal limit from B to C



# OBSERVATIONS ON LMP PRICES

- LMP prices reflect the impact of congestion on:
  - The value of incremental generation at different locations
  - The bid-based cost of serving incremental load at different locations
  - The bid-based cost of the redispatch required to reliably accommodate an incremental transaction between two locations
- The LMP at a location is not necessarily equal to the bid of any single supplier. It is not the bid of the last generator capacity segment dispatched in a "zone"

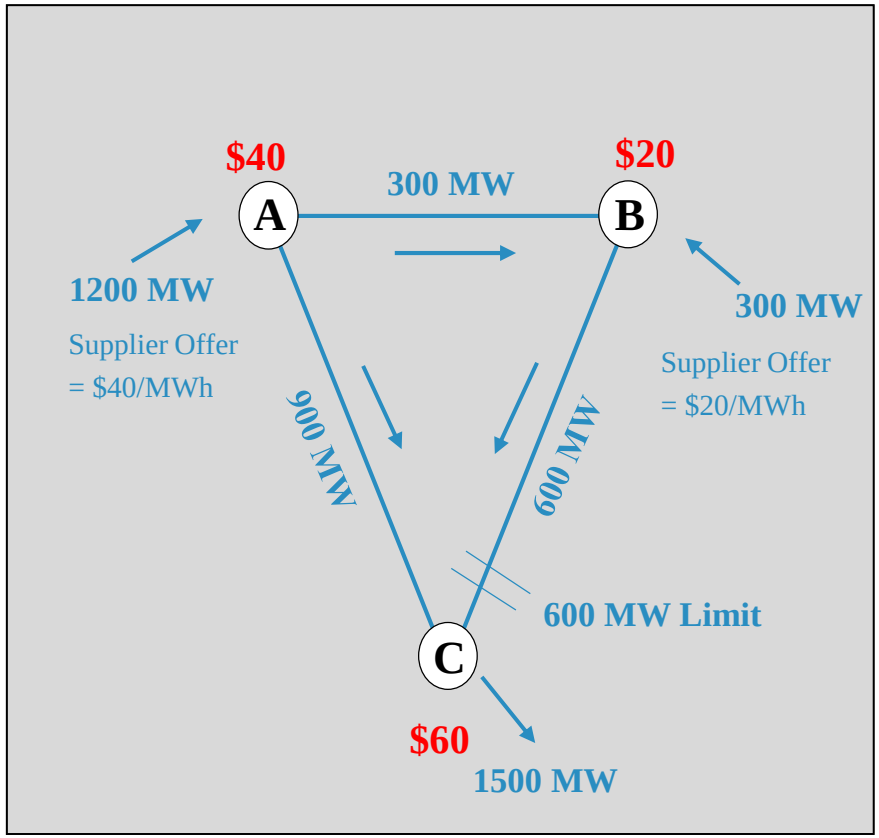
**Least-Cost Security-Constrained Dispatch**



# OBSERVATIONS ON LMP PRICES

- The LMP can differ between two busses even if a line between them is not at a limit
- Transmission constraints may “divide” the system in two, leading to different LMPs on the two “sides” of the constraint (Radial case)
- More generally, transmission constraints do not divide the system neatly in two, and the LMPs may differ at many locations (Network case)

**Least-Cost Security-Constrained Dispatch**

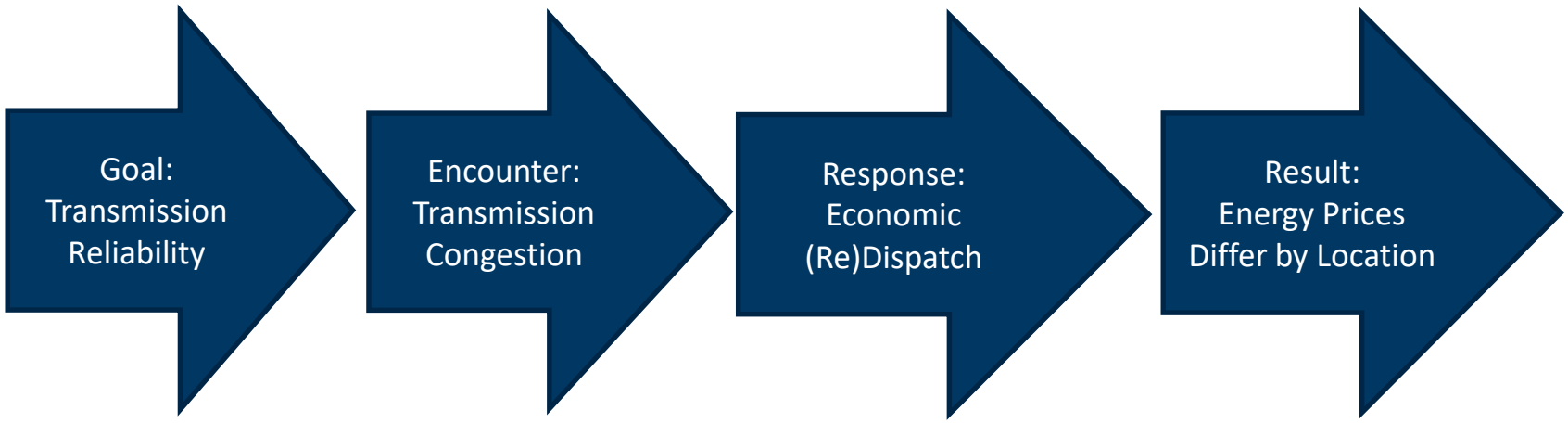


# LMP SETTLEMENTS

- Under an LMP system, energy settlements for suppliers and loads may be for their full dispatch or for balancing energy, depending on the market design
  - Suppliers are paid the LMP at their transmission bus
  - Loads pay the LMP at their location (node or zone)
- Transmission users pay transmission congestion charges
  - The transmission congestion charge is the difference between the LMP at the withdrawal location less the LMP at the injection location
  - This is the lowest cost redispatch that reliably accommodates the transaction, on margin

**LMPw - LMPi = Congestion Charge**

# SUMMARY




- Reliable transmission operation encounters transmission congestion due to parallel flow and reliability constraints
- Centralized dispatch is required to manage transmission congestion and insure reliability
- Economic dispatch is based on voluntary supplier offers and loads bids
  - Suppliers sell energy into the energy balancing market and/or through bilateral transactions
  - Loads buy energy from the energy balancing market and/or through bilateral transactions
- LMPs are a consequence of the security-constrained economic dispatch
  - Using LMPs for balancing settlements provides incentives for market participants to make voluntary decisions consistent with reliability

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