Transmission Considerations for Market Operation: U.S. Design

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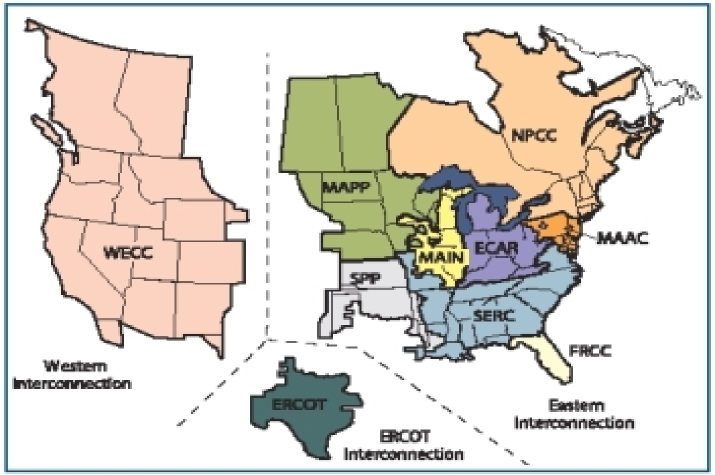
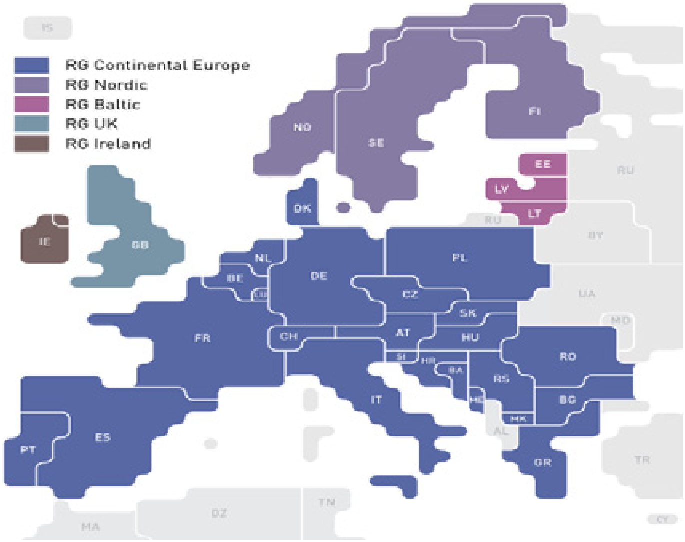
The Largest and Most Complex (Man-Made) Machine in the World





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- Transmission from X to Y can be 1,000s of miles.
- All generators and motors spin at about the same speed at the same time.
- A problem in Florida felt in Manitoba.

A Market Like No Other

- So other than that what makes an energy market so unique?

A Market Like No Other

- Electrical energy cannot be stored:
  - It can be converted to other forms of energy and stored but for very large costs and efficiency losses (e.g., pumped hydro plants).
- Energy is generated and consumed at almost the exact same time:
  - Once the corn is harvested, it must be sold, transported, and eaten in a fraction of a second.
- Energy must be transported to consumers at the speed of light often from far distances.
- Laws of physics will dictate where power will go, who will get it, and how much of it will be lost along the way; NOT laws of economics:
  - If the road is full of trucks, you can't deliver anymore supply, and you can't use a different road.
- There are many different ways to supply it, but the end product is the exact same thing no matter how it is supplied:
  - Some suppliers have large capital costs and low variable costs, others are the opposite (price highly volatile even throughout day).

Outline

- Brief overview of U.S. Markets;
- The LMP: What is it, how is it calculated, and what does it do?
- How do variable renewable act in LMP markets?
- Financial Transmission Rights (FTR): What are they and how do they work?

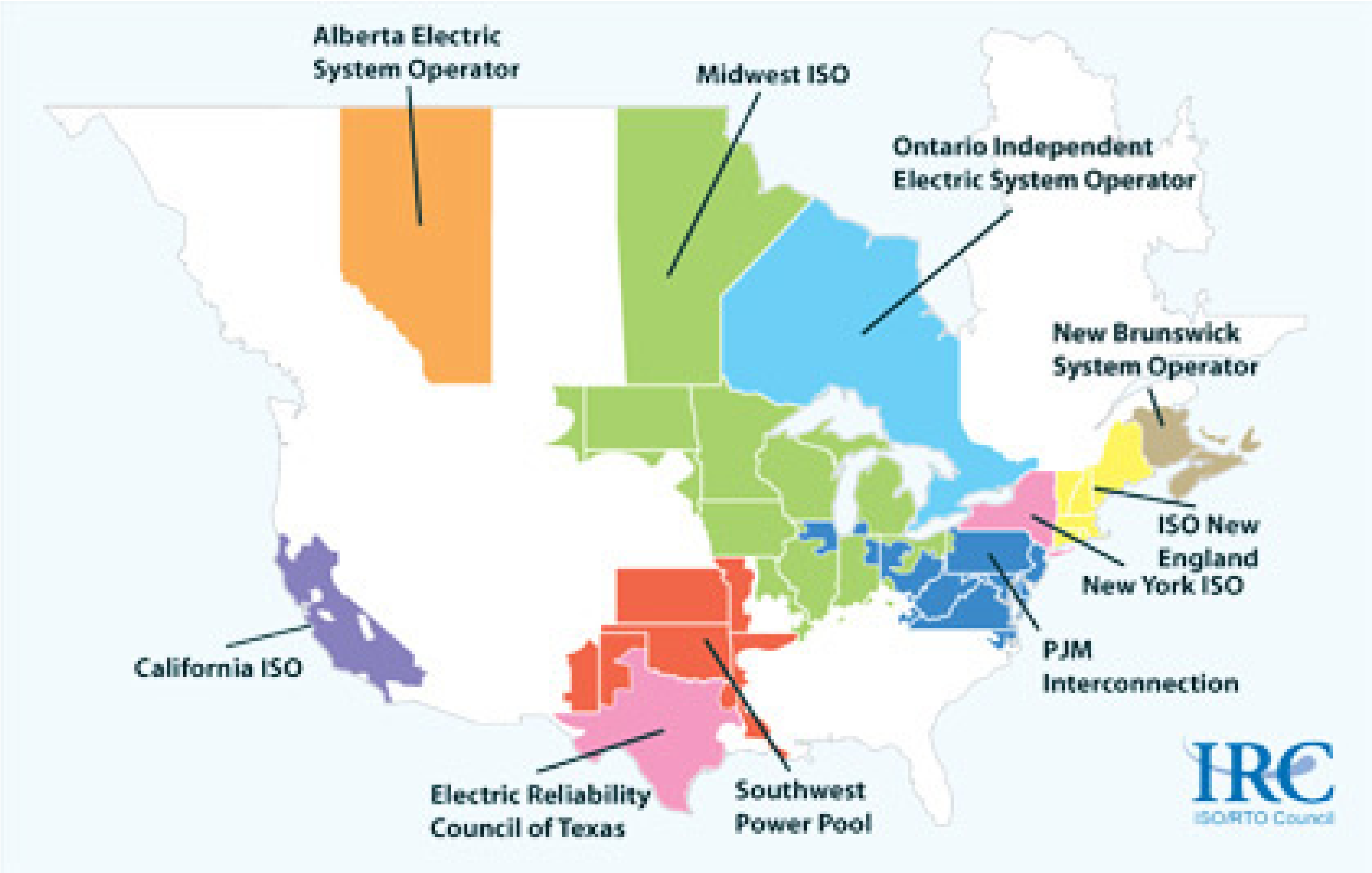
The Electric Utility

- Since electricity industry was first started, most electric utilities were vertically integrated:
  - They owned and operated generation, transmission, and distribution.
- The utility reported costs to state utility commissions who then allowed prices to reflect those costs plus a reasonable rate of return on investment;
- Generally, trading electricity between utilities was rare and only usually occurred during emergency situations;
- In the 1960s and 1970s many power pools were formed to help coordinate electricity trading between utilities for both reliability and economic reasons.

The Emergence of the RTO

- Electric Restructuring started in the mid-90s;
- FERC order 888 – Open access transmission;
- FERC Order 2000 – Encouragement of Regional Transmission Organizations (RTOs or ISOs);
- Different RTOs have varying responsibilities. These may include:
  - Transmission planning;
  - Overseeing bulk electricity grid operations;
  - Maintaining generator/infrastructure interconnection queues and interconnection studies;
  - Administering Wholesale energy markets and commitment and dispatch directions;
  - Administering Ancillary service markets and ancillary service implementation;
  - Other markets (e.g., financial transmission rights).

North American Energy Markets



How Do They Work?

- ISOs must be fair and unbiased;
- All sectors, all generator types, must be treated equally in the market;
- This becomes complicated since not all participants are equal in terms of technology and capabilities;
- Overall goal in energy markets is to create the least cost solution both short term and long term to electricity consumers while maintaining reliability levels;
- Spot prices influence the cost of energy;
- All market rules are decided on by agreement of market participants and FERC oversight.

Congestion Management

- In the U.S., agreement that locational marginal prices (LMP) the most efficient way to manage congestion on the transmission system;
- LMP is the marginal cost of supplying load at individual locations;
- LMP calculated using optimal power flow:
  - Sometimes with unit commitment constraints (day-ahead market);
  - Sometimes with reserve constraints;
  - Etc.
- Usually a dc power flow approximation:
  - Voltage and reactive power usually ignored.
- Security constraints often considered.

LMP

$LMP = LMP_{energy} + LMP_{congestion} + LMP_{losses}$

$LMP_{energy} = \lambda_{energy}$:

The marginal cost of providing energy on the entire system.

Will depend on the system reference bus.

$LMP_{congestion} = \Sigma\alpha_{il} * \mu_l$:

The marginal cost of congestion for that bus

α_{il} : The generation shift factor, How much bus i contributes to the congested line l.

μ_l: Shadow price of congestion. How much that constraint impacts the total production costs.

LMP

LMP_{losses} = (DF-1)* λ_{energy}:

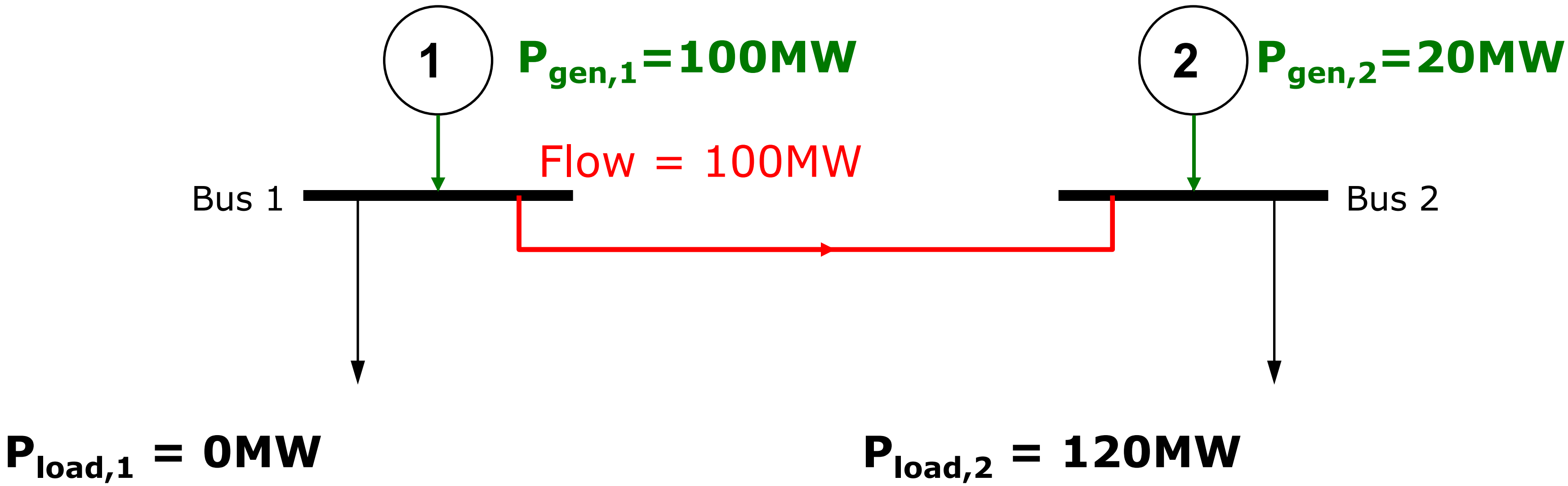
The marginal cost of introducing losses to the system.

DF: Delivery Factor. For every unit energy injection how much is delivered to loads.

Also depends on reference bus.

Note: Losses are usually approximated using linear techniques.

LMP 2-Bus Example



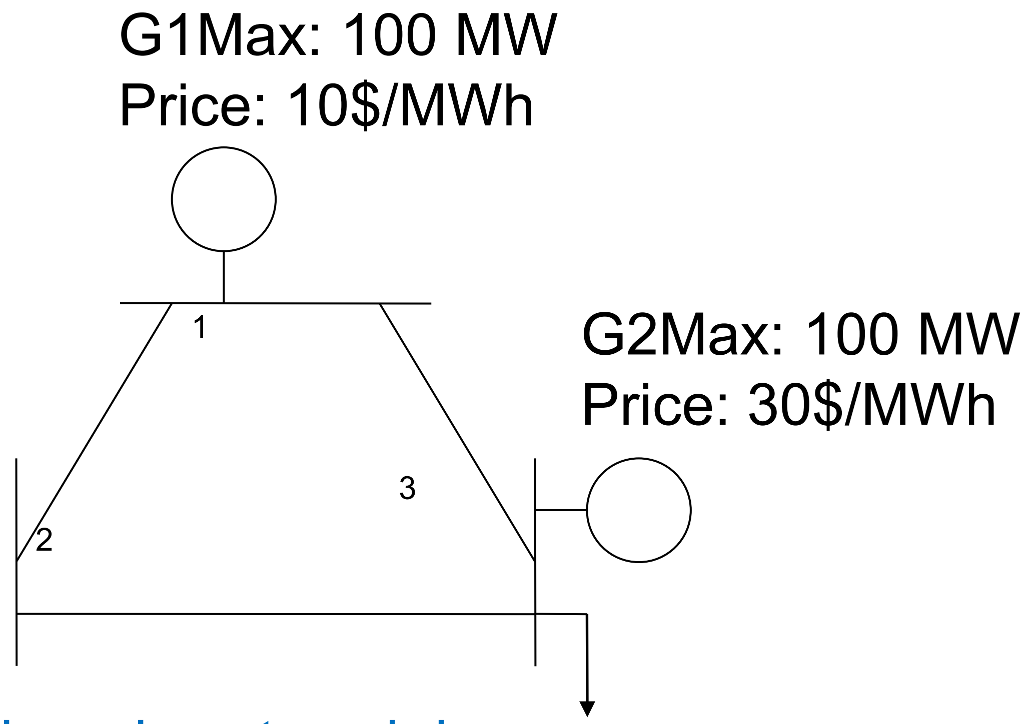
$\lambda = 20,$

$\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0,$

$\mu^+ = 10, \ \mu^- = 0$

$LMP_1 = \lambda - \mu^+ + \mu^- = 10$ \$/MWh $\quad LMP_2 = \lambda = 20$ \$/MWh

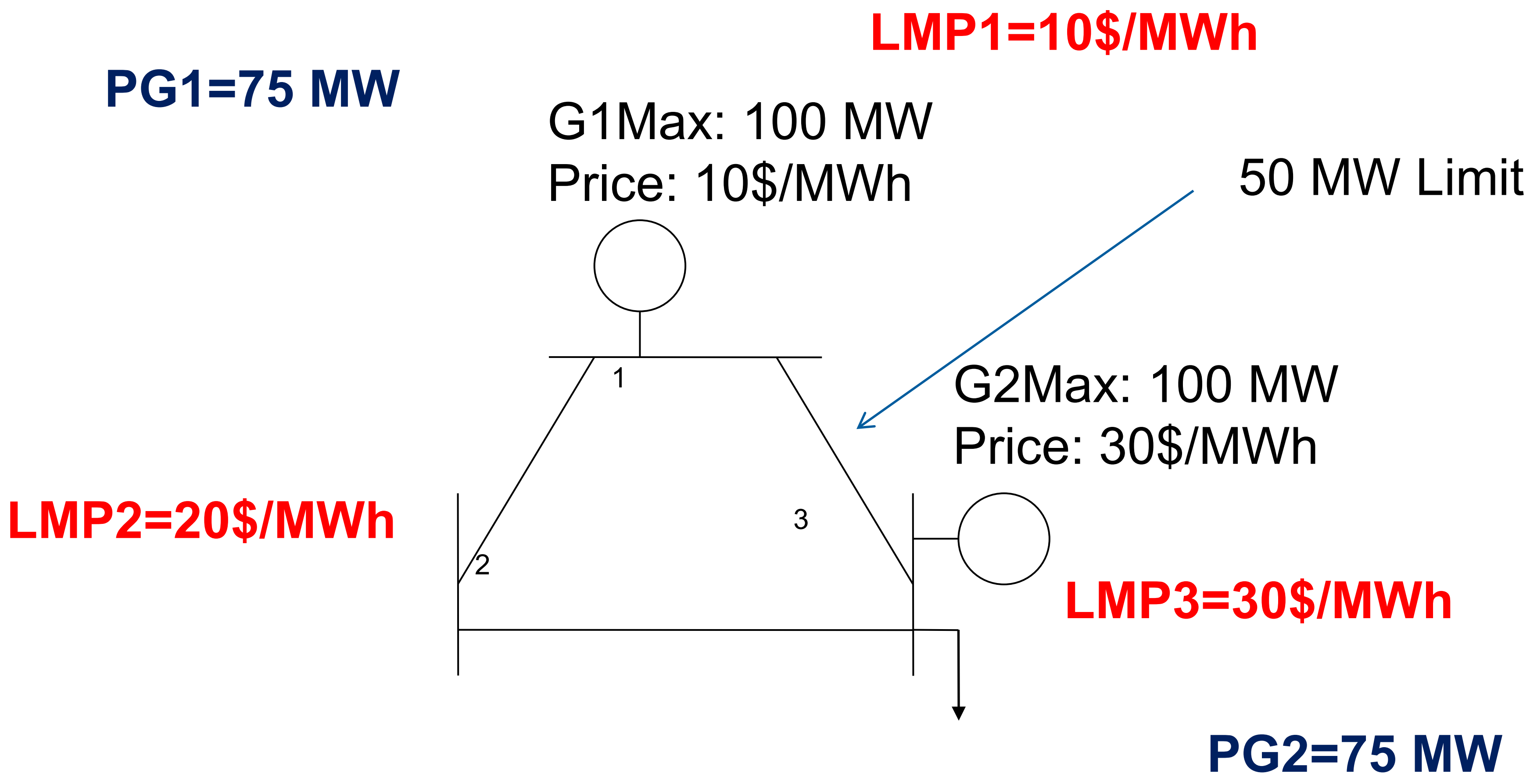
3-Bus Example



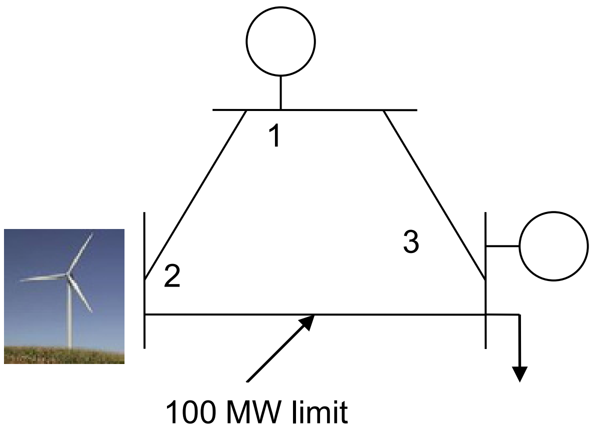
What is the price at each bus:

- If the load is 50 MW?
- If the load is 150 MW?
- If there is a transmission constraint of 50 MW from bus 1 to bus 3?

3-Bus Example (LMPS)



LMP Impact of Renewables



G1: 250 MW
10 $/MWh
Wind: Forecast 100 MW
G3: 100 MW
50 $/MWh

L3: 250 MW
X12 = X13 = X23

Allowing Wind to Participate in LMP Markets

$1500 or over 40% savings in total production costs.

Output, Cost, and LMP											
Without Curtailment											
	Wind Gen MW	**Gen 1 MW**		**Gen 1 Cost**		**Gen 3 MW**		**Gen 3 Cost**		**Total Cost**	**LMP at Bus**
Base Case (250 MW)	100	100	*	$10/ MWh	+	50	*	$50/ MWh	=	$3500	
Add 1 MW to Bus 1	100	101	*	$10/ MWh	+	50	*	$50/ MWh	=	$3510	$10
Add 1 MW to Bus 3	100	100	*	$10/ MWh	+	51	*	$50/ MWh	=	$3550	$50
Add 1 MW to Bus 2	100	102	*	$10/ MWh	+	49	*	$50/ MWh	=	$3470	$-30

Output, Cost, and LMP											
With Curtailment											
	Wind Gen MW	**Gen 1 MW**		**Gen 1 Cost**		**Gen 3 MW**		**Gen 3 Cost**		**Total Cost**	**LMP at Bus**
Base Case (250 MW)	50	200	*	$10/ MWh	+	0	*	$50/ MWh	=	$2000	
Add 1 MW to Bus 1	50	201	*	$10/ MWh	+	0	*	$50/ MWh	=	$2010	$10
Add 1 MW to Bus 3	49	202	*	$10/ MWh	+	0	*	$50/ MWh	=	$2020	$20
Add 1 MW to Bus 2	51	200	*	$10/ MWh	+	0	*	$50/ MWh	=	$2000	$0

Other Benefits

- Market-based solution that improves market efficiency while maintaining reliability
- Allows curtailment to proceed through scheduling software rather than manual intervention
- Less financial harm to wind and other generators.

Load pays $30 less.

Wind generator no longer is financially harmed to produce.

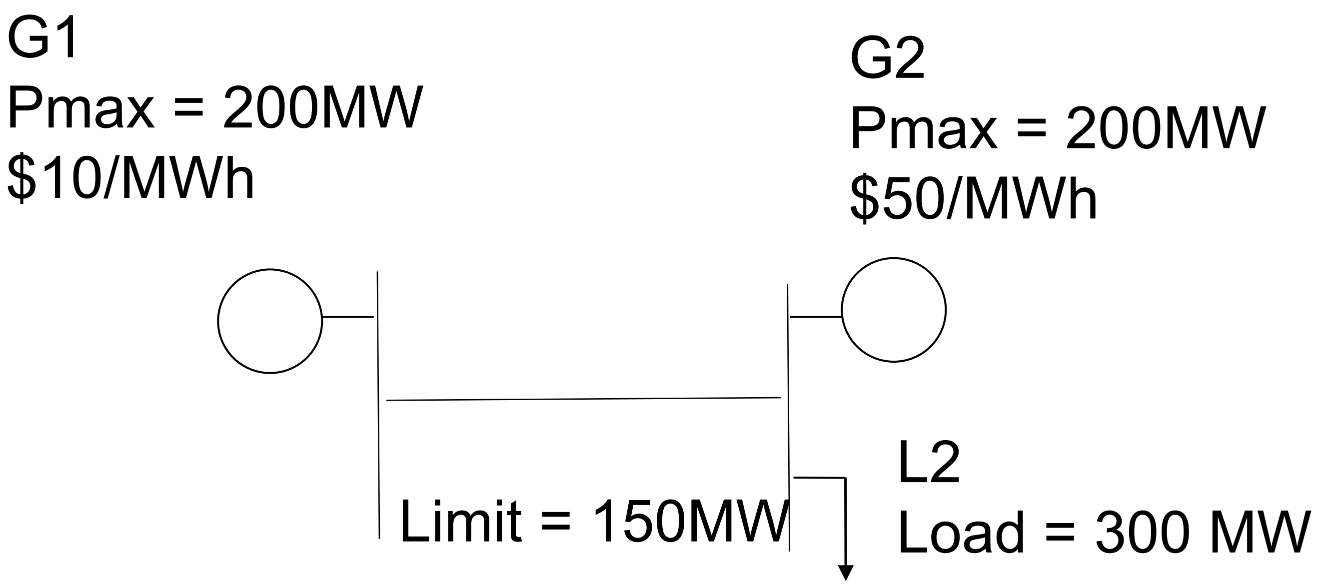
Security Constraints

- In the U.S., security constraints will also impact the spot prices;
- The security-constrained unit commitment and economic dispatch programs run by the ISO will have selected n-1 transmission constraints;
- If line L1 fails, and the system would not be under limits following the outage without corrective action, the generator schedules will be re-dispatched;
- This will impact the LMP at all buses.

Financial Transmission Rights

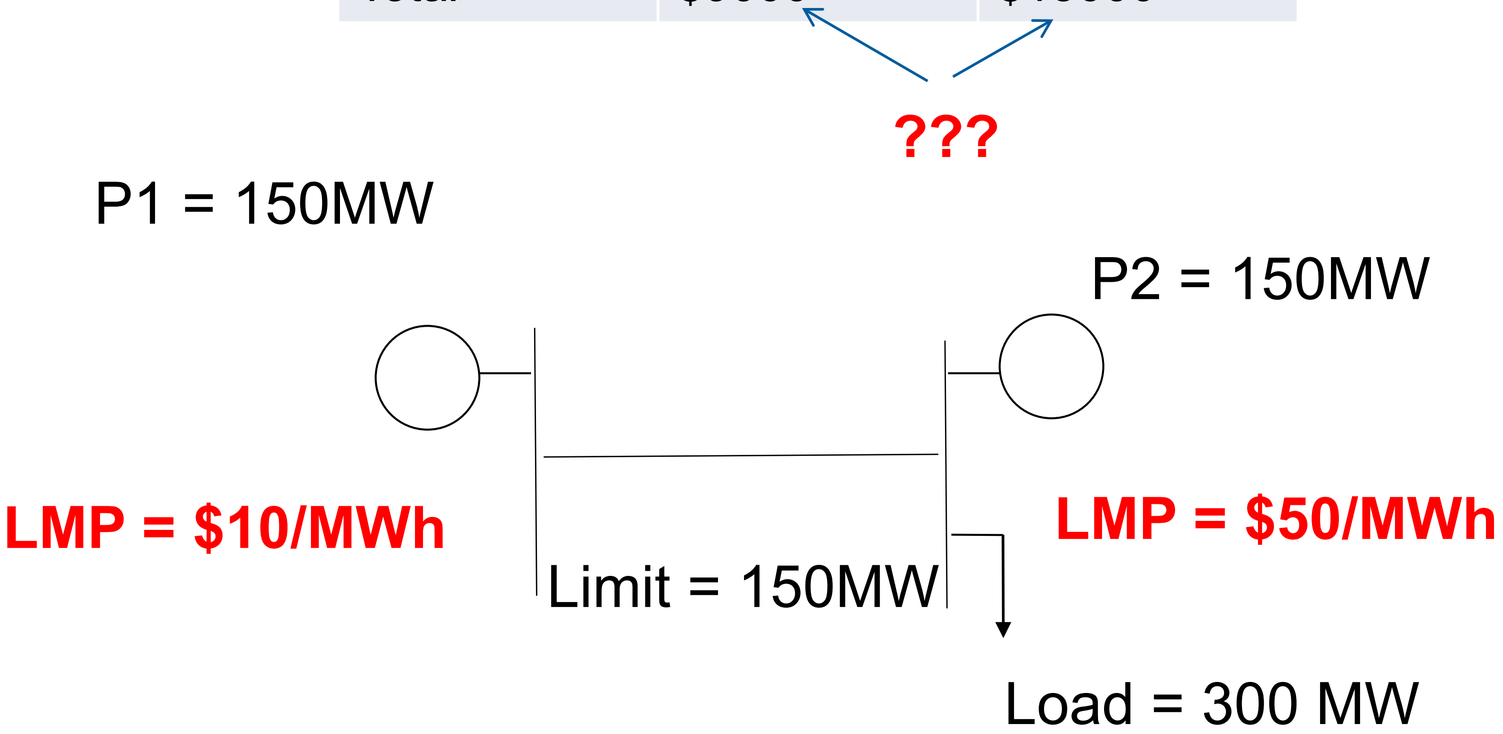
- Financial Transmission Rights (FTR) Markets – When transmission congestion is apparent in the energy market, there may be more money collected from loads than is paid to generators.
- Market Participants bid on rights to these moneys by “financially” owning the transmission line where congestion occurs;
- Do not have to physically own line;
- Use to hedge against different prices between supply and demand.

Financial Transmission Rights



Financial Transmission Rights

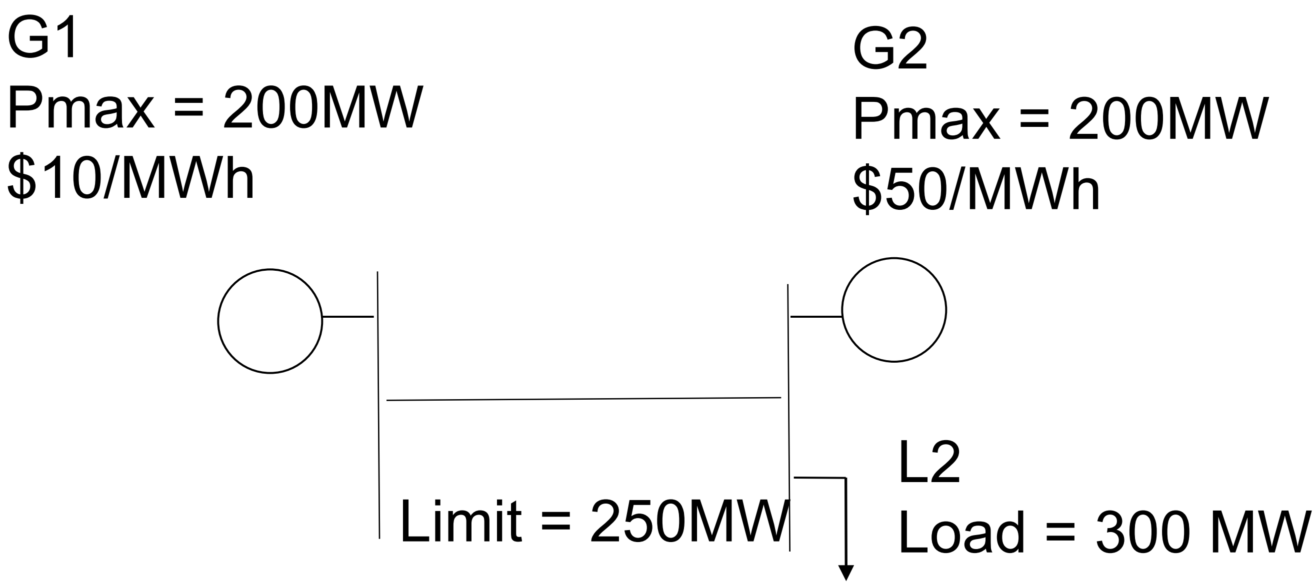
	Gen Payments	Load Payments
G1	$1500	
G2	$7500	
L2		$15000
Total	$9000	$15000



Financial Transmission Rights

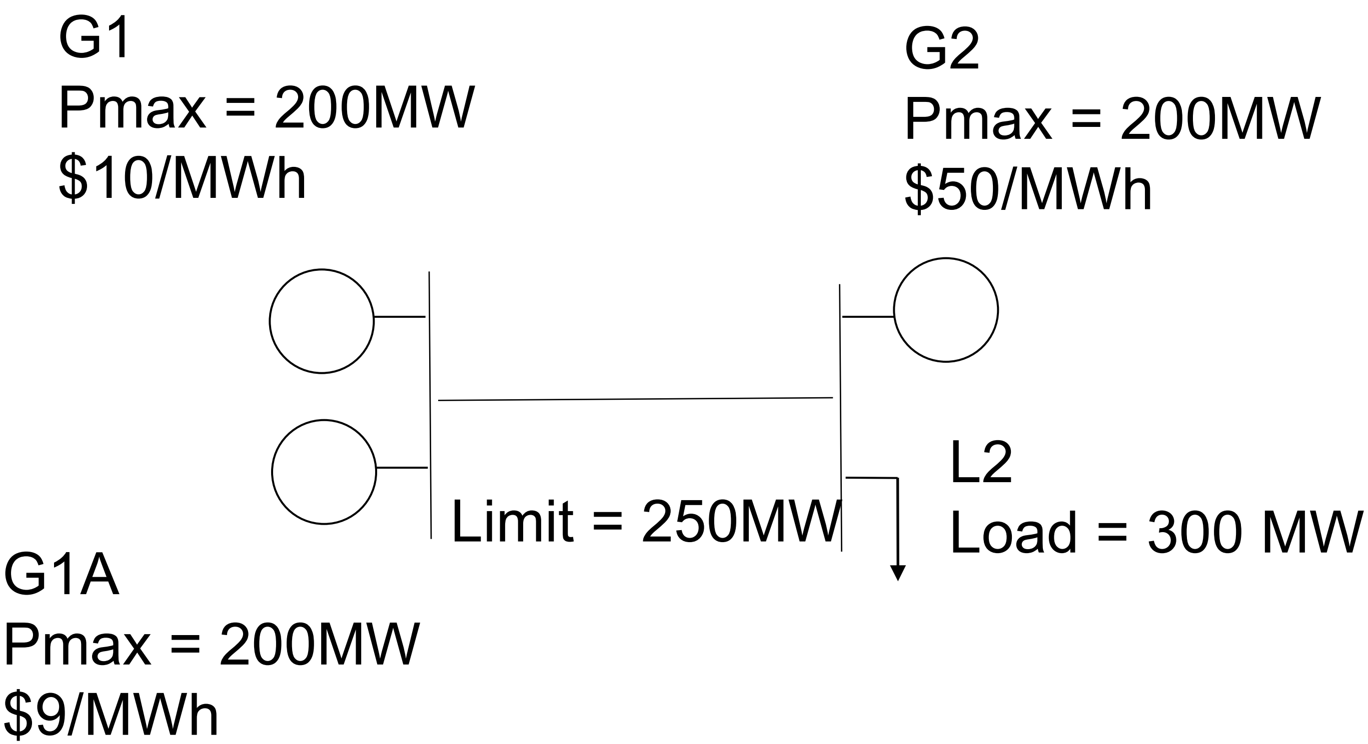
- At the origin of the energy markets, it was found that physical transmission rights would not work for efficient and reliable operation of the system;
- Financial Transmission Rights are given through:
  - Network integration service customers;
  - Firm point-to-point service customers;
  - FTR auctions;
  - FTR bilateral transactions.
- FTR auctions run through optimization program reducing cost of all FTR bids:
  - Power flow including security constraints.

Incentivizing Transmission Investment



G1 invests in increasing capacity of line to 250 MW.
Now holds FTR of 100 MW.
G1 now makes the LMP of $50/MWh for his energy.

Incentivizing Transmission Investment



G1A sneaks in and undercuts G1, now LMP reduced back to $10/MWh.

G1 however still makes as much as $50/MWh for some of his energy due to his FTR.

Impacts of Renewables on FTRs

- FTRs are generally not impacted significantly by the introduction of variable renewable resources;
- Renewable power producers should have ability to purchase FTRs if desired:
  - Might reduce negative price impacts that occur.
- The variability of renewable might impact the change of power flow on system and therefore the prediction of the value of FTR;
- Significant difference in price between variable renewable bus location and load centers could incentivize merchant transmission investment through FTR process:
  - Not sure this has occurred yet???

Summary

- LMP and FTR seem to be working well in U.S. market regions;
- Renewables can have large impact on LMP and should be encouraged to participate in LMP markets;
- Renewables have not been seen on impact in FTR markets, however, can have impact on FTR through their impact on LMP pricing;
- Transmission is important!! When designing markets, incentives should not only be in place for locating generators and loads, but where to build transmission!

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Questions

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