# Additional Details and Examples — Locational Reserves and Down RUR Pricing

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# Summary of PJM's Perspective on Reserve Location Procurement

| | |
|---|---|
| **Synchronized and Primary Reserves** | Nodal procurement where PJM models the same reserve congestion constraints that we use today or reserve constraints of similar reliability concern for SR deployment in the future. |
| **Ramp/Uncertainty Reserves** *(both 10-Min and 30-Min)* | Nodal procurement where the reserve congestion constraints reflect that Ramp/Uncertainty Reserves must be deliverable under normal operating conditions along with energy. |
| **30-Min Reserves** | Nodal procurement where the reserve congestion constraints reflect transmission facilities or interfaces of heightened reliability risk, particularly under post-contingency conditions. |
| **Day-Ahead Reserves** *(DASR and Energy Gap)* | Procured at a system level |

# Synchronized Reserve Locational Procurement

- The procurement of Synchronized Reserves would be very similar to the design used today in the existing reserve sub-zone construct in that PJM would only model deliverability over the sub-set of interfaces or network constraints that present a reliability risk for SR deployment.
- PJM would no longer define a “sub-zone” but would use the actual distribution factors for each generation resource to reflect its impact on the congestion on the Interconnection Reliability Operating Limit (IROL) or relevant network constraints.
- If a deliverability constraint binds, this would lead to reserve price separation between nodes. These reserve prices would reflect each resource’s individual impact on the congestion on that constraint.

# Ramp/Uncertainty Reserve Locational Procurement

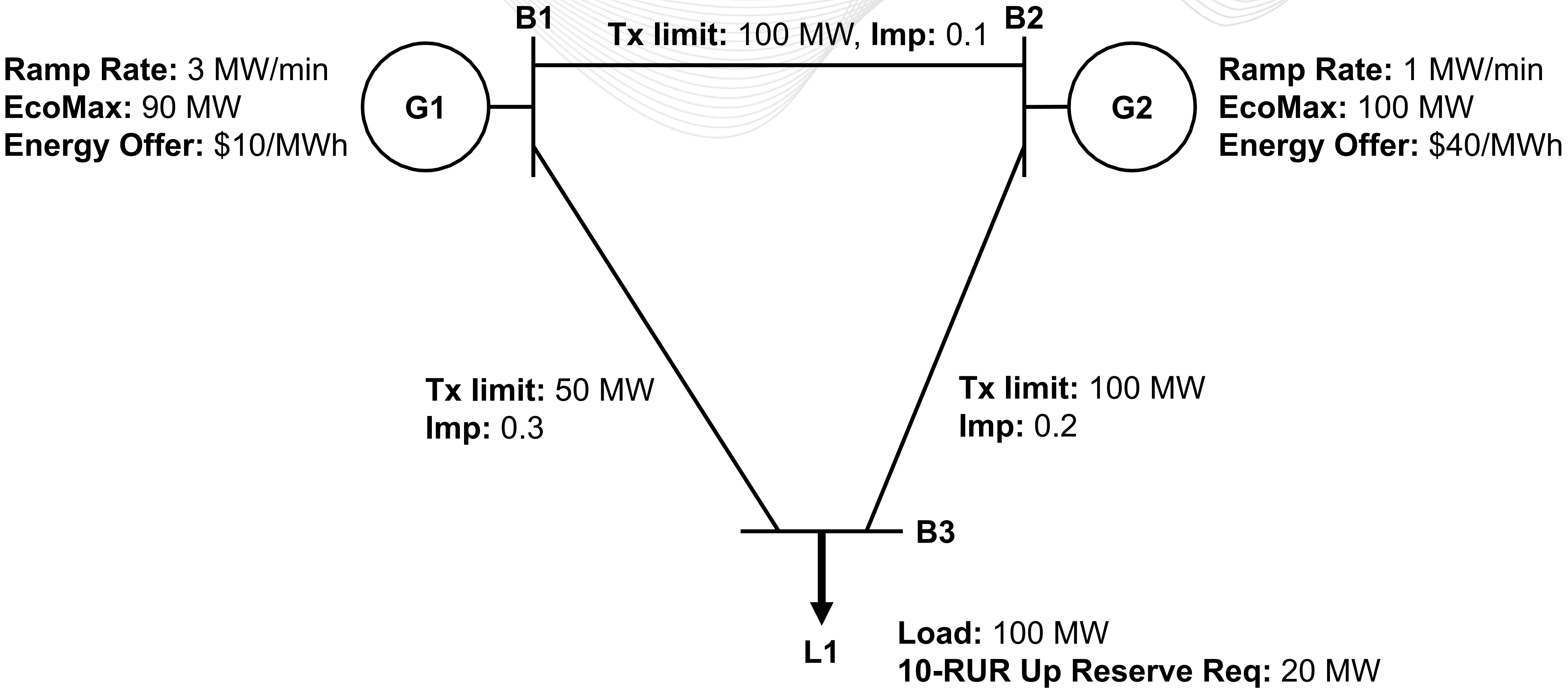
- The procurement of Ramp/Uncertainty Reserves is to serve *expected* net-load in future intervals, recognizing uncertainty in the net-load forecast. Because these services are provisioned to serve system energy needs in the near-term, the same network constraints used for energy would be modeled to ensure the deliverability of these services.

- The expected change in net-load and the uncertainty associated with that net-load forecast would be modeled at the load, wind and solar buses, proportional to the net-load forecast. This would ensure that the Ramp/Uncertainty Reserves procured could be distributed to those buses.

- If provisioned reserves would cause network constraints to bind, this would lead to nodal reserve prices. If there is no congestion on the network that requires a change in dispatch to ensure reserve deliverability, then prices would be the same across the system, and the same as if the reserves had been procured at a system-level.

# 30-Min Reserve Locational Procurement

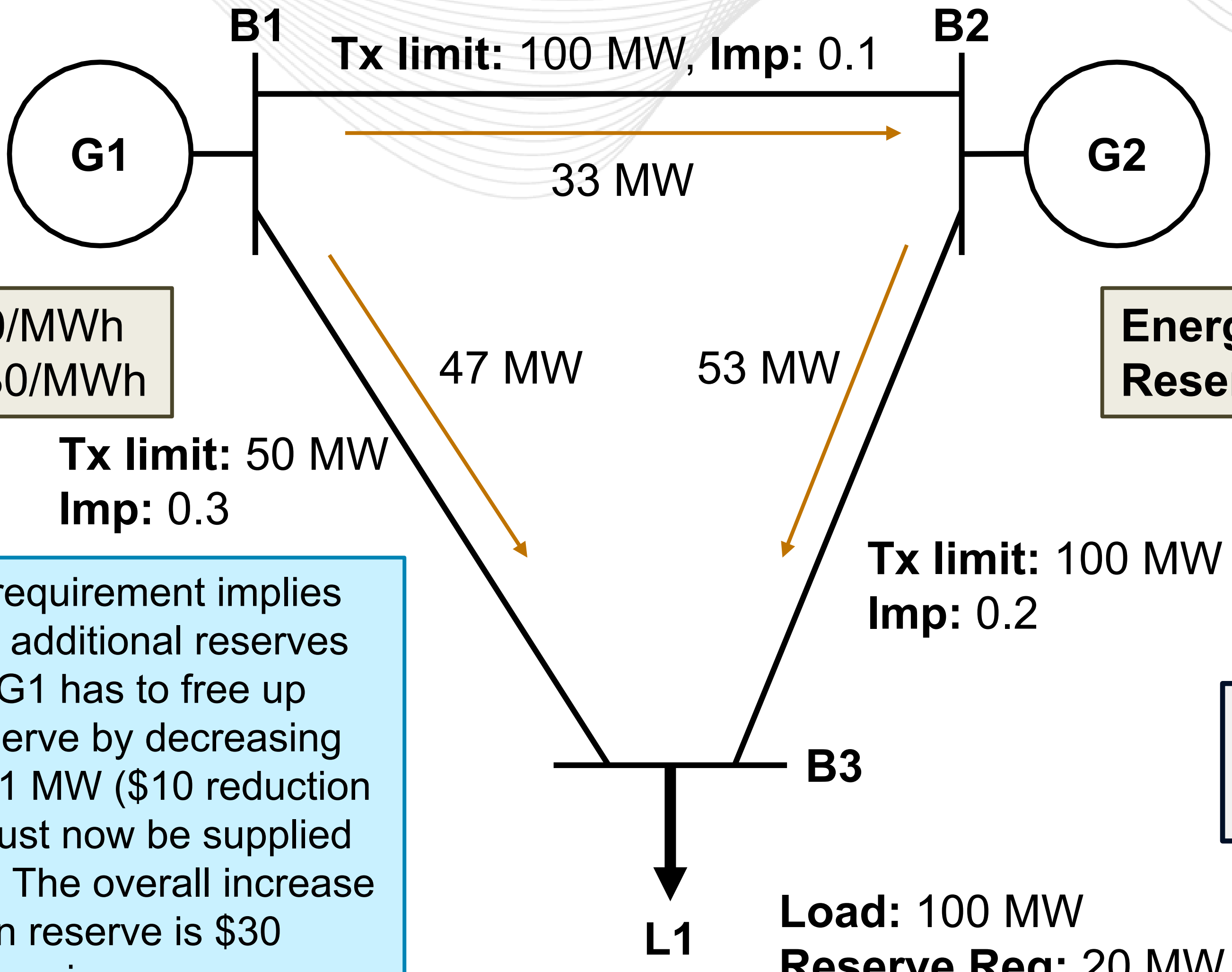
- The procurement of 30-Min Reserves would be conceptually similar to the procurement of Synchronized Reserves in that a set of deliverability constraints would be modeled, which reflect significant reliability concerns or cascade risk.
- The interfaces or network constraints of reliability concern might be different for the 30-Min Reserve service than for the Synchronized Reserve service given how the services are used. Synchronized Reserve deployment occurs immediately and for a limited amount of time during an emergency. 30-Min Reserve are deployed to rebalance the system and return to a stable operating posture.
- If provisioned reserves would cause network constraints to bind, this would lead to nodal reserve prices. If there is no congestion on the network that requires a change in dispatch to ensure reserve deliverability, then prices would be the same across the system, and the same as if the reserves had been procured at a system-level.


B1
Tx limit: 100 MW, Imp: 0.1
B2
Ramp Rate: 3 MW/min
EcoMax: 90 MW
Energy Offer: $10/MWh
G1
G2
Ramp Rate: 1 MW/min
EcoMax: 100 MW
Energy Offer: $40/MWh
Tx limit: 50 MW
Imp: 0.3
Tx limit: 100 MW
Imp: 0.2
B3
L1
Load: 100 MW
10-RUR Up Reserve Req: 20 MW

# **3-Bus Example 1:** No Locational Constraint on Reserves

**Ramp Rate:** 2 MW/min
**EcoMax:** 90 MW
**Energy Offer:** $10/MWh

**Energy:** 80 MWh @ $40/MWh
**Reserves:** 10 MW @ $30/MWh




**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**Energy Offer:** $40/MWh

**Energy:** 20 MWh @ $40/MWh
**Reserves:** 10 MW @ $30/MWh

A 1 MW increase in reserve requirement implies that since G2 cannot provide additional reserves due to ramp rate limitations, G1 has to free up headroom to provide that reserve by decreasing its power (energy) output by 1 MW ($10 reduction in cost). This 1 MW power must now be supplied by G2 ($40 increase in cost). The overall increase in cost for a 1 MW increase in reserve is $30 yielding the $30/MWh reserve price.

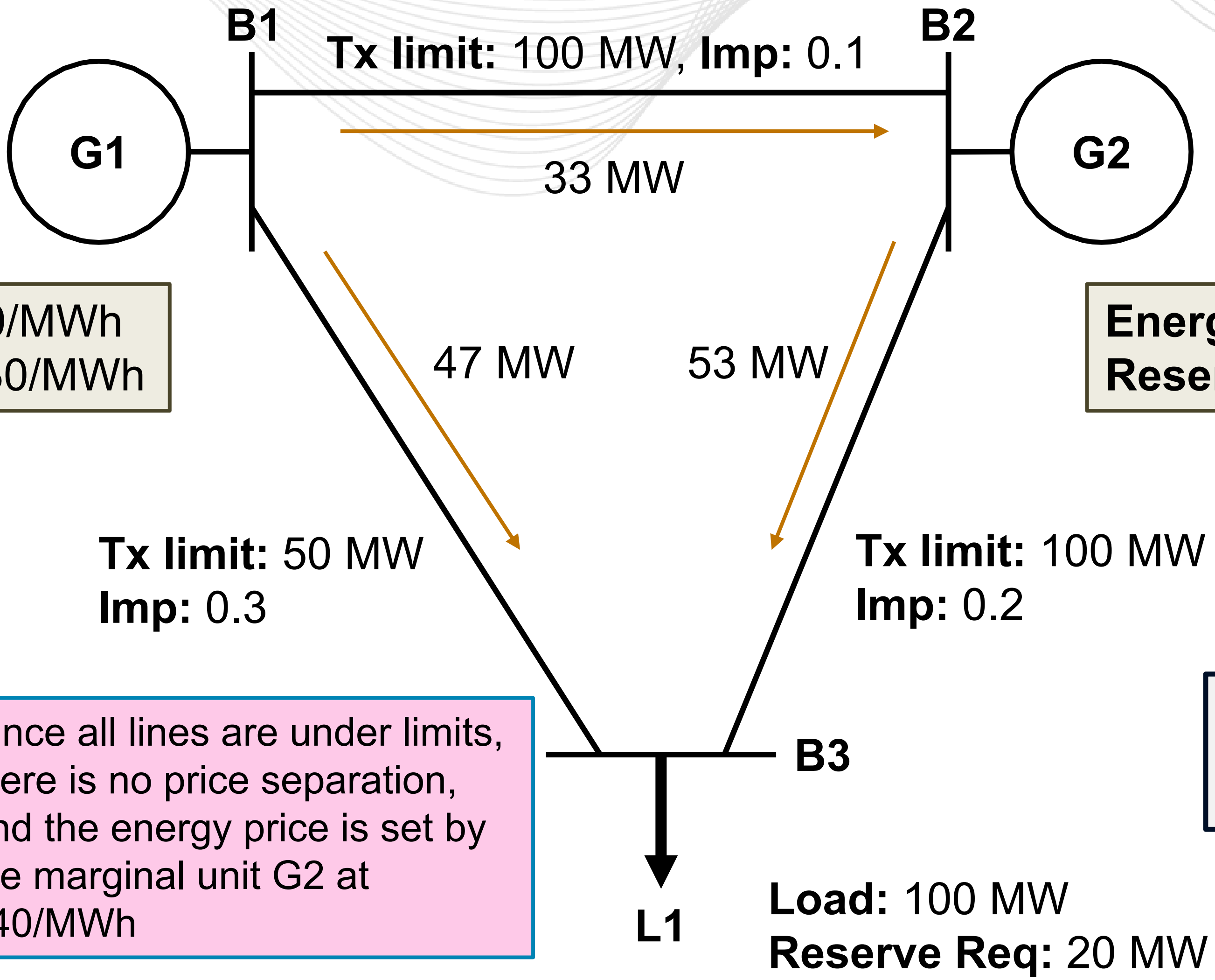
**Load:** 100 MW
**Reserve Req:** 20 MW

Flows are energy only.

# **3-Bus Example 1:** No Locational Constraint on Reserves

**Ramp Rate:** 2 MW/min
**EcoMax:** 90 MW
**Energy Offer:** $10/MWh

**Energy:** 80 MWh @ $40/MWh
**Reserves:** 10 MW @ $30/MWh




**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**Energy Offer:** $40/MWh

**Energy:** 20 MWh @ $40/MWh
**Reserves:** 10 MW @ $30/MWh

When we don't evaluate the deliverability of the procured reserves, the optimization will back down G1 to provide reserve capability, which shows up as lost opportunity cost incurred and sets a system-level reserve market clearing price of $30/MWh.

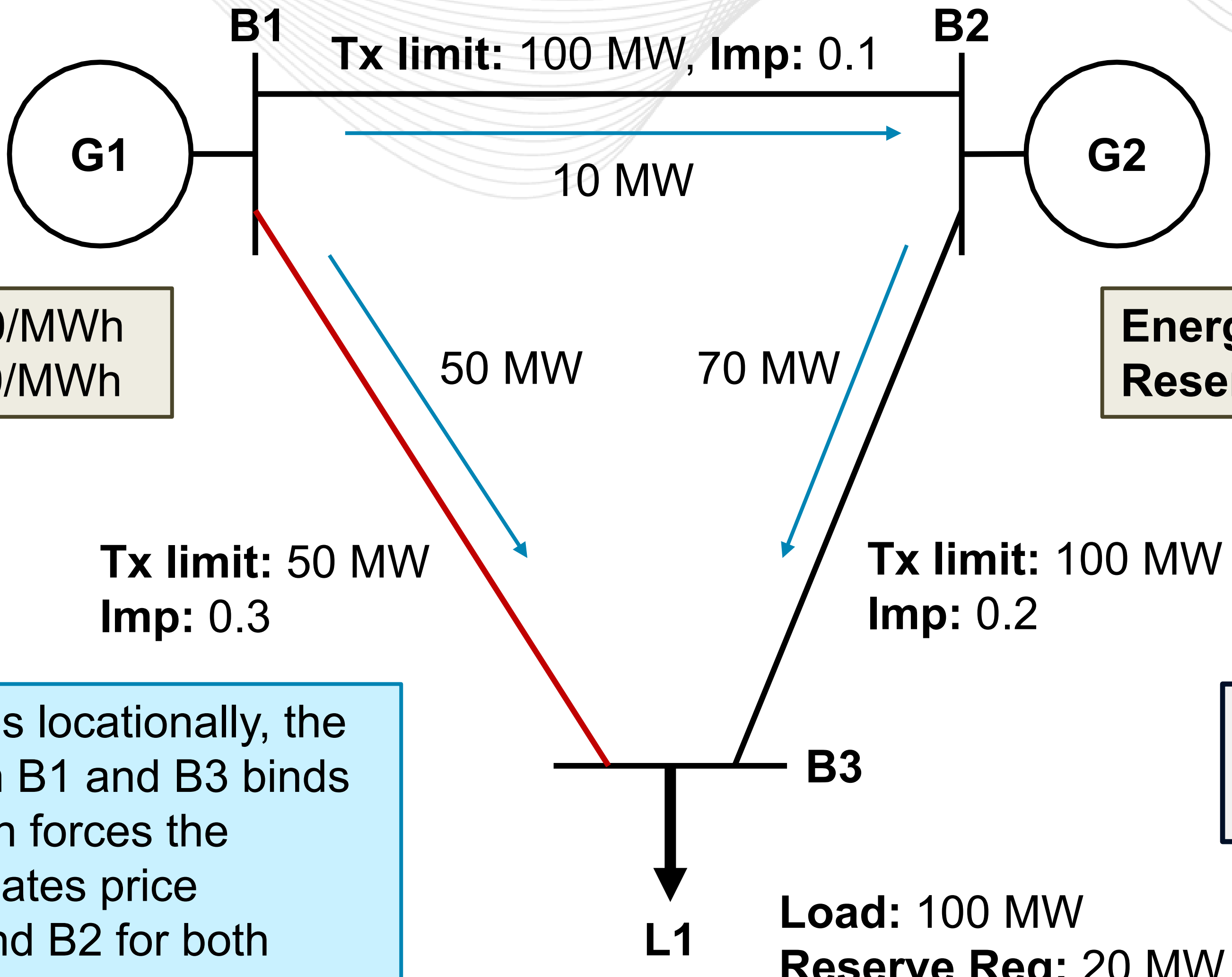
Since all lines are under limits, there is no price separation, and the energy price is set by the marginal unit G2 at $40/MWh

Flows are energy only.

# 3-Bus Example 1: Locational Constraint on Reserves

**Ramp Rate:** 3 MW/min
**EcoMax:** 90 MW
**Energy Offer:** $10/MWh

**Energy:** 50 MWh @ $10/MWh
**Reserves:** 10 MW @ $0/MWh




**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**Energy Offer:** $40/MWh

**Energy:** 50 MWh @ $40/MWh
**Reserves:** 10 MW @ $30/MWh

When we procure reserves locationally, the transmission line between B1 and B3 binds at its limit of 50 MW, which forces the redispatch of G1. This creates price separation between B1 and B2 for both energy and reserves.

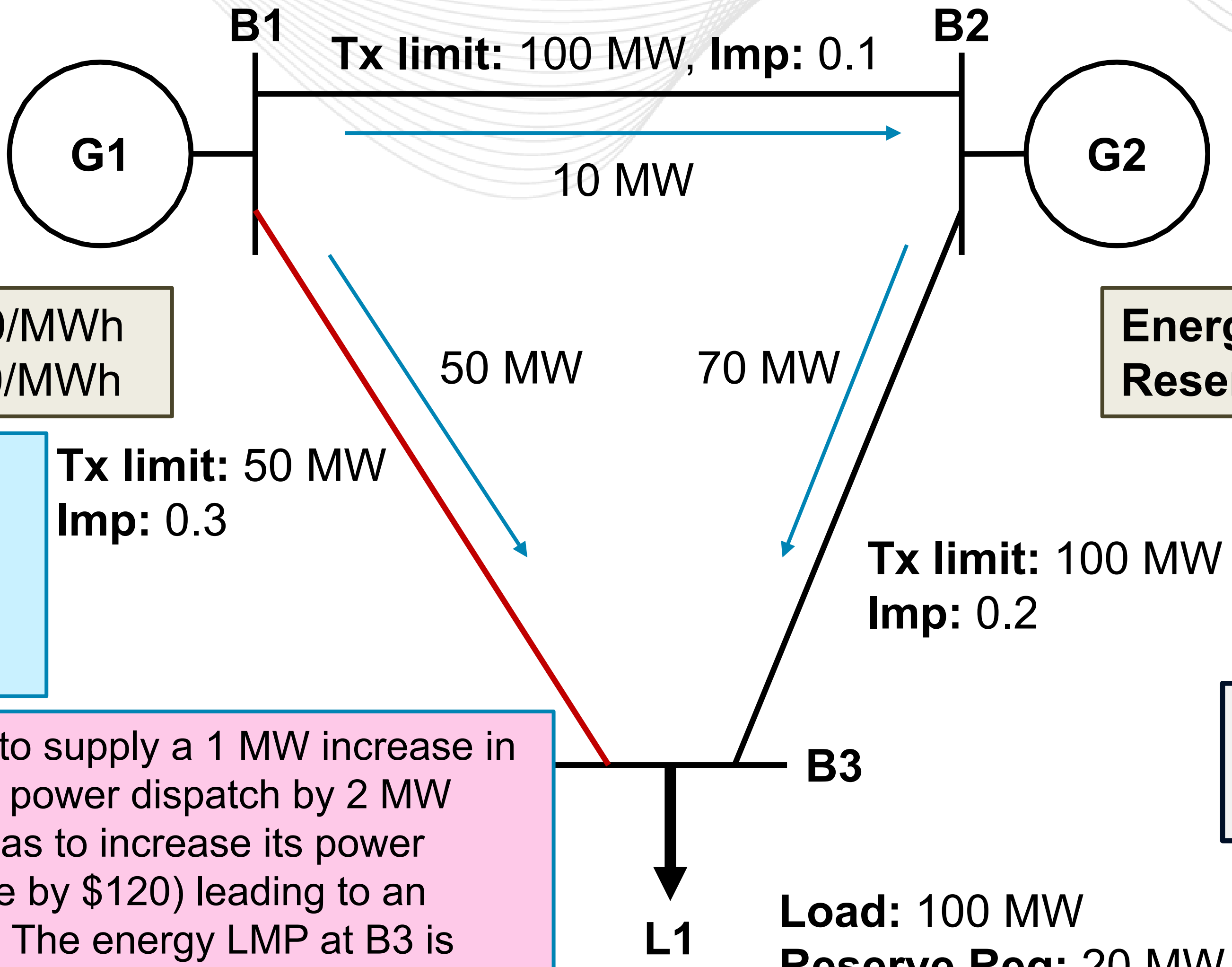
Flows are energy + reserves.

# 3-Bus Example 1: Locational Constraint on Reserves

**Ramp Rate:** 3 MW/min
**EcoMax:** 90 MW
**Energy Offer:** $10/MWh

**Energy:** 50 MWh @ $10/MWh
**Reserves:** 10 MW @ $0/MWh

Since G1 is not binding on headroom (ECOMAX) or ramp rate, the energy price at B1 is $10/MWh (marginal cost of G1) and reserve price is $0/MWh




**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**Energy Offer:** $40/MWh

**Energy:** 50 MWh @ $40/MWh
**Reserves:** 10 MW @ $30/MWh

Flows are energy + reserves.

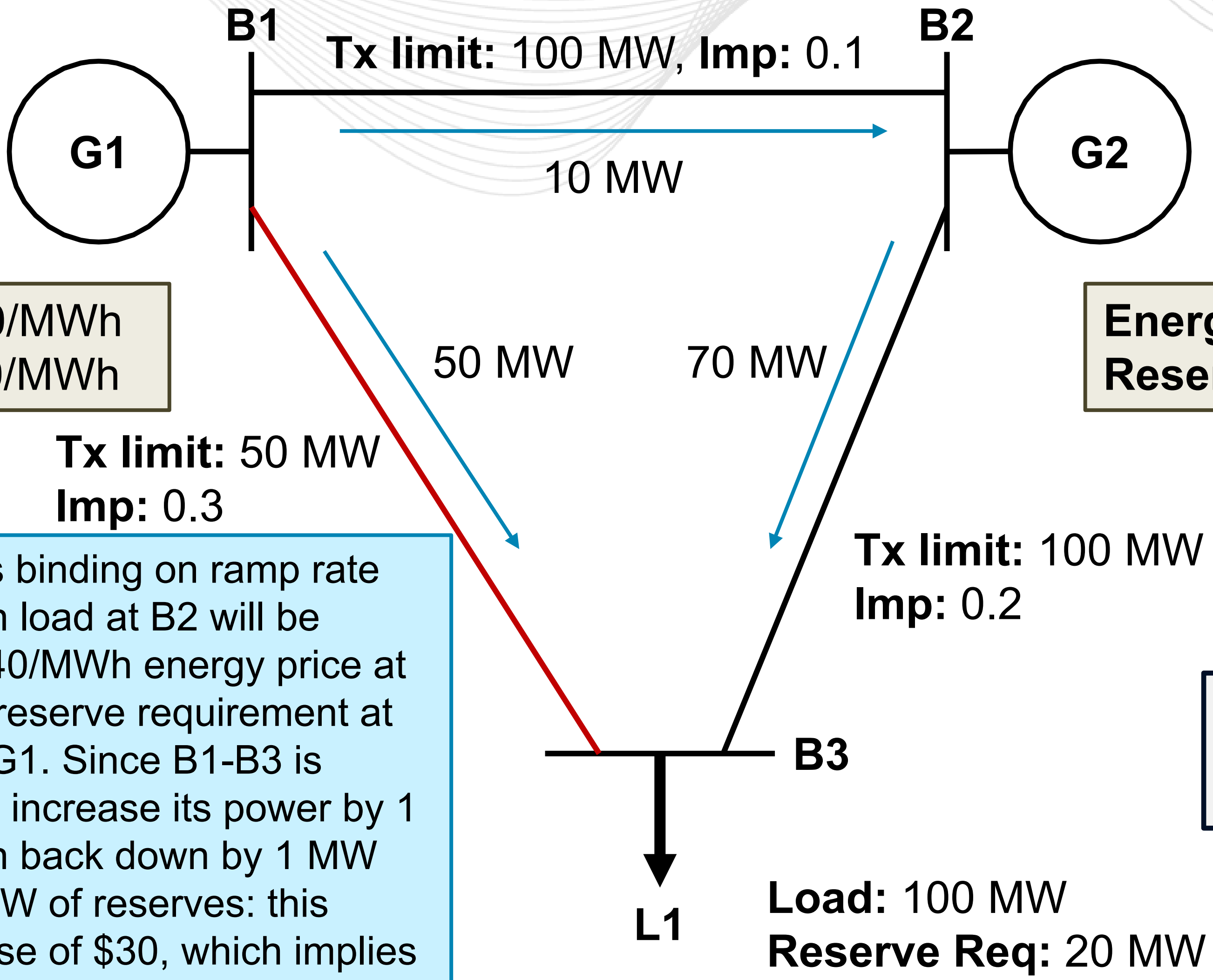
Since B1-B3 flow is at the limit, to supply a 1 MW increase in load at B3, G1 has to reduce its power dispatch by 2 MW (cost reduced by $20) and G2 has to increase its power dispatch by 3 MW (cost increase by $120) leading to an overall increase in cost of $100. The energy LMP at B3 is consequently $100/MWh

**Load:** 100 MW
**Reserve Req:** 20 MW

# 3-Bus Example 1: Locational Constraint on Reserves

**Ramp Rate:** 3 MW/min
**EcoMax:** 90 MW
**Energy Offer:** $10/MWh

**Energy:** 50 MWh @ $10/MWh
**Reserves:** 10 MW @ $0/MWh



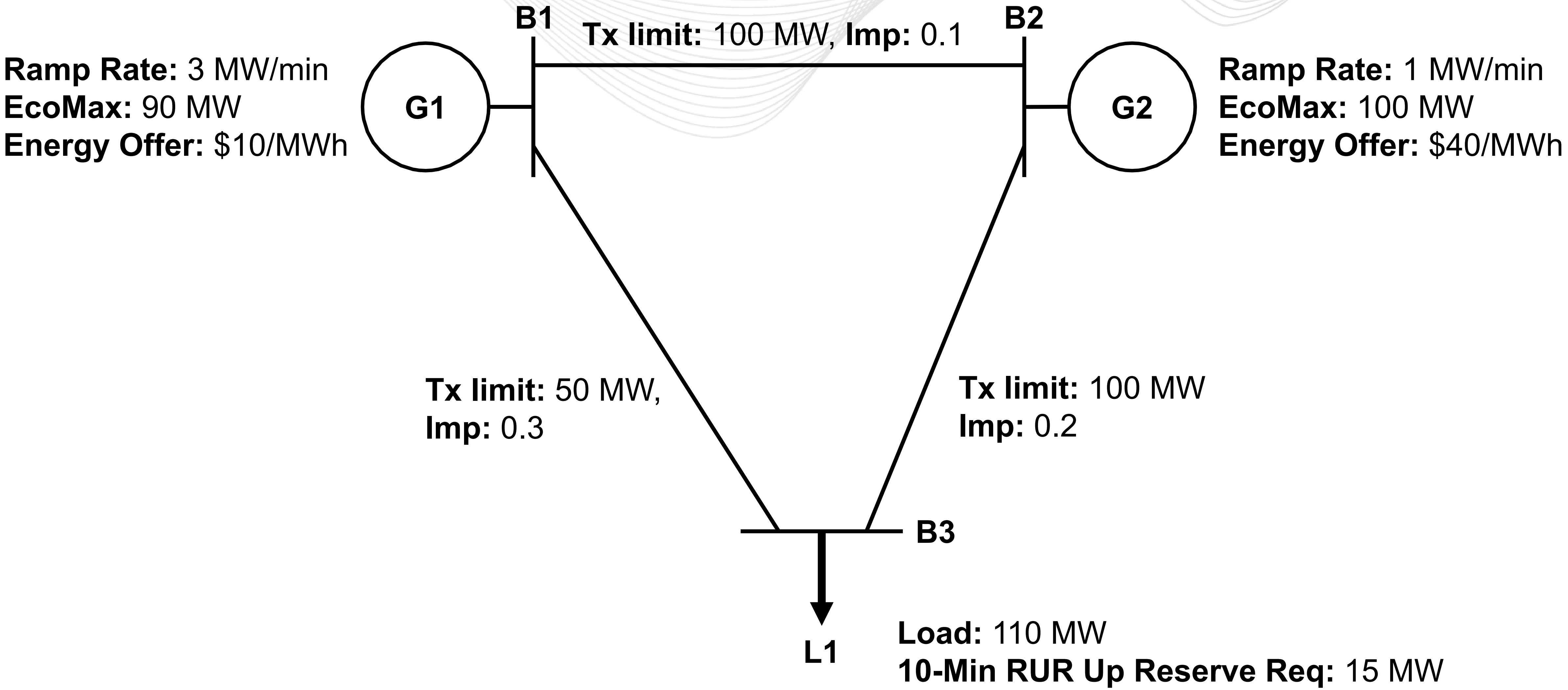

**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**Energy Offer:** $40/MWh

**Energy:** 50 MWh @ $40/MWh
**Reserves:** 10 MW @ $30/MWh

Flows are energy + reserves.

Since G2 has headroom but is binding on ramp rate for reserves, a MW increase in load at B2 will be supplied by G2 leading to a $40/MWh energy price at B2, while a 1 MW increase in reserve requirement at B2 must be supplied through G1. Since B1-B3 is binding, this implies G2 has to increase its power by 1 MW ($40 increase), so G1 can back down by 1 MW ($10 reduction) to provide 1 MW of reserves: this leads to an overall cost increase of $30, which implies that the price of reserves at B2 is $30/MWh

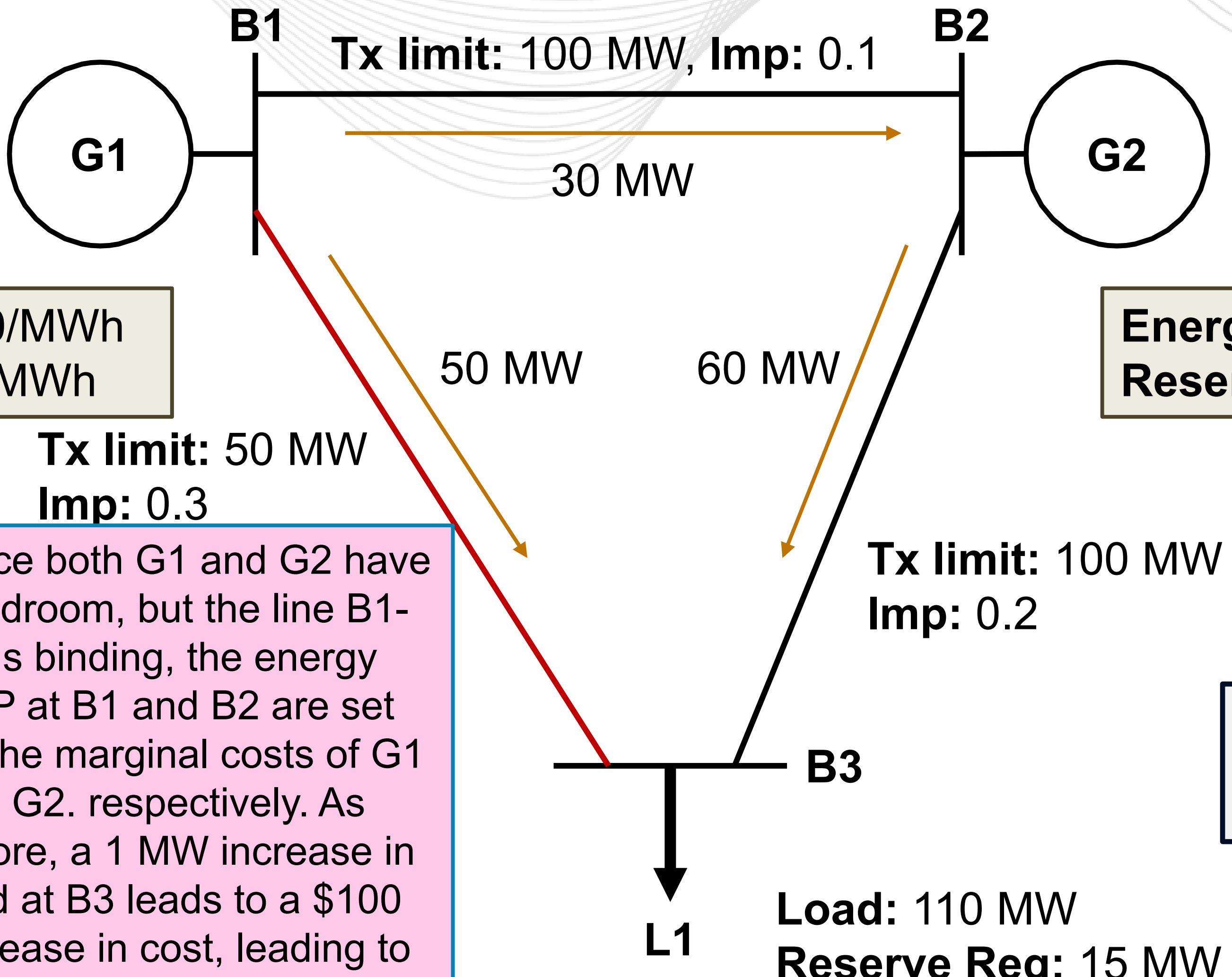
# 3-Bus Example 2: Set-Up



# 3-Bus Example 2: No Locational Constraint on Reserves

**Ramp Rate:** 3 MW/min
**EcoMax:** 90 MW
**Energy Offer:** $10/MWh

**Energy:** 80 MWh @ $10/MWh
**Reserves:** 5 MW @ $0/MWh




**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**Energy Offer:** $40/MWh

**Energy:** 30 MWh @ $40/MWh
**Reserves:** 10 MW @ $0/MWh

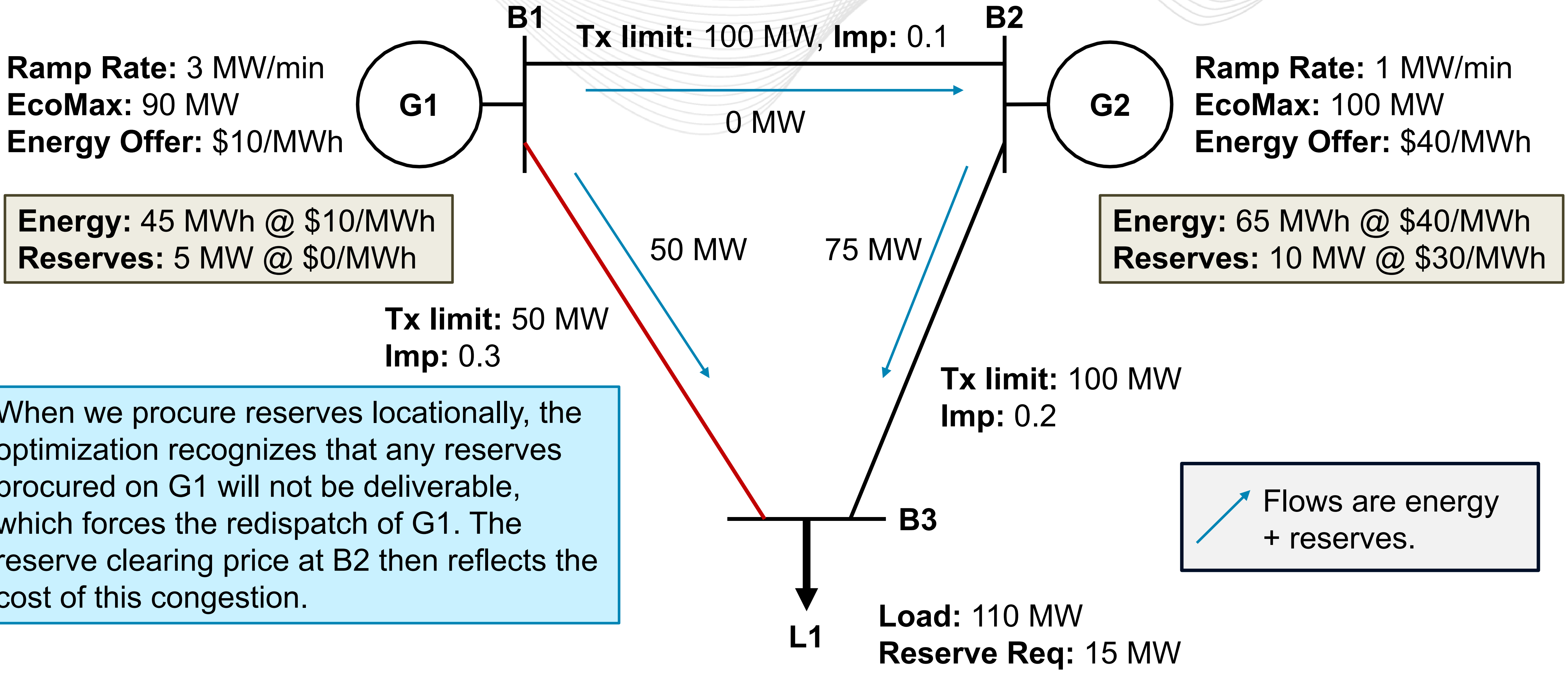
When we don't evaluate the deliverability of the procured reserves, the optimization will assign reserves to G1, despite it being backed down to manage the binding constraint between B1 and B3. These reserves look like free, unloaded headroom at all buses.

Since both G1 and G2 have headroom, but the line B1-B3 is binding, the energy LMP at B1 and B2 are set by the marginal costs of G1 and G2. respectively. As before, a 1 MW increase in load at B3 leads to a $100 increase in cost, leading to LMP at B3 of $100/MWh

**Load:** 110 MW
**Reserve Req:** 15 MW

Flows are energy only.

# 3-Bus Example 2: Locational Constraint on Reserves

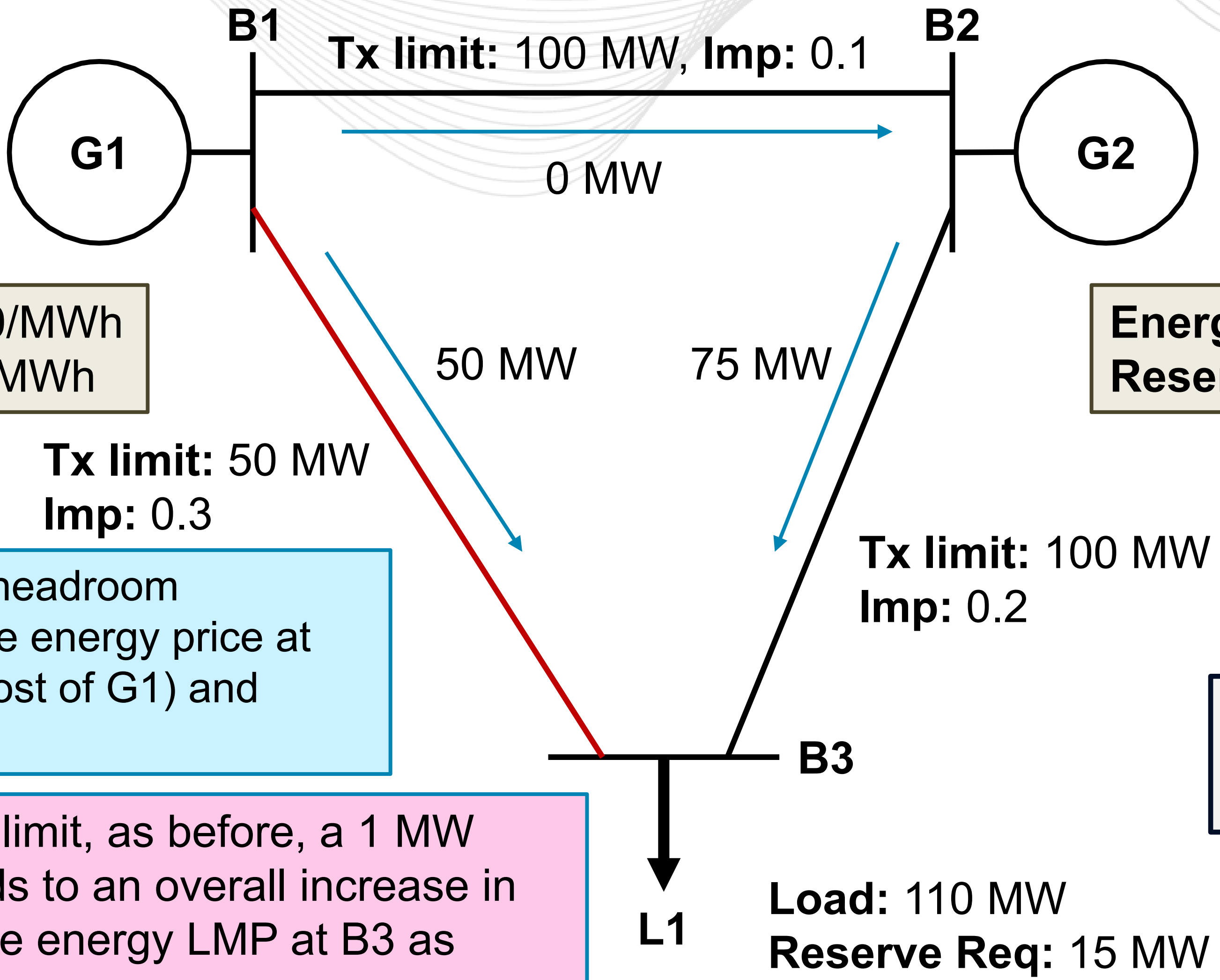



When we procure reserves locationally, the optimization recognizes that any reserves procured on G1 will not be deliverable, which forces the redispatch of G1. The reserve clearing price at B2 then reflects the cost of this congestion.

# **3-Bus Example 2:** Locational Constraint on Reserves

**Ramp Rate:** 3 MW/min
**EcoMax:** 90 MW
**Energy Offer:** $10/MWh

**Energy:** 45 MWh @ $10/MWh
**Reserves:** 5 MW @ $0/MWh




**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**Energy Offer:** $40/MWh

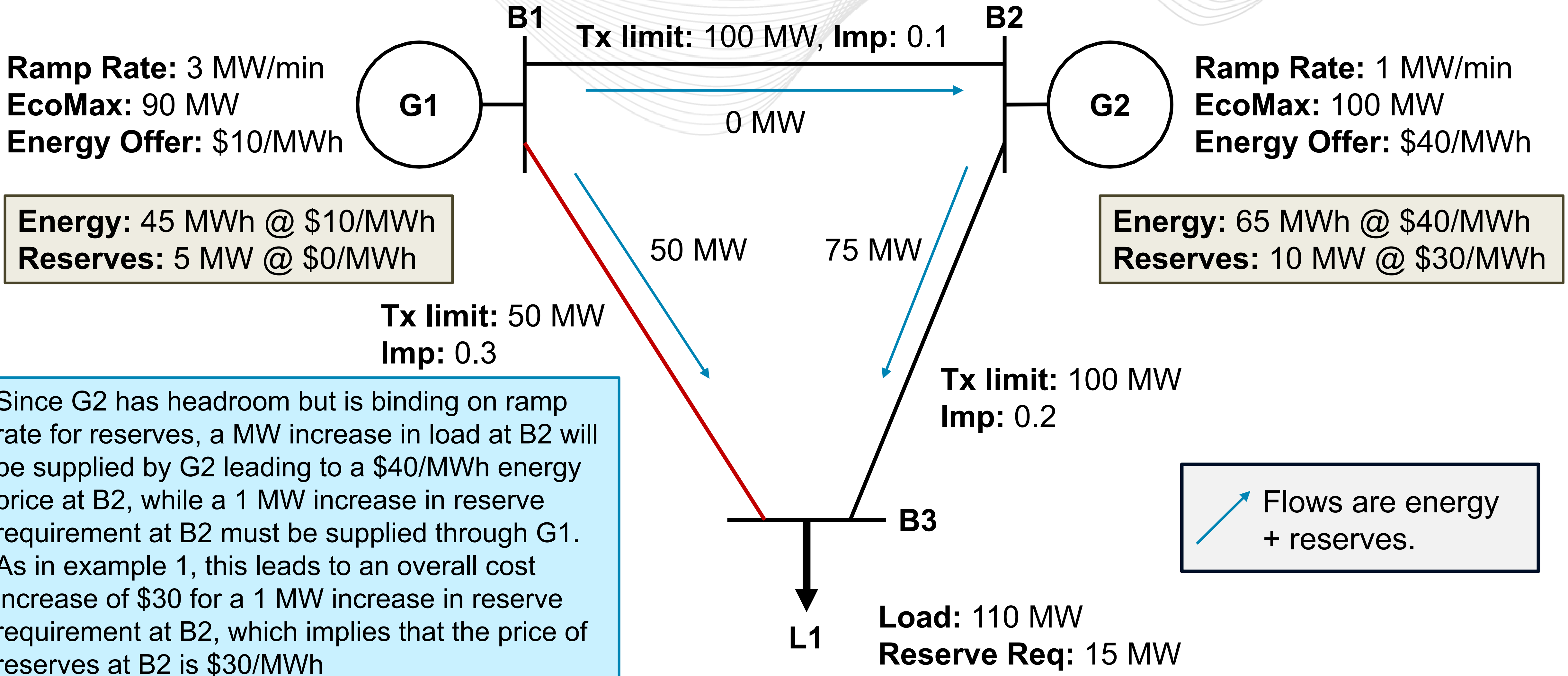
**Energy:** 65 MWh @ $40/MWh
**Reserves:** 10 MW @ $30/MWh

Since G1 is not binding on headroom (ECOMAX) or ramp rate, the energy price at B1 is $10/MWh (marginal cost of G1) and reserve price is $0/MWh

Since B1-B3 flow is at the limit, as before, a 1 MW increase in load at B3 leads to an overall increase in cost of $100. This gives the energy LMP at B3 as $100/MWh

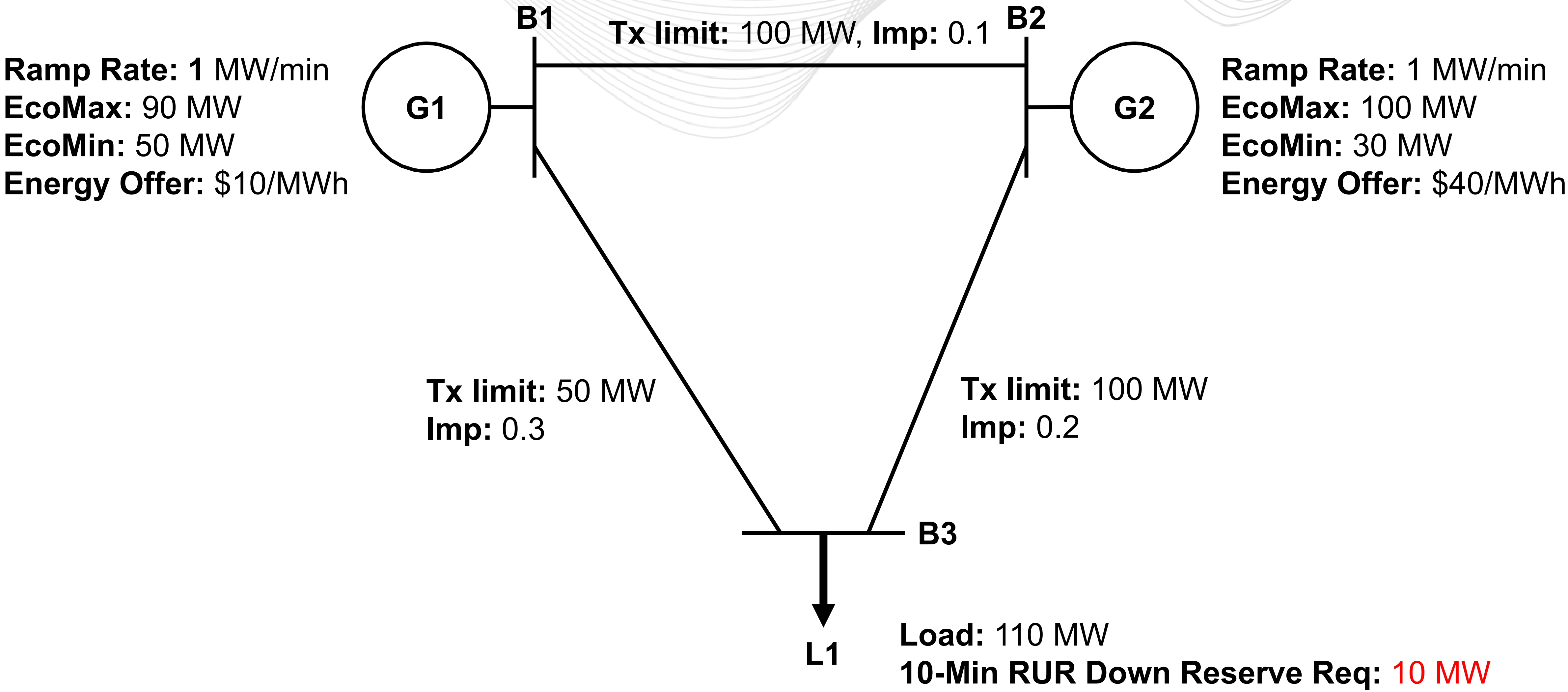
Flows are energy + reserves.

# 3-Bus Example 2: Locational Constraint on Reserves




Since G2 has headroom but is binding on ramp rate for reserves, a MW increase in load at B2 will be supplied by G2 leading to a $40/MWh energy price at B2, while a 1 MW increase in reserve requirement at B2 must be supplied through G1. As in example 1, this leads to an overall cost increase of $30 for a 1 MW increase in reserve requirement at B2, which implies that the price of reserves at B2 is $30/MWh

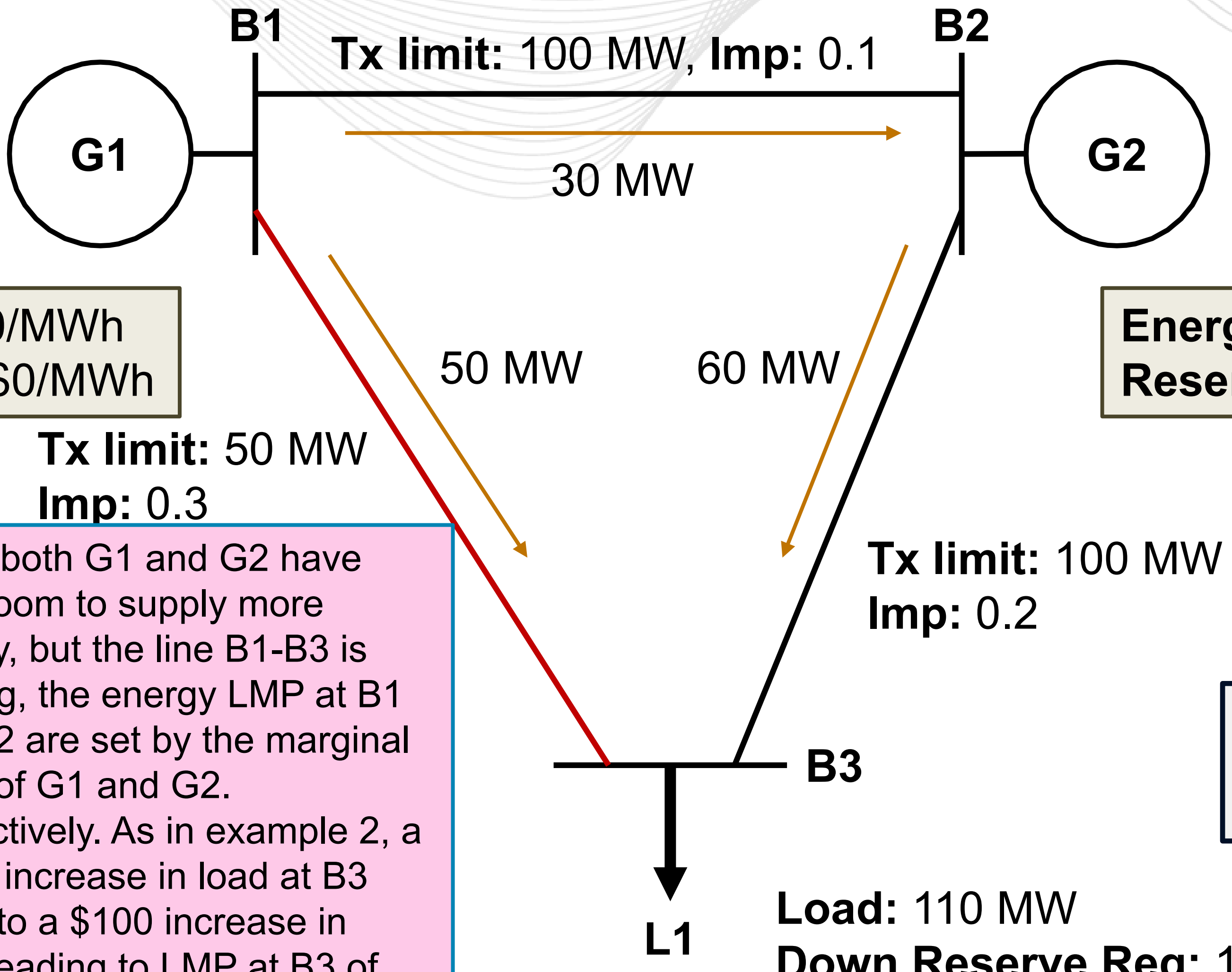
# **3-Bus Example 3:** Set-Up with Lower 10-Min RUR Down Req.



# 3-Bus Example 3: Dispatch and Pricing with Down RUR

**Ramp Rate:** 1 MW/min
**EcoMax:** 90 MW
**EcoMin:** 30 MW
**Energy Offer:** $10/MWh

**Energy:** 80 MWh @ $10/MWh
**Down RUR:** 10 MW @ $0/MWh




**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**EcoMin:** 30 MW
**Energy Offer:** $40/MWh

**Energy:** 30 MWh @ $40/MWh
**Reserves:** 0 MW @ $0/MWh

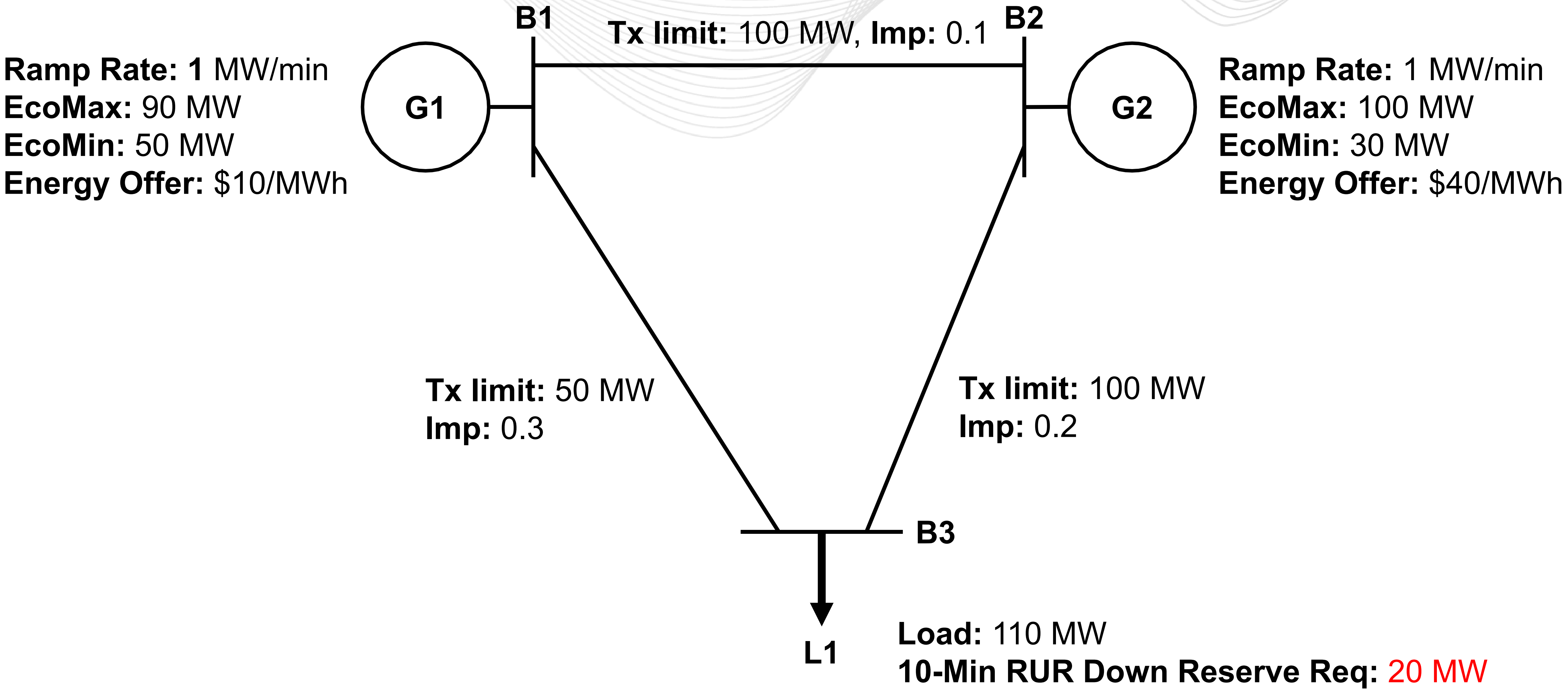
Due to the binding on B1-B3, the cost minimizing energy dispatch provides ample room on G1 (with respect to ECOMIN) to satisfy the Down RUR requirement. Consequently, the reserve clearing price is $0. The locational constraints do not bind on energy + down RUR

Since both G1 and G2 have headroom to supply more energy, but the line B1-B3 is binding, the energy LMP at B1 and B2 are set by the marginal costs of G1 and G2. respectively. As in example 2, a 1 MW increase in load at B3 leads to a $100 increase in cost, leading to LMP at B3 of $100/MWh

**Load:** 110 MW
**Down Reserve Req:** 10 MW

Flows are energy only.

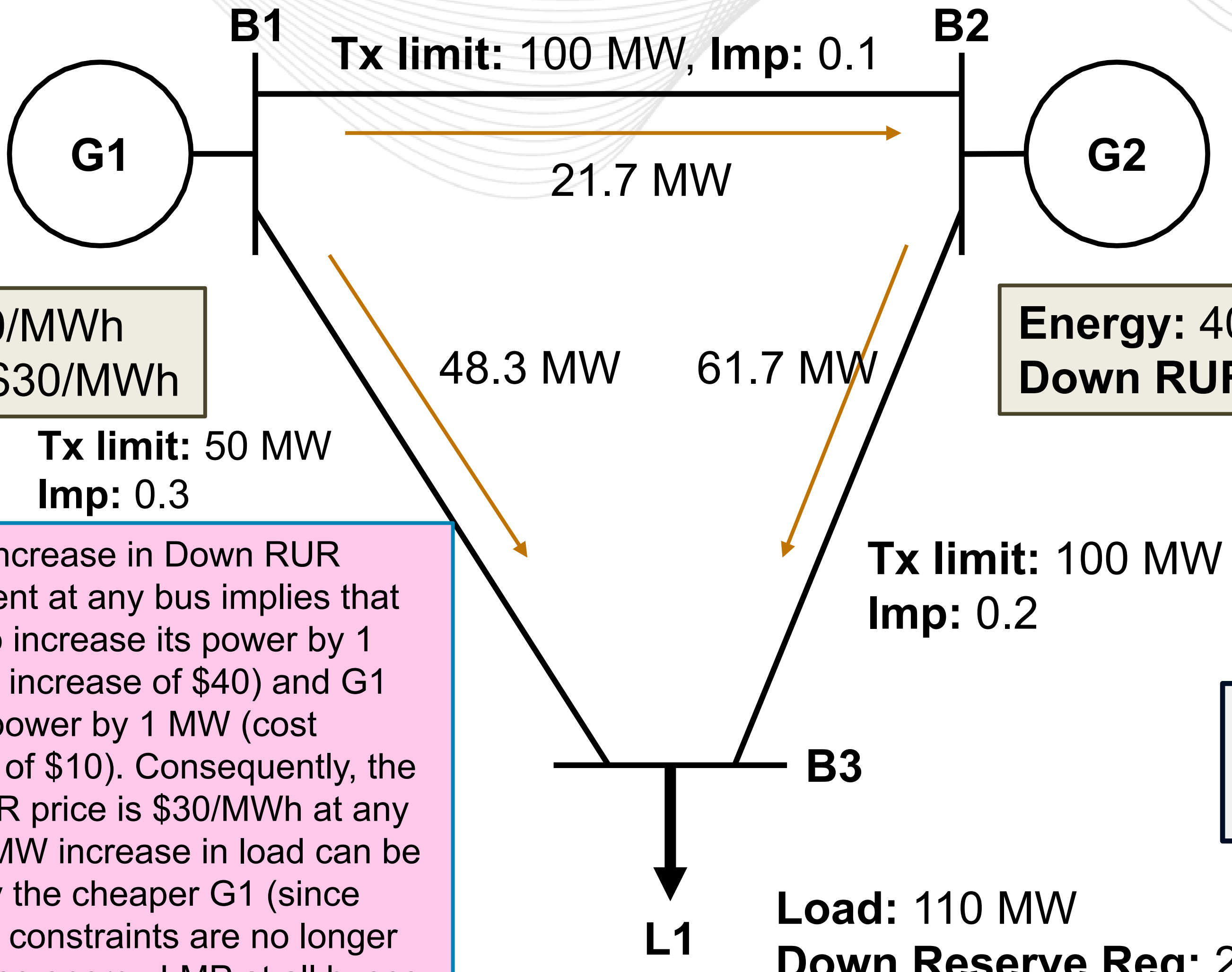
# **3-Bus Example 4:** Set-Up with Higher 10-Min RUR Down Req.



# 3-Bus Example 4: Dispatch and Pricing with Down RUR

**Ramp Rate:** 1 MW/min
**EcoMax:** 90 MW
**EcoMin:** 30 MW
**Energy Offer:** $10/MWh

**Energy:** 70 MWh @ $10/MWh
**Down RUR:** 10 MW @ $30/MWh




**Ramp Rate:** 1 MW/min
**EcoMax:** 100 MW
**EcoMin:** 30 MW
**Energy Offer:** $40/MWh

**Energy:** 40 MWh @ $10/MWh
**Down RUR:** 10 MW @ $30/MWh

Due to ramp rate constraints, the cheaper G1 can only provide 10 MW of down RUR. The remaining 10 MW has to come from G2; therefore, G2 has to increase its power (energy) 10 MW above its ECOMIN. This redispatch implies locational constraints no longer bind, and there is no price separation.

A 1 MW increase in Down RUR requirement at any bus implies that G2 has to increase its power by 1 MW (cost increase of $40) and G1 reduces power by 1 MW (cost decrease of $10). Consequently, the down RUR price is $30/MWh at any bus. A 1 MW increase in load can be served by the cheaper G1 (since locational constraints are no longer binding), so energy LMP at all buses is $10/MWh

**Load:** 110 MW
**Down Reserve Req:** 20 MW

Flows are energy only. Energy & down RUR flows are lower.

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**Additional Details on PJM's Proposed Solutions for Locational Reserves**

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# Acronyms

| Acronym | Term & Definition |
|---|---|
| SR | **Synchronized Reserves** are reserves provided by resources that are synchronized to the grid and can respond within 10 minutes. |
| RUR | **Ramp/Uncertainty Reserves** are reserves procured to meet expected net-load ramp and to manage net-load forecast uncertainty in upcoming intervals. |


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