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Production Cost Model Fundamentals

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Outline

- What is a Production Cost Model?
- Basics of Security Constrained Economic Dispatch
- What is PROMOD?
- PowerBase Database
- PROMOD Input Files and Assumptions
- PROMOD Output
- Economic Benefits Calculation
- PROMOD GUI Demo

What is a Production Cost Model?

What is a Production Cost Model?

- Captures all the costs of operating a fleet of generators
  - Originally developed to manage fuel inventories and budget in the mid 1970's
- Developed into an hourly chronological security constrained unit commitment and economic dispatch simulation
  - Minimize costs while simultaneously adhering to a wide variety of operating constraints.
  - Calculate hourly production costs and location-specific market clearing prices.

What Are the Advantages of Production Cost Models?

- Allows simulation of all the hours in a year, not just peak hour as in power flow models.
- Allows us to look at the net energy price effects through
  - LMP's and its components.
  - Production cost.
- Enables the simulation of the market on a forecast basis
- Allows us to look at all control areas simultaneously and evaluate the economic impacts of decisions.

Disadvantages of Production Cost Models

- Require significant amounts of data
- Long processing times
- New concept for many Stakeholders
- Require significant benchmarking
- Time consuming model building process
  - Linked to power flow models
- Do not model reliability to the same extent as power flow

Production Cost Model vs. Power Flow

- **Production Cost Model**
  - SCUC&ED: very detailed
  - All hours
  - DC Transmission
  - Selected security constraints
  - Market analysis/ Transmission analysis/planning
- **Power Flow**
  - Hand dispatch (merit Order)
  - One hour at a time
  - AC and DC
  - Large numbers of security constraints
  - Basis for transmission reliability & operational planning

Basics of
Security Constrained
Economic Dispatch

What is covered in this section

- Understanding constrained dispatch
- Shift factor concept
- Shadow price of constraints
- LMP calculation and its components;

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Economic Dispatch Formulation

$$Min\sum_{i=1}^{N} C_i \cdot P_{gi}, \quad \text{Objective function – total cost}$$

$$S.T.$$

$$\sum_{i=1}^{N} P_{gi} - \sum_{j=1}^{L} P_{lj} - Loss = 0, \quad \text{System Balance}$$

$$\sum_{1}^{N} S_{ki} \cdot P_{gi} \le T_k^{\max}, k = 1, 2, ..., K, \quad \text{Transmission Constraints}$$

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max}, i = 1, 2, ..., N, \quad \text{Capacity Constraints}$$

Where S_{ki} is a shift factor of branch k to the generator i,
C_i is an incremental price of energy at the generator i.

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Economic Dispatch Solution

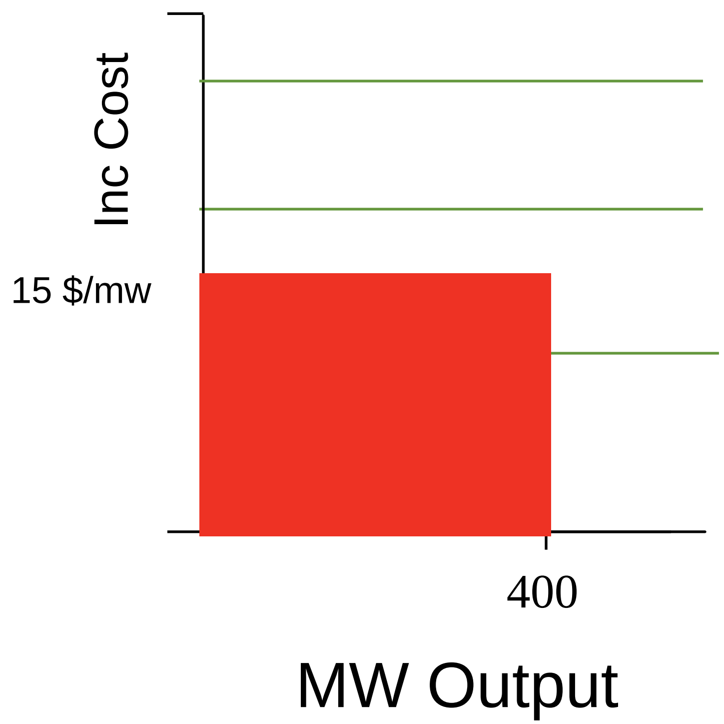
- Non-linear optimization problem
- Quick Solution Using Linear Programming (LP)
- Desired generation dispatch for every dispatchable generator.
- Shadow prices corresponding to each constraint.
- Binding constraints

Shift Factor

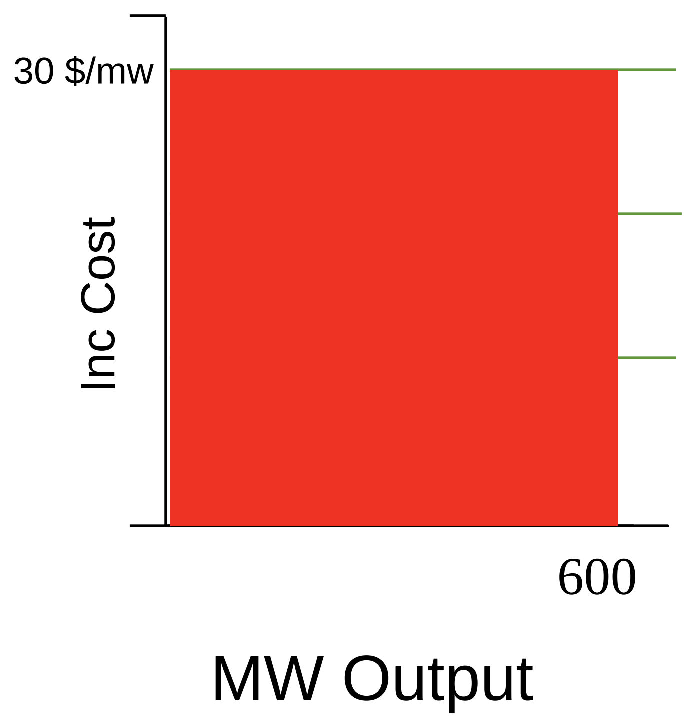
- Shift Factor (SF) shows how the flow in the branch will change if the injection at the bus changes by one (1) MW.
- All shift factors are computed relative to the reference bus, shift factor is dependent on the location of the reference bus.
- The shift factor at the reference bus equals to zero.
- Shift factors are solely dependent on the network topology and impedance.

Five Bus System Example - Generation Cost

Incremental Cost Unit 1



Incremental Cost Unit 5



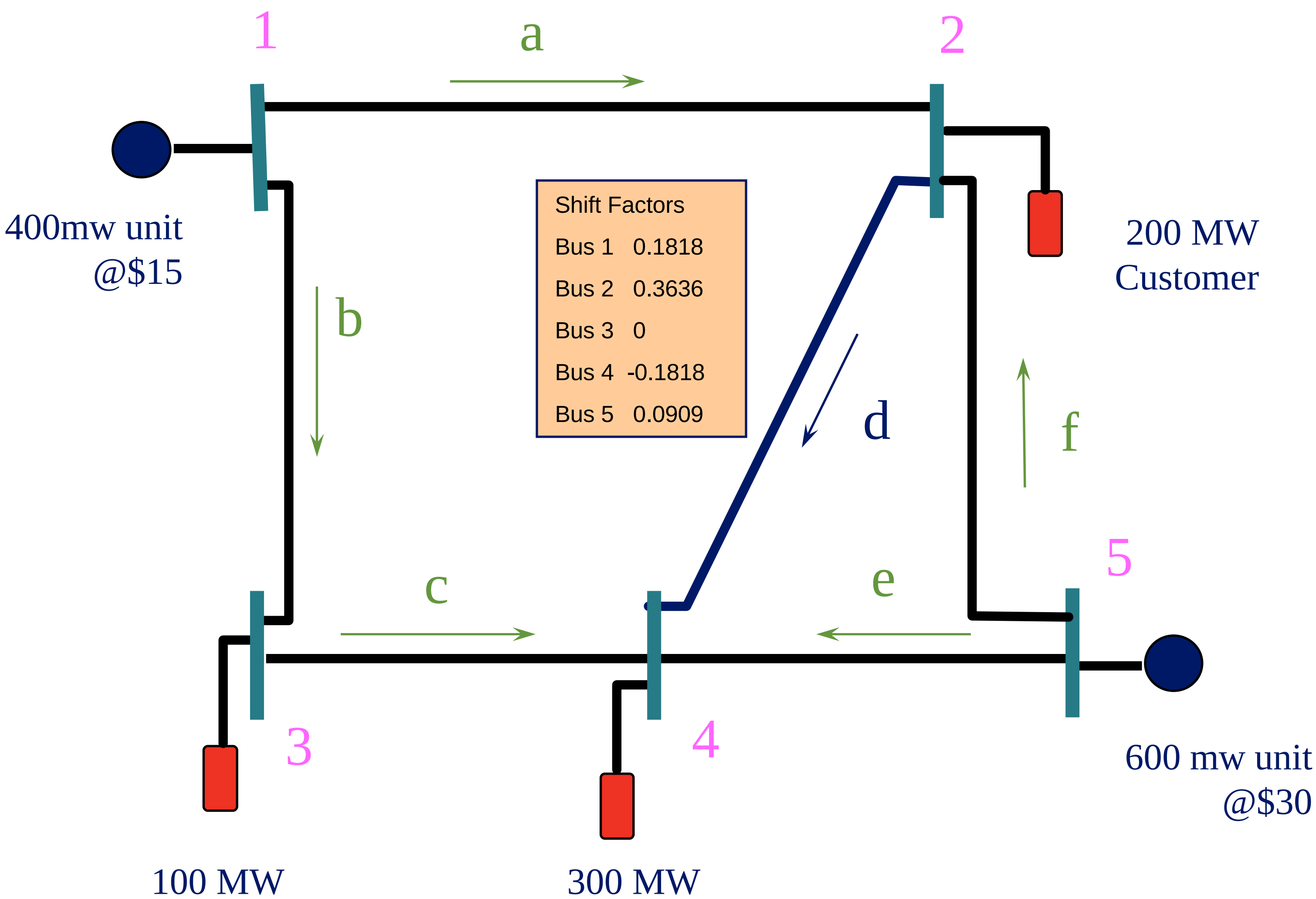
Economic Dispatch (No Transmission)

Load: 600 MW

G_1 = 400 MW
G_5 = 200 MW (Marginal)

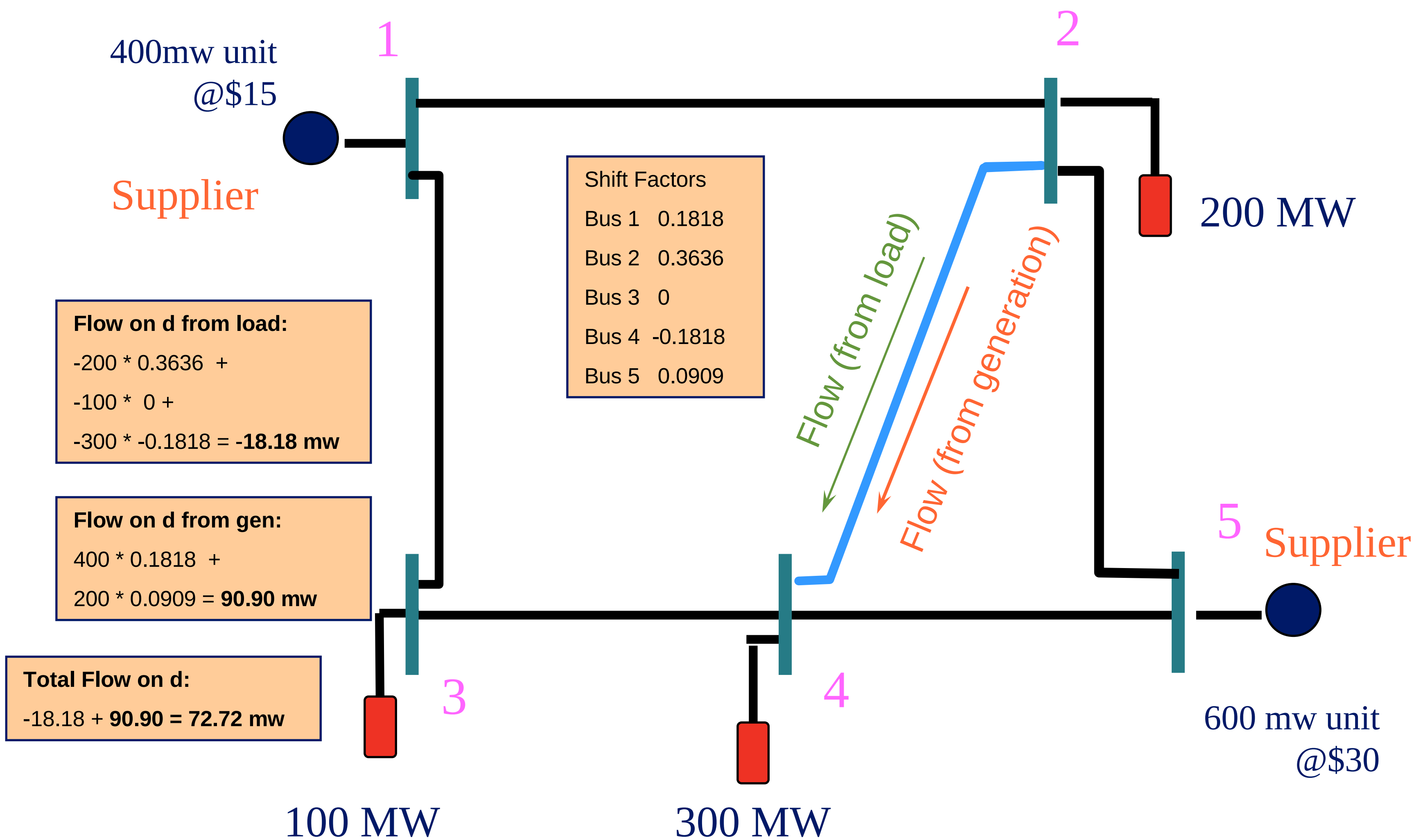
Cost = 400 x \$15 + 200 x \$30 = \$12,000

5 Bus Power Network



Shift Factors	
Bus 1	0.1818
Bus 2	0.3636
Bus 3	0
Bus 4	-0.1818
Bus 5	0.0909

5 Bus Power Network



Flow "d" Components

Load Component → -18.18; Shift Factors → $.1818$, $.0909$

Flow on Line d	=	-18.18	+	.1818	G_1	+	.0909	G_5
	=	-18.18	+	.1818	400	+	.0909	200
	=	-18.18	+	72.73		+	18.18	
	=	72.73	Megawatts total flow					

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Transmission Constraint Applied

If d_{max} = 50 MW , the dispatch is *not acceptable!*

Flow: $d = -18.18 + .1818\, G_1 + .0909\, G_5 = 50$

Load Balance: $G_1 + G_5 = 600$

$G_1 = 150$

$G_5 = 450$

Cost = $15,750

→ *Both Marginal !*

Constraint Shadow Price

- What if the constraint were 51 mw?
- The *incremental increase* in cost is the shadow price

Flow:	$d = -18.18 + .1818\ G_1 + .0909\ G_5 = 51$
Load Balance:	$G_1 + G_5 = 600$

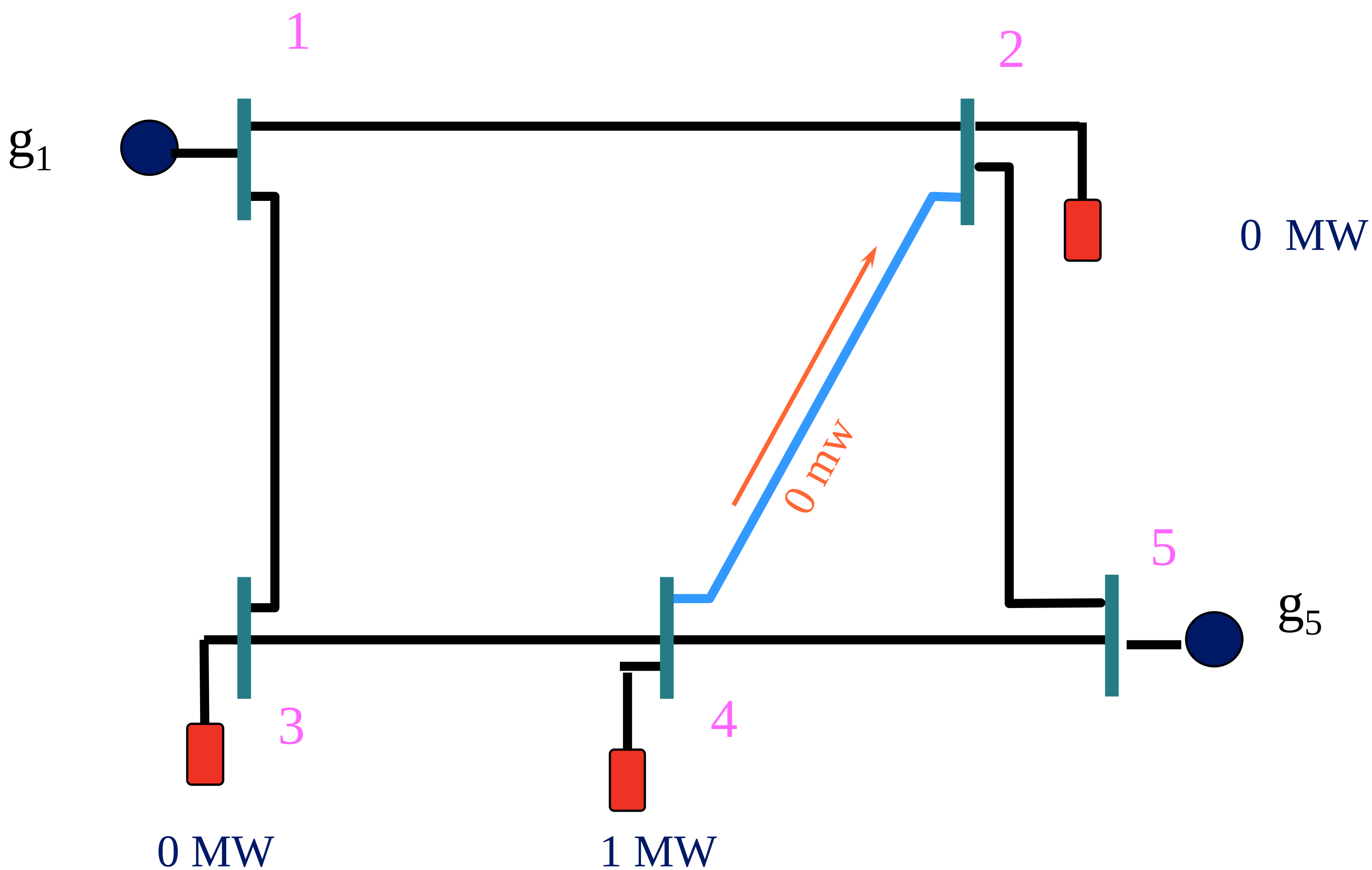
Cost = $15,585 G1=161MW, G5=439MW

Shadow price = 15,585 – 15,750 = -165 $/mw

Bus Locational Marginal Prices

- How much will the next mw *of load* cost?
  - Is it simply the marginal unit cost?
- LMP definition:
  - A change in the total cost of production due to increment of load at this location.
- Bus LMPs can be calculated by adding one MW of load at each bus and determining the corresponding change in the total production cost

5 Bus System Incremental Network



The Incremental Flow Equation

- The change in generation must result in zero flow change
- Power changes at the marginal units, and at the load bus
- The sum of power change must be zero

Bus 4: Add 1 MW Load

New flow equation...

$$.1818\, g_1 + .0909\, g_5 - .1818\,(-1) = 0$$

Incremental Equations

Load Balance: $g_1 + g_5 = 1$

Flow "d" : $.1818\, g_1 + .0909\, g_5 = -\,.1818$

Solution: $g_1 = -3$

$g_5 = +4$ *(wow !)*

$\text{Imp} = -3 \times \$15 + 4 \times \$30 = 75$ $/mw

Price at Bus 2

Bus 2: Add 1 MW Demand.
New equations...

$$.1818\, g_1 + .0909\, g_5 + .3636\,(-1) = 0$$

$$g_1 + g_5 = 1$$

Solution: $g_1 = 3$

$g_5 = -2$

Imp = $3 \times 15 - 2 \times 30 = -15$ \$/mw (!)

What about Bus 3 (slack bus)?

Bus 3: Add 1 MW Demand.
New equations...

$$.1818\, g_1 + .0909\, g_5 + .0000\,(-1) = 0$$
$$g_1 + g_5 = 1$$

Solution: $g_1 = -1$

$g_5 = +2$

Imp = (-1*15) + (2*30) = 45 $/mw

Buses 1 and 5?

- These are the “price setting buses”
- LMP at these buses will be the gen price
- LMP_1 = $15
- LMP_5 = $30

LMP Calculation

- LMP at any location is calculated based on the shadow prices out of LP solution.
- The following fundamental formula is used to calculate LMPs. For any node *i*:

$$\lambda_i = \lambda - LF_i \cdot \lambda + \sum_{k=1}^{K} S_{ik} \cdot \mu_k ,$$

- $\sum_{k=1}^{K} S_{ik} \cdot \mu_k$ → **Congestion Component**
- $LF_i \cdot \lambda$ → **Loss Component**
- λ → **Energy Component**

where λ is a shadow price of the system balance constraint.

5 Bus System – LMP Calculation using Shadow Price

Bus	Shift Factor
1	0.1818
2	0.3636
3	0.0000
4	-0.1818
5	0.0909

-165	45
-30.000	15.000
-60.000	-15.000
0.000	45.000
30.000	75.000
-15.000	30.000

$$\lambda_i = \lambda - LF_i \cdot \lambda + \sum_{k=1}^{K} S_{ik} \cdot \mu_k ,$$

What is PROMOD

Background

- PROMOD is a Production Cost Model developed by Ventyx (Formerly known as NewEnergy Associates, A Siemens Company).
- Detailed generator portfolio modeling, with both region zonal price and nodal LMP forecasting and transmission analysis including marginal losses

How PROMOD Works - PROMOD Structure

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PSS/E™

PowerWorld

NewEnergy PowerBase

Common API

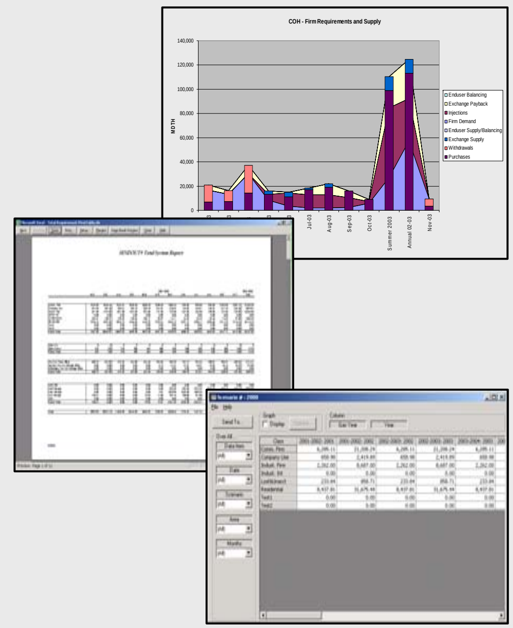
Common Data Source

NewEnergy PROMOD IV®

- Detailed unit commitment and dispatch
- Detailed transmission simulation
- Asset Valuation with MarketWise
- FTR Valuation with TAM

Report Agent

Visualization & Reporting



Access, Excel, Pivot Cube…

- Easy-to-use interface
- Powerful scenario management
- Complete NERC data with solved powerflow cases

How PROMOD Works – Input and Output of PROMOD

- Generation Data: heat rate, different costs, etc.
- Demand & Energy
- Fuel Forecasts: Gas, Coal, Oil
- Environmental Costs: Sox, Nox, Mercury
- Power Flow Case
- Monitored Flowgates
- Other Information: reserve requirement, market territory, etc.

PROMOD

- Hourly LMP of buses and hubs, include energy, loss and congestion components.
- Hourly unit generation and production cost
- Hourly binding constraints and shadow prices
- Hourly line flows
- Hourly company purchase/sale
- Environmental emissions.
- Fuel consumptions.
- etc.

Magnitude of the Challenge

Real System Dimensions –

MTEP 08 PROMOD Cases

- Footprint: East interconnection excluding FRCC
- Generators: ~ 4,700
- Buses: ~ 47,500
- Branches: ~ 60,000
- Monitored Lines: ~ 1,500
- Contingencies: ~ 500
- Run Time: 60-90 Hrs (for one year 8760 hours)

Powerbase Database

Data in PowerBase

- Generation
- Demand & Energy
- Transmission Network Data
- Fuel Forecasts
  - Coal, Uranium, Gas, Coal, Oil
- Environmental Effluent and Costs
  - CO2, Sox, Nox, Mercury

PROMOD Input Files and Assumptions

PROMOD input files

- PFF file
  - Main input file, includes units, fuels, environmental and transmission data, pool configuration, reserve requirement, run option switches, etc.
- Load data file
  - Hourly load profiles for each company for a selected study period.
  - Based on the 8760 hour load shape and each year's peak load and annual energy for each company defined in PowerBase.
- Gen Outage Library and automatic maintenance schedule
  - Same outage library and maintenance schedule used by all cases

PROMOD input files

- Event files
  - Define the monitored line/contingency pairs which are the transmission constraints
  - Combine MISO and NERC Book of Flowgates
  - Modify existing events or add new events according to member's comments.
  - Create new events which have the potential of overflow using PAT tool

PROMOD Assumptions

- Study Footprint
  - East interconnection excluding Florida
  - Hourly fixed transactions modeled to include the influence of external areas to the study footprint
    - SETRANS sale to Florida

PROMOD Assumptions (Cont')

- Pool Definition
  - a group of companies in which all its generators are dispatched together to meet its loads.
  - Hurdle rates are defined between pools to allow the energy exchange between pools.
  - Hurdle rates are based on the filed transmission through-and-out rates, plus a market inefficiency adder.
  - In current MISO cases, 11 pools are defined: MISO, PJM, TVA, MRO, East Canada, SPP, IMO, MHEB, ISONE,NYISO,SERC

PROMOD Assumptions (Cont')

- Loss Calculation
  - Option1: Load is equal to actual load plus loss. Loss and LMP loss component are not calculated.
  - Option 2: Load is equal to actual load plus loss. Loss is not calculated while LMP loss component is calculated using an approximation method – Single Pass Loss Calculation.
  - Option 3: Load is equal to actual load. Loss and LMP loss component are calculated – Multi Pass Loss Calculation. Run time is 4 times of Option 2.

Option 2 is used in MISO PROMOD cases.

PROMOD Assumptions (Cont')

- Wind Units – fixed load modifier transactions
  - Set at a same capacity factor for every hour (~ 33%);
  - Set different capacity factors for different months (15% for summer months, and 20% for winter months);
  - Set hourly profile for each unit to capture geographical diversity.
- Smelter Loads modeled as transactions

PROMOD Output

PROMOD Output

- LMPs (include the energy, loss and congestion components):
  - Hourly LMP of selected buses, defined hubs.
  - Hourly Load Weighted and Gen Weighted LMP of defined zones.
- Constraints:
  - Hourly shadow price;
  - Number of hours at Pmax, total shadow price at Pmax;
  - Number of hours at Pmin, total shadow price at Pmin;

PROMOD Output (Cont')

- Generators:
  - Hourly generation
  - Hourly production cost (sum of fuel, variable O&M, environmental cost)
  - Hourly fuel consumption, BTU consumption
  - Hours on line, hours of startup, hours at margin, Hours profitable.
  - Monthly variable O&M cost, fuel cost, emission, and emission cost.

PROMOD Output (Cont')

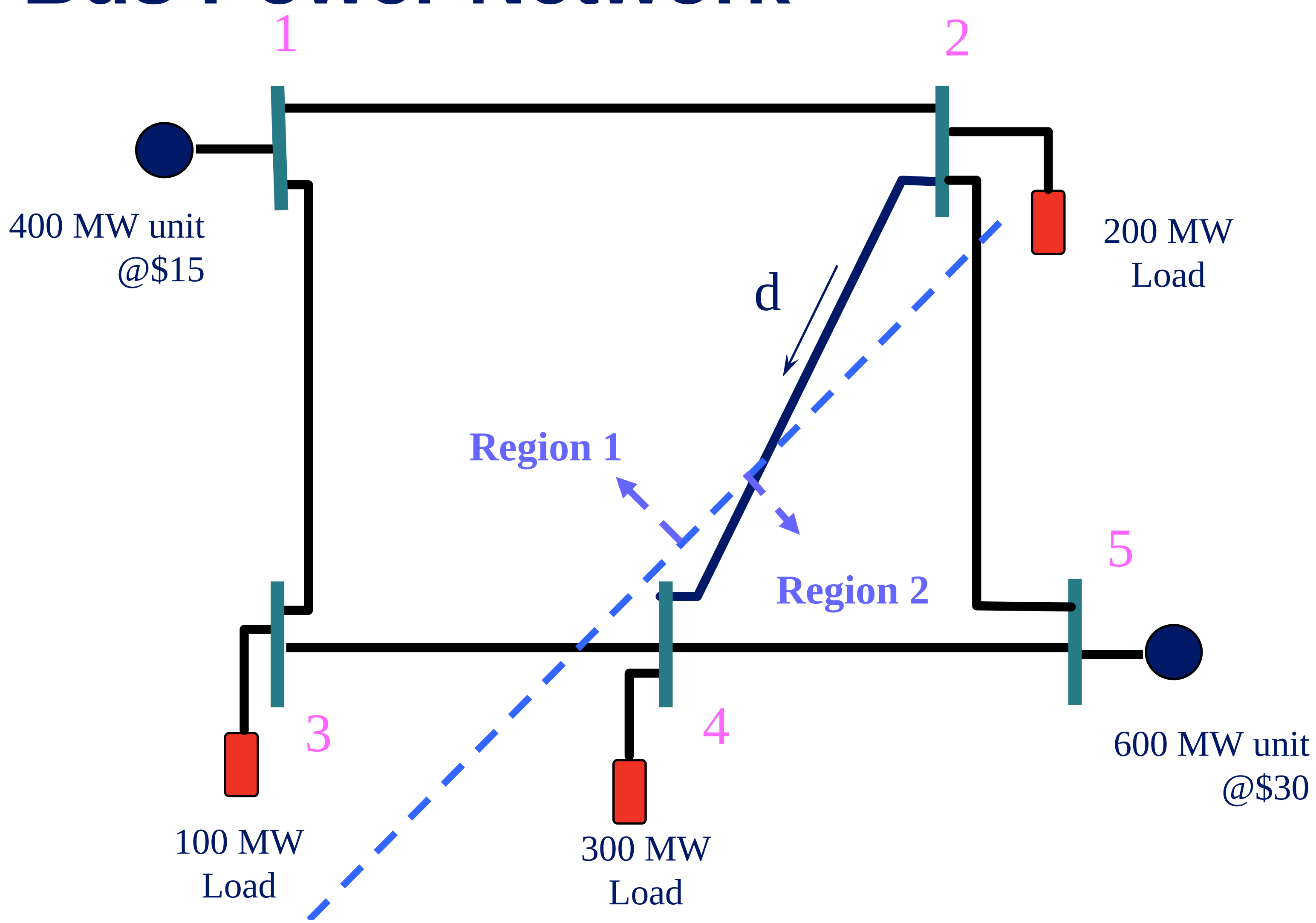
- Fuel:
  - Hourly fuel consumption.
- Power Flow:
  - Hourly flow for selected lines, interfaces, and DC lines.
  - Monthly transmission losses (only for marginal loss calculation option)
- Company:
  - Hourly purchase/sale.
  - Hourly dump and emergency energy.

Economic Benefits Calculation

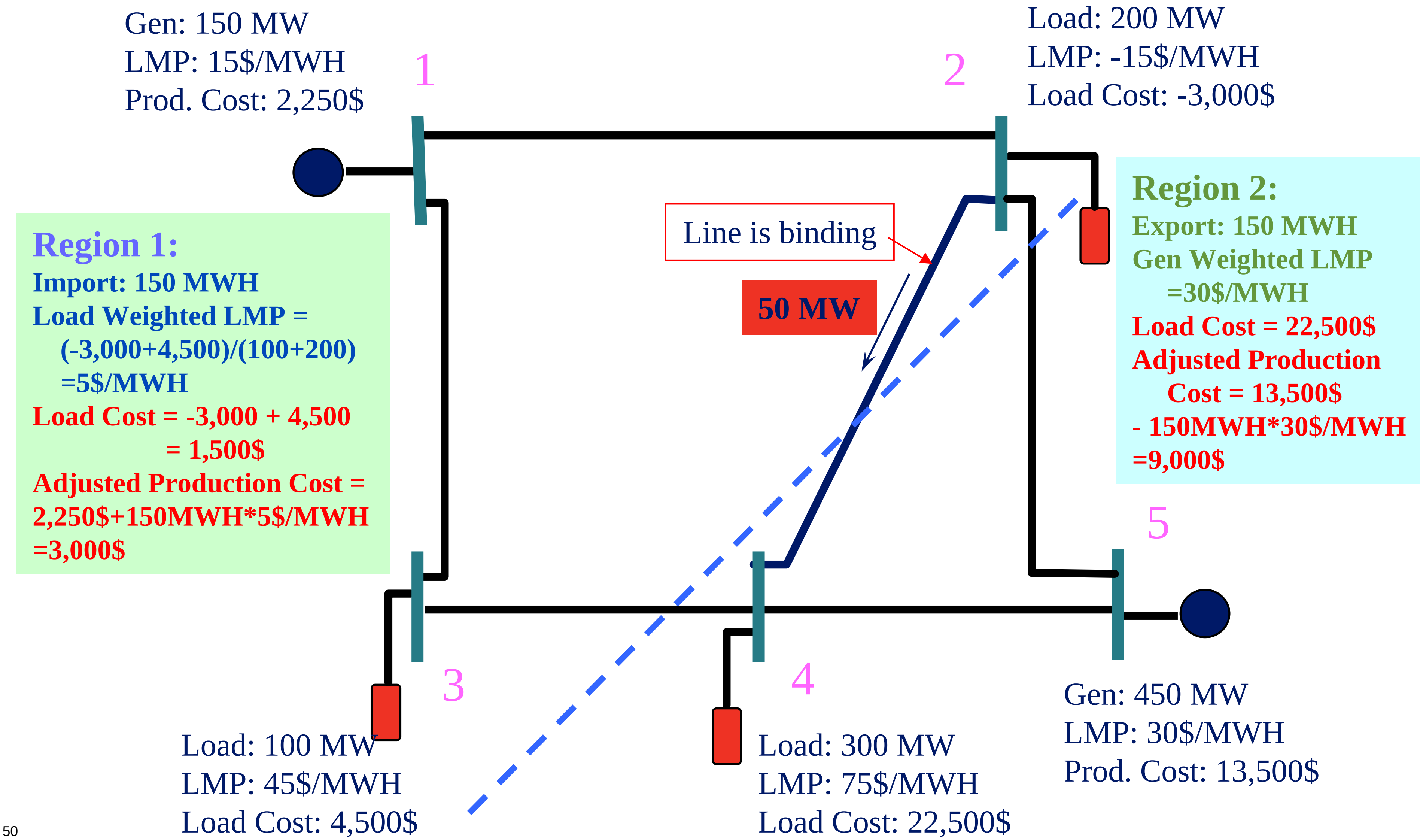
Economic Benefit

- To capture the economic benefit of transmission upgrade: run two PROMOD cases, one with transmission upgrade, one without. For each case, calculate (for each region):
  - Load Cost = Load LMP * Load
  - Adjusted Production Cost = Production Cost + Import * Load Weighted LMP (or) - Export *Gen Weighted LMP
- Economic Benefit:
  - Load Cost Saving: Load Cost difference between two cases;
  - Adjusted Production Cost Saving: Adjusted Production Cost difference between two cases
  - RECB II Benefit = sum over all regions (30%* Load Cost Saving + 70%*Adjusted Production Cost Saving)

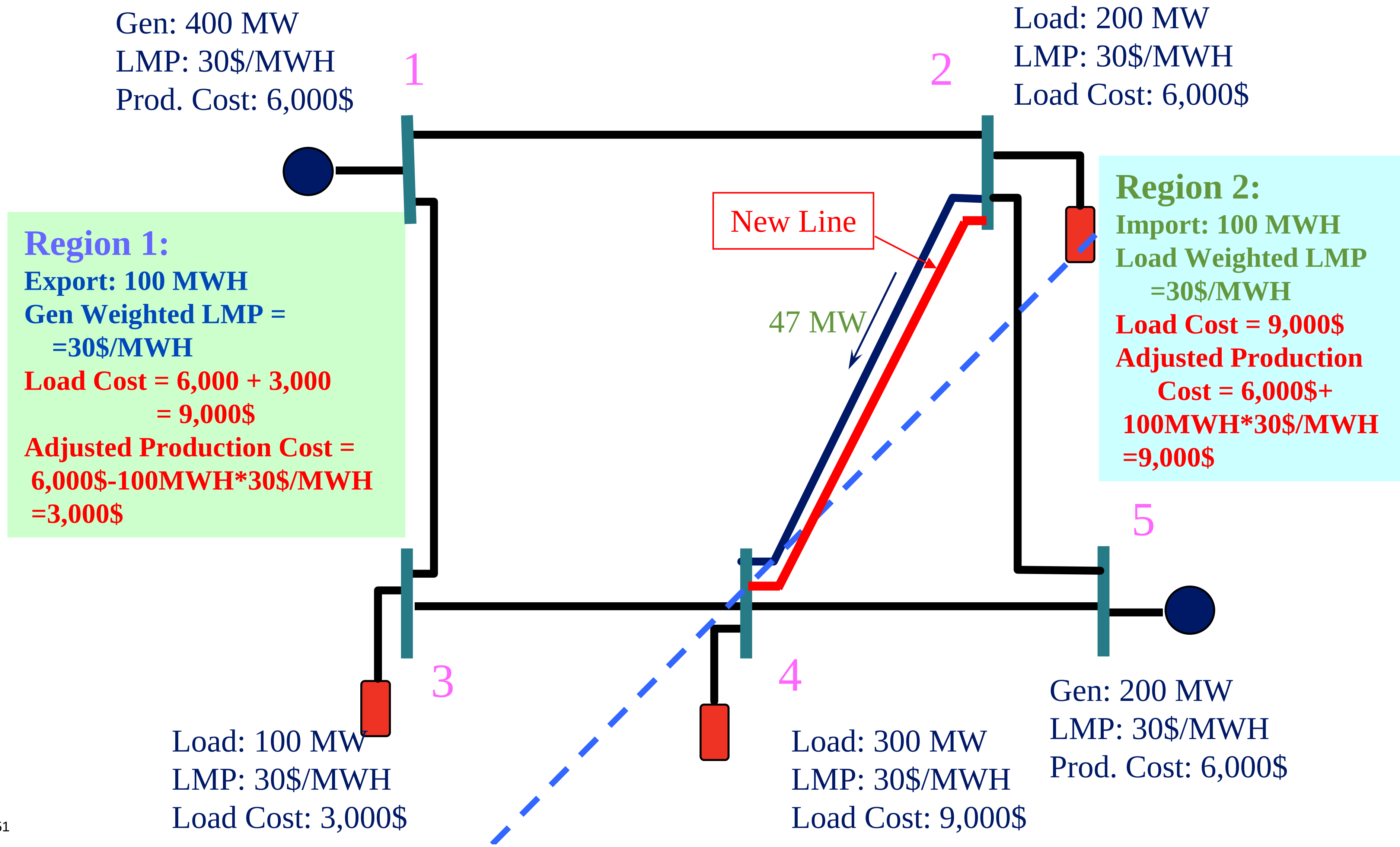
Example:
5 Bus Power Network



5 Bus Power Network (Original) – PROMOD result



5 Bus Power Network (After upgrade) – PROMOD result



5 Bus Power Network
– New Transmission RECB II Benefit

		Original Case	Case with New Line	Saving
Region 1	Load Cost	$1,500	$9,000	$-7,500
Region 1	Adjusted Production Cost	$3,000	$3,000	$0
Region 2	Load Cost	$22,500	$9,000	$13,500
Region 2	Adjusted Production Cost	$9,000	$9,000	$0

RECB II Benefit = 70% * 0 +30% * (-7,500+13,500) = $1,800