From: Dale Osborn [mailto:DOsborn@misoenergy.org]
Sent: Monday, April 27, 2015 1:39 PM
To: PUC - Executive.Director; Speidel, Alexander; Shulock, David; epler@unitil.com; McCluskey, George; Bailey, Kate; Stachow, Leszek; matthew.fossum@eversource.com; mdean@mdeanlaw.net; PUC - OCA Litigation; robert.bersak@nu.com; sarah.knowlton@libertyutilities.com; steven.camerino@mclane.com
Cc: Kurt W. Bilas; rsedano@raponline.org; Tom Levy; John Lawhorn
Subject: Larger market access-lower energy prices for New Hampshire

I saw that there is an order to investigate energy pricing in New Hampshire. The discussion below presents an option for capacity diversity exchange, that may be a future cooperative solution.

There is a potential value of load diversity exchange in the U.S. of about $50B. Capturing the diversity with a HVDC transmission overlay and exchanging your diversity with someone who would obtain a value from it may more than pay for the transmission costs. Your area may be able to obtain peaking power for a lower cost than building combustion turbines with the exchange without building gas pipelines. The concept for an HVDC overlay for New England and a market of markets depends heavily on Hydro Quebec participation.

The high price of transmission estimates in PJM, NYISO and ISONE and the low potential exchange, did not produce an HVDC transmission solution for PJM, NYISO and ISONE to add to the HVDC Network. The benefit/cost ratios were less than 1:1. However, using Canadian price estimates for transmission, the HQ exchange potential and possibly the more efficient use of combined HVDC projects in the NYISO and ISONE regions may produce a conceptual HVDC overlay that may prove to have a sufficient benefit/cost ratio(1.25:1) to justify building transmission. The carbon production of the U.S.-Canadian footprint may also be lowered.

The exchange of capacity is a new concept for many. When MISO combined 26 Balancing Areas into a single market with primarily two time zones, the coincident load of the MISO Market single Balancing Area was reduced by 6% or 6,000 MW on a then 100,000 MW system. Time zone diversity was the primary driver. When the U.S. and Canada were analyzed to see what the ultimate effect that FERC Order 1000 may have on the Eastern Interconnect and future transmission, potential diversity partner pairings were driven by an east-west time zone diversity and a north-south load pattern diversity. The maximum exchange partners are located at a diagonal on the U.S.-Canadian footprint. If Mexico were added to the HVDC Network, Mexico would probably add enough diversity to include most of the Northeast EI into exchanges. There is little capacity diversity exchange potential with neighboring entities.

New Hampshire would have a potential share of the potential savings. Studies in other areas show that benefits and costs are approximately proportional to a load ratio share of the total load in the exchange footprint. The displaced peaking capacity of the HVDC Network currently is 30,000 MW for a 315,000 footprint. Using a 10% estimate for the displaced capacity, New Hampshire may be able to expect about a 220 MW share an HVDC Network including the Northeast EI. Using the HVDC Network economics, a simple cost savings calculation would lower the capacity price of 220 MW by 20%, for a present value cost saving estimate of $123M for the capacity only. A modest energy price savings may also be in addition to the $123M in capacity savings.
Assumptions:
$700,000/MW value of construction for a combustion turbine
1.25:1 Benefit/cost ratio of the HVDC Network - 80% of the alternate cost

220 MW displaced peaking generation in New Hampshire estimated on a 2,200 MW load

One business concept for the HVDC Network is that all participants would have the same cost. Benefits may vary by geographical areas due to cost of construction and financing option. The construction cost of the HVDC Network plus the Transmission Service cost for point to point transmission service to the nearest HVDC Network terminal would be the total cost of the HVDC Network. Each participant would have a share of the cost roughly proportional to the load ratio share of the total load in the HVDC Network footprint. New Hampshire's estimated cost would be the load in New Hampshire over the total HVDC Network load. Each state would not require an HVDC terminal to obtain proportional benefits. The lowest rating of HVDC terminals for the HVDC Network is 2200 MW, which is ten times the requirements for New Hampshire. Sharing terminals is economically necessary.

A second business concept is associated with the MISO External Asynchronous Resource tariff (EAR) that is FERCC approved and being used by Manitoba Hydro. The EAR allows the purchase or sale of any MISO market product, including Ancillary Services similar to a market participant, but not participate in the MISO dispatch or cost allocation of the transmission expansion. The EAR participant is independent of MISO except for the obligations of buying or selling MISO market products.
The HVDC Network may operate under an EAR concept. An HVDC Network Board of Directors elected by participants and the HVDC Network staff may be the governance foundation to determine the operation of the HVDC Network.

While the justification of the HVDC Network transmission is based on the exchange of peak capacity over a few hours of the year. The energy price of the peaking capacity delivery to the NEISO for New Hampshire, would be based on an off peak supply price and the NEISO price-supply curve on peak. The settled price may be estimated by reducing the ISONE price by 10% MW on the NEISO Price-supply curve. The sharp peak characteristic would be truncated by moving the price down the Price-Supply curve to a new load point of 90% of peak. Needle peak prices at other times would also see a price reduction with 10% of the supply coming from a lower priced region.

The transmission capacity of the participating share for the other 8700 hours of the year could be used for energy arbitrage or the delivery of renewable energy to the HVDC Network market footprint. Gas will be on the margin and setting prices for most regions off peak. Little price difference would be expected for gas-gas generation exchanges. The HVDC Network would also supply another path to purchasing hydro energy or wind energy from Hydro Quebec. The HVDC Network may also provide a third competitive price to establish energy price levels(NEISO, Hydro Quebec, HVDC Network) depending the on location of a HVDC terminal in ISONE. The use of the 220 MW of HVDC Network transmission capacity from the HVDC Network may be better used for selling or buying renewable energy.

For renewable generation in New Hampshire, the renewable generator would have a footprint price to work with. If the price is higher than the ISONE price, sales would take place. The additional revenue allocation to the New Hampshire renewable generators or customers is depending upon the state regulators.

Purchasing renewable energy from geographically diverse generation has been shown to increase the capacity credit for renewable generation(reduce the need for fossil fuel generation) and reduce the net variability of the aggregated renewable generation mix.

Some of the 220 MW might be used by the ISONE to reduce the Area Control Error which includes renewable variability by buying and selling ACE over the HVDC lines. The net result is a lower price to the customers.
MISO developed a conceptual design for an HVDC Network to capture potential capacity and energy diversity for WECC, ERCOT and the Partial East(Eastern Interconnection minus PJM, Ontario, Hydro Quebec, NYISO, ISONE, and the Maritimes)
The supply of capacity diversity is limited by the smallest diversity polarity. WECC's diversity supply limits the footprint of the Partial Eastern Interconnection. All of the WECC diversity is consumed within MISO and SERC.

The Eastern Interconnection minus PJM, Ontario, Hydro Quebec, NYISO, ISONE, and the Maritimes has been named the North East EI. The North East EI has a small diversity with MISO or other areas in the Eastern Interconnection with the exception of Hydro Quebec. The attached presentation was for the Pan Canada study for wind integration in Canada. The presentation suggest that there are opportunities to coordinate with the U.S. that may more than pay for the HVDC transmission in benefits.

Considering that HQ would most likely have market activity with the NYISO and ISONE, there is about 3,400 MW of potential capacity exchange potential with MISO.

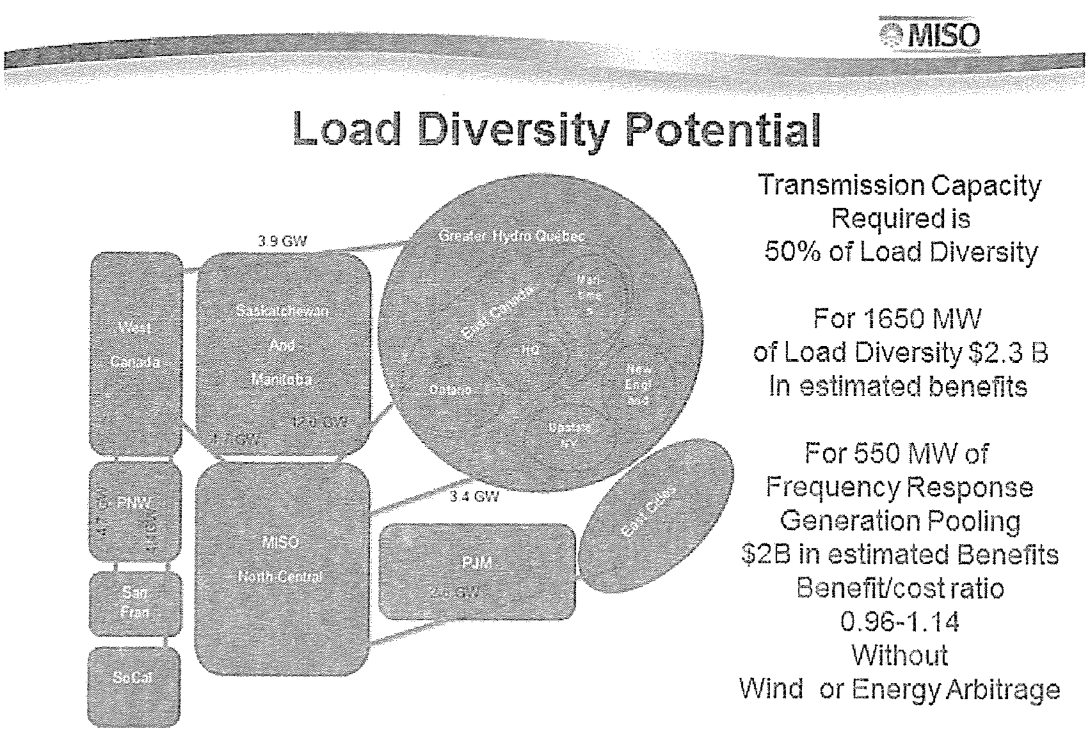
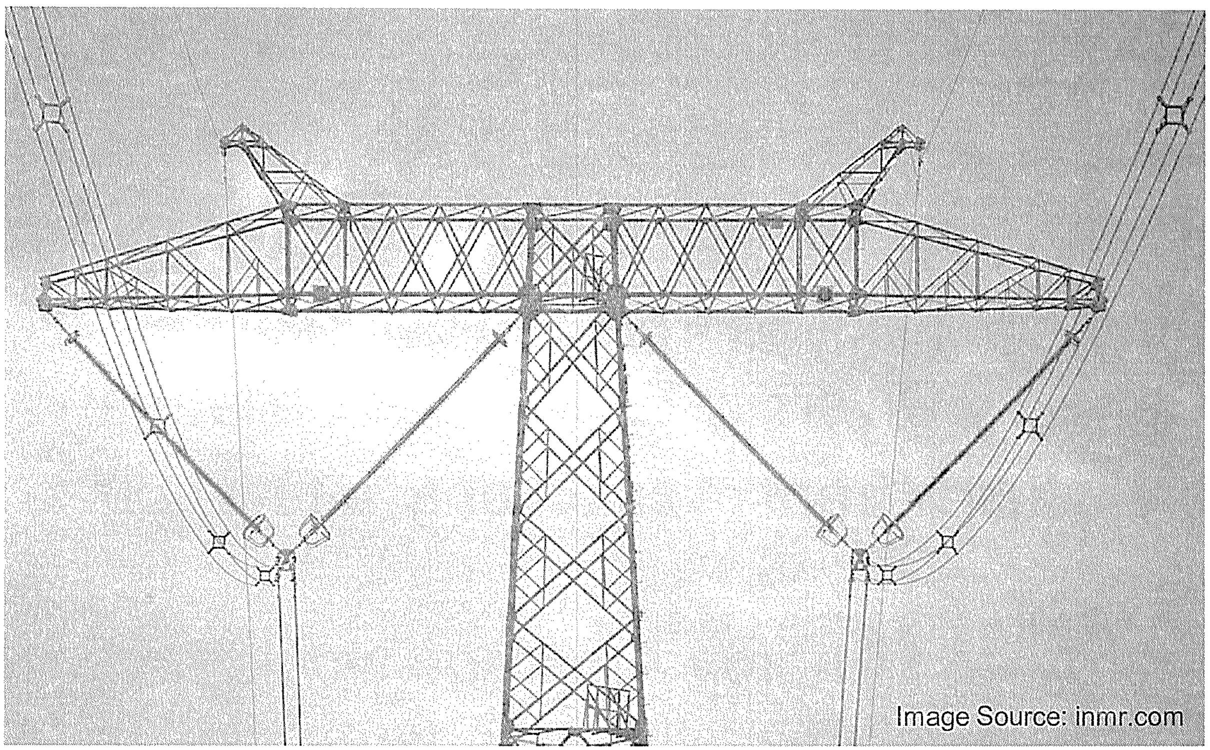


Figure 2: Minimum Bilateral Diversity Bubble Map

A conceptual HVDC transmission integration to the HVDC Network is shown below. The HVDC Voltage Source Converters allow for back start support, fast reversal of power flows for market products such as Regulation or renewable energy variability export or import and voltage support. Probably one VSC would be located in ISO NE, but is not shown on the map.

Conceptual Interregional HVDC Network



October 30th, 2014

Dale Osborn

Inter Regional Transmission will be Economically Justified

- **Low gas prices produce few benefits from the energy sales and purchases**
- **Capacity Diversity exchanges have a maximum potential of about $50B for the U.S.**
  - Transmission may be justified from the value of participation Capacity Diversity Exchanges (bilateral)
  - Capacity Diversity uses transmission only a few hours of the year
  - Renewable Energy and Energy Arbitrage would have reduced price transmission available- energy market

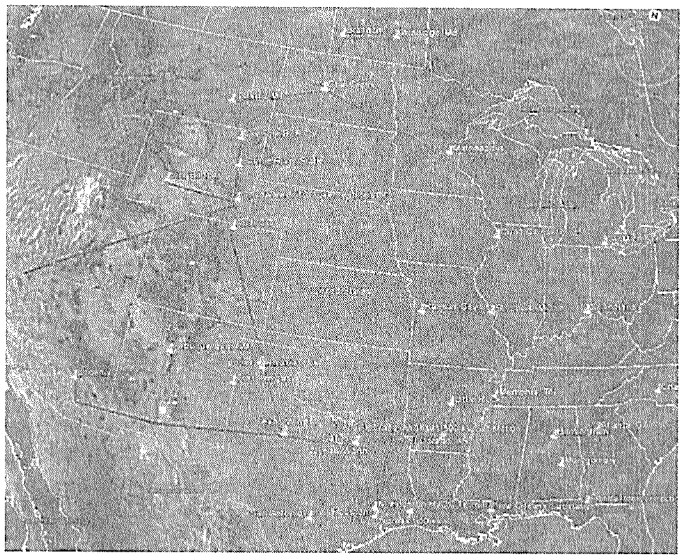
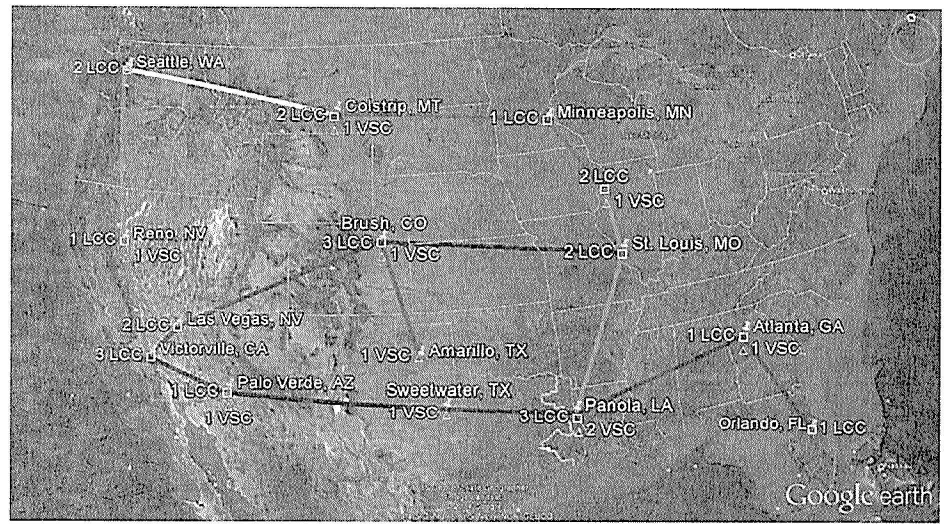
Asynchronous External Resource Tariff

- **Asynchronous systems connected to MISO with HVDC may participate as a generator or a load in all the MISO markets-market price for energy-hydro has maximum benefits**
- **Manitoba operates on the EAR tariff**
  - Buying energy from wind resources at lower prices
  - Storing the energy by reducing hydro
  - Selling on peak periods
  - PLEXOS market-hydro model of how MHEB would operate with the MISO market

Potential Benefits Exist Today

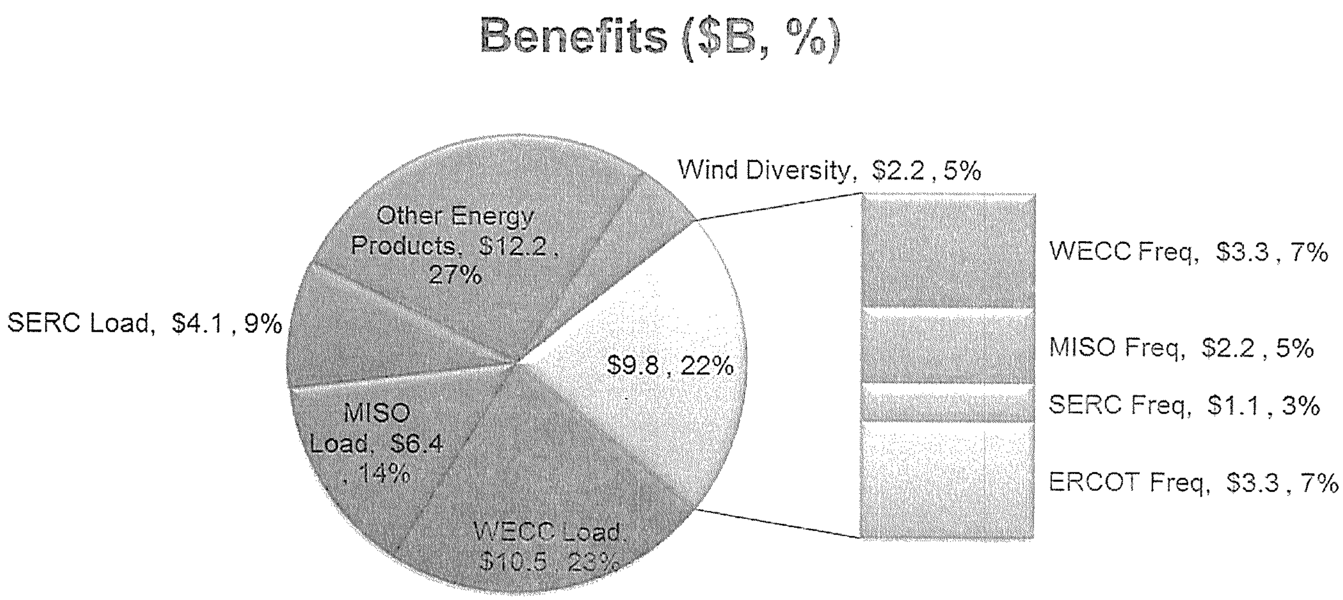
- **Collecting and delivering Capacity Diversity is a one time opportunity**
- **An under designed system would probably block future economic expansions**
  - Under designing may be a result of individual projects with no coordination
- **A properly designed system may extract a high percentage of the potential benefits and eliminate further expansion for Capacity Diversity for a long time**

HVDC Sketch Differences

Jan 8th, 2014	Oct 16th, 2014
	
• <u>Bottom Up</u> Topology • Based first on Frequency Response • 2012 load data • 23,000 MW of diversity and renewables	• <u>Top Down</u> Topology • Based first on Load Diversity • 2006-2012 Load Data • 70,100 MW of diversity and renewables

Increased scope by ~33% of MISO total load

Costs allocated by % of benefits



Value Drivers		
Load diversity	46%	Capacity
Frequency response	22%	Capacity
Wind diversity	5%	Capacity
Other Energy Based Products	27%	Energy

Example:

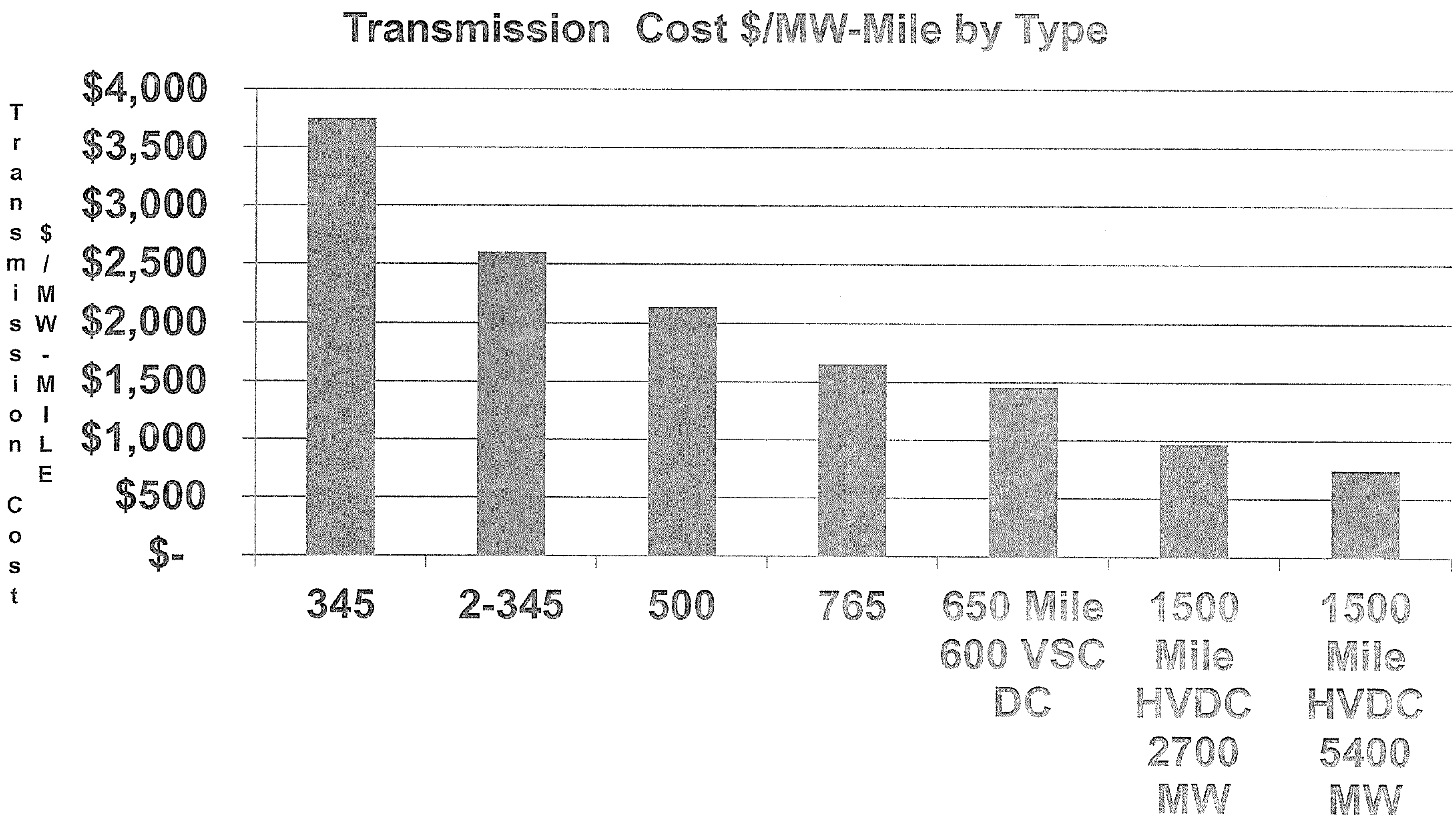
SERC Load Cap. Cost = $36.2B * 9% = $3.3B

SERC Freq Reg Cost = 36.2B * 3% = $1.1B

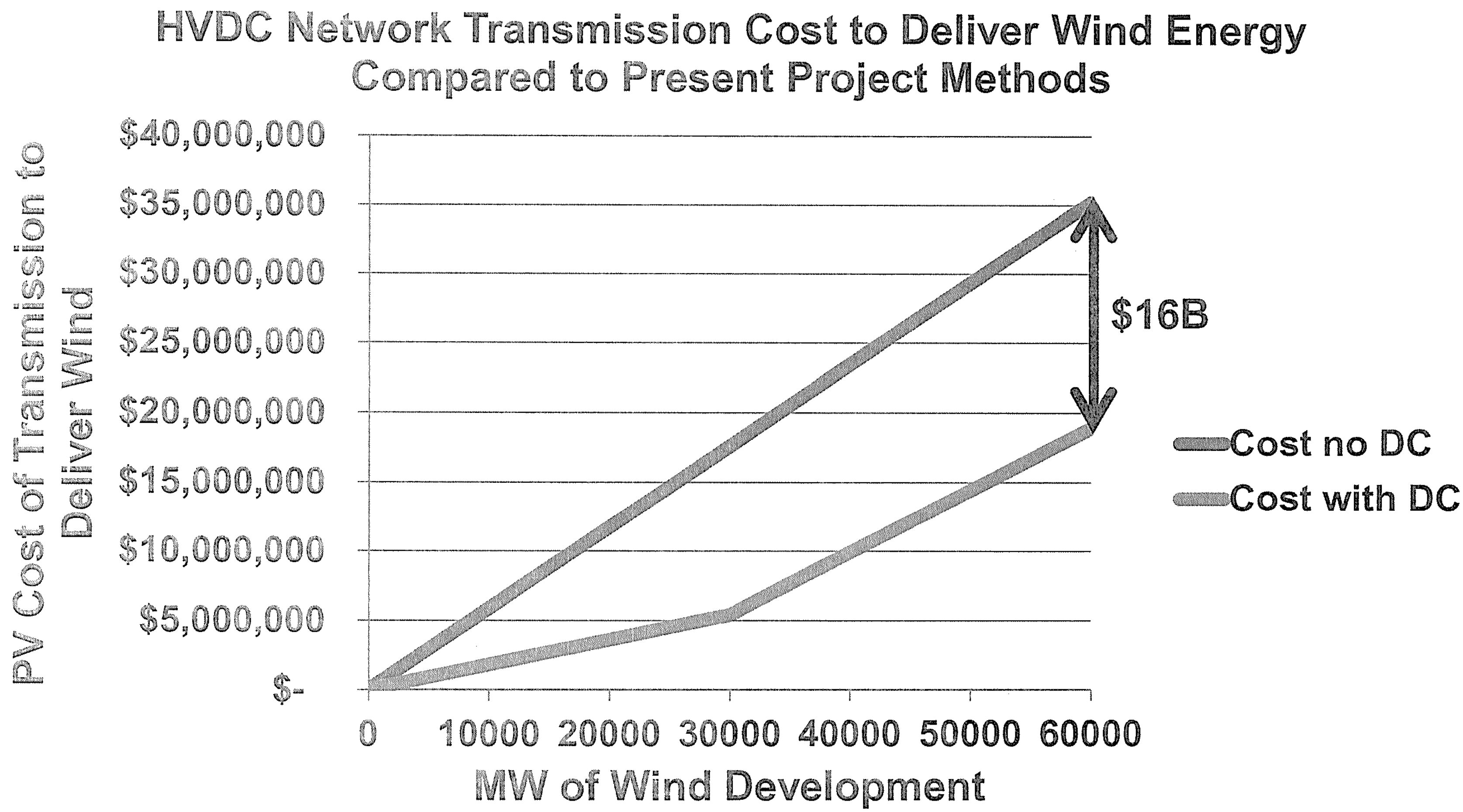
Self Contingent Design

- A system of three transmission lines can be economically designed and operated to set a new level of maximum contingency.
- HVDC is particularly effective and simpler to design a self contingent system
  - Does not overload unless programmed to do so
  - Consistent response for the same state of contingency
  - Can be designed to operate over long distances to collect and deliver benefits
  - Low risk of heavily impacting underlying AC systems that are designed to a lower contingency level

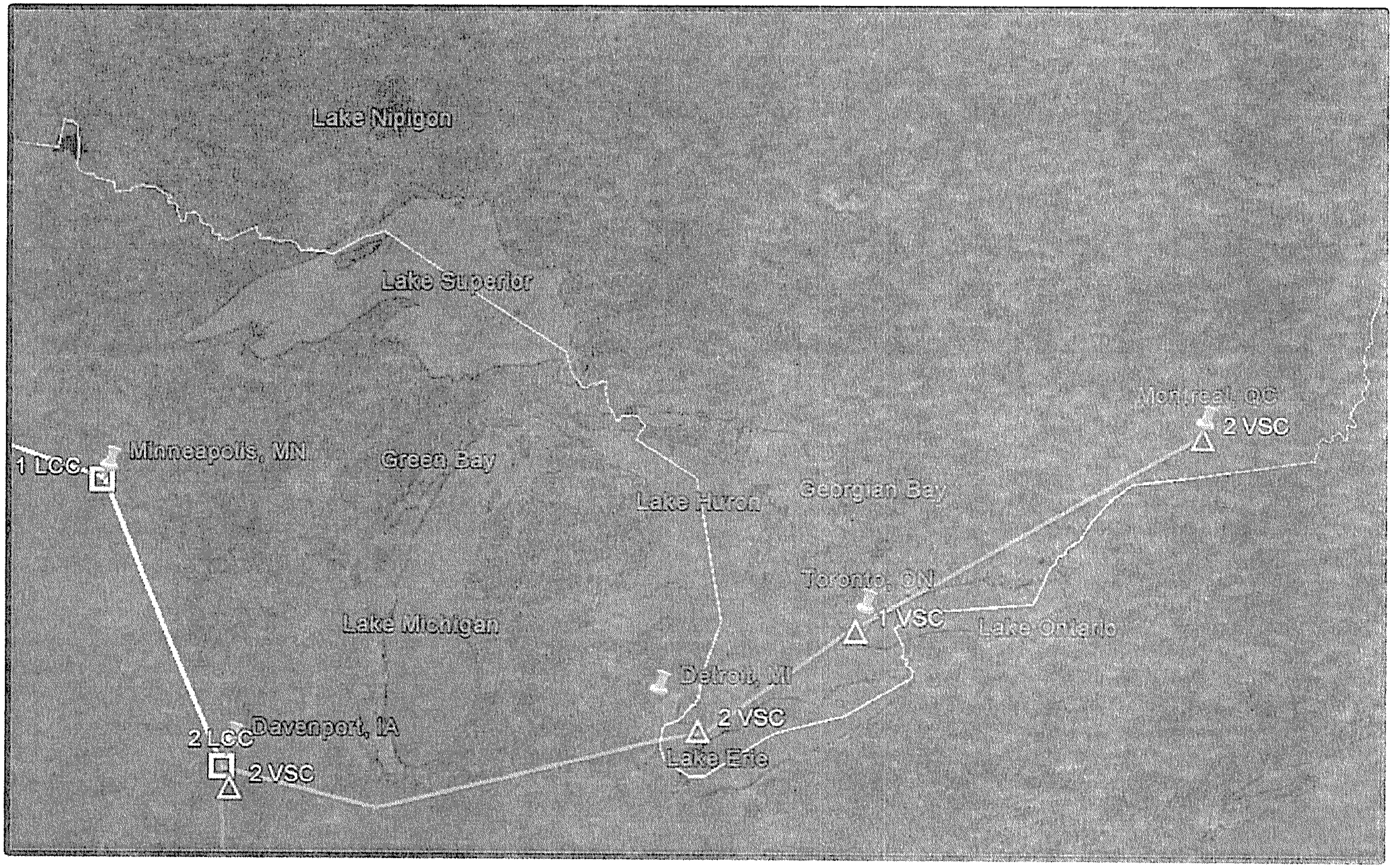
Typical Long Distant Transmission Cost



Continuing Benefits



Minimum Concept for Adding Eastern Canada



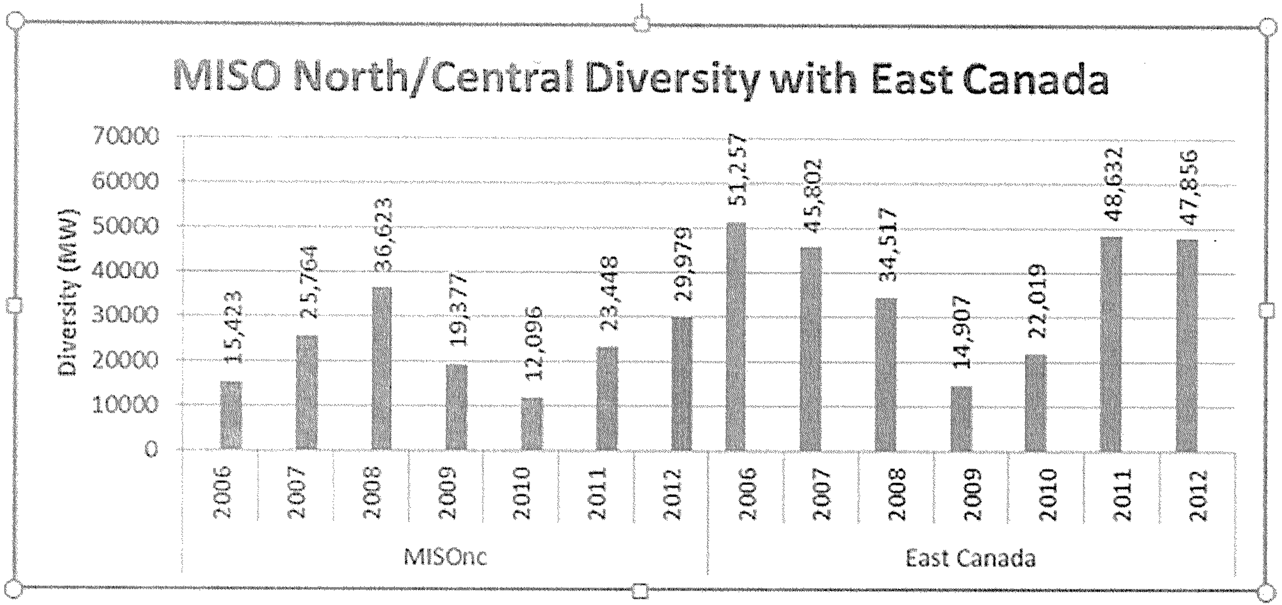


Figure 3: MISO North/Central diversity with East Canada

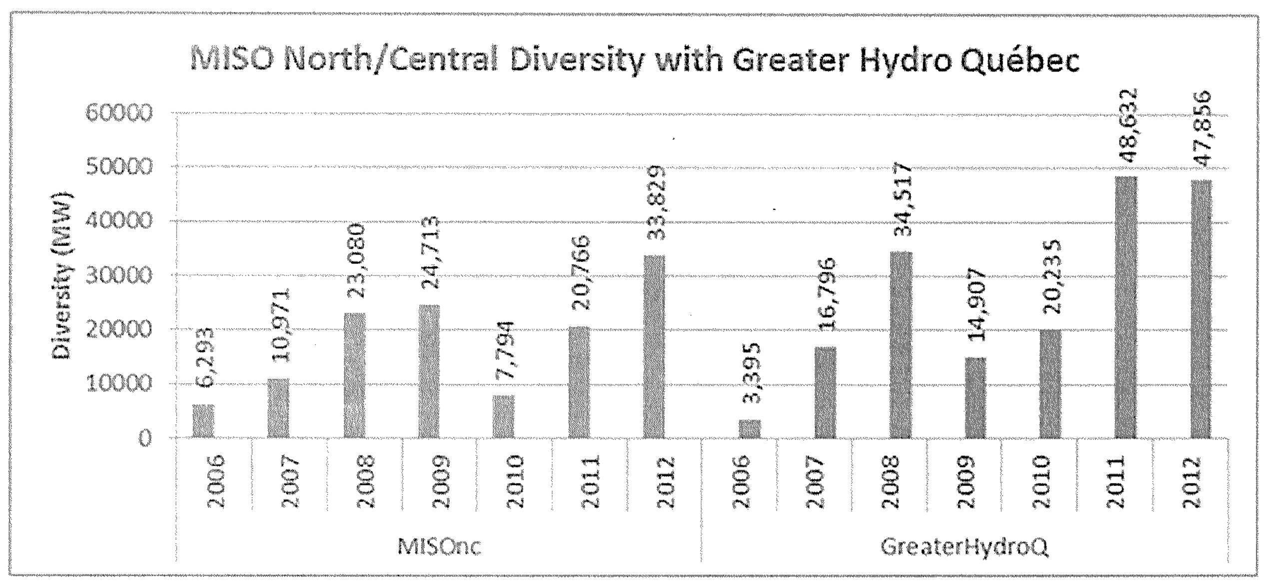


Figure 4: MISO North/Central diversity with Greater Hydro-Québec (includes East Canada and New England)

Load Diversity Potential

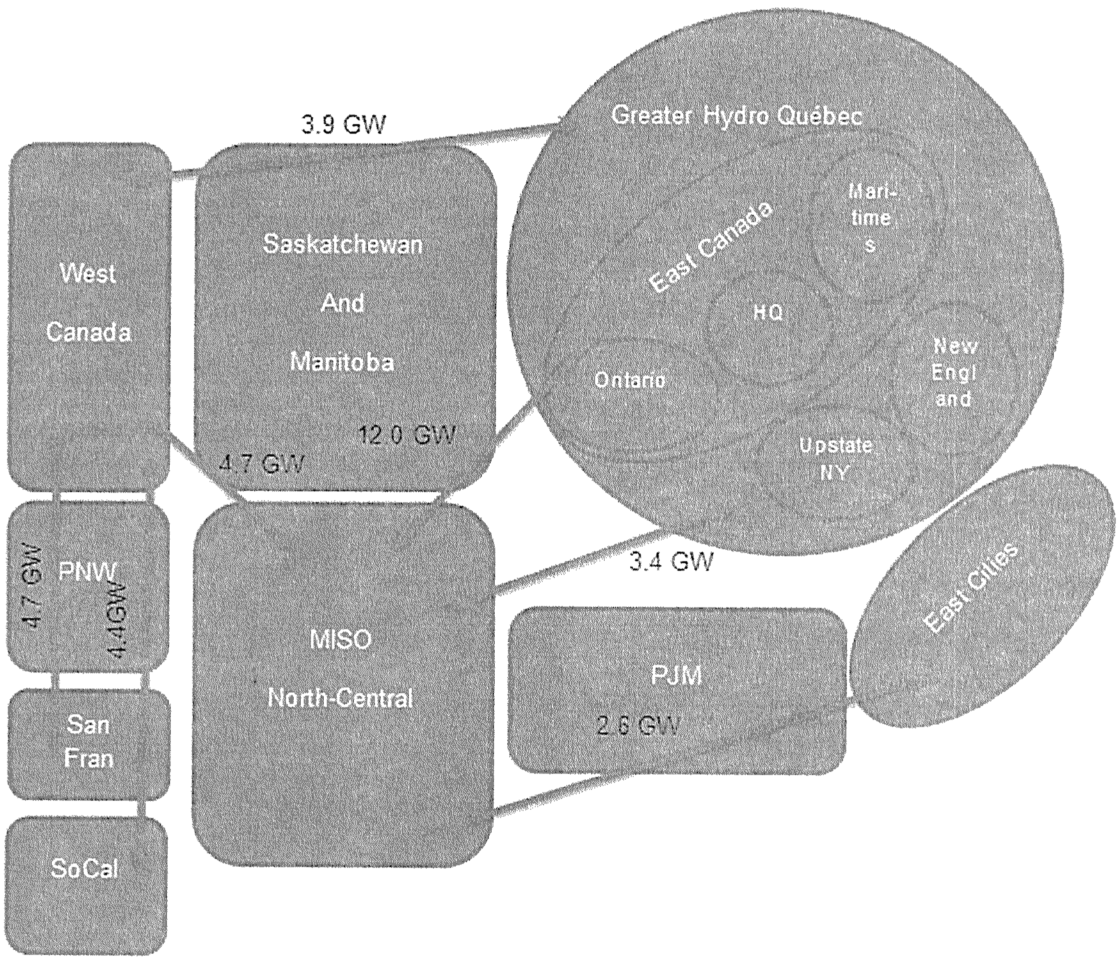


Figure 2: Minimum Bilateral Diversity Bubble Map

Transmission Capacity
Required is
50% of Load Diversity

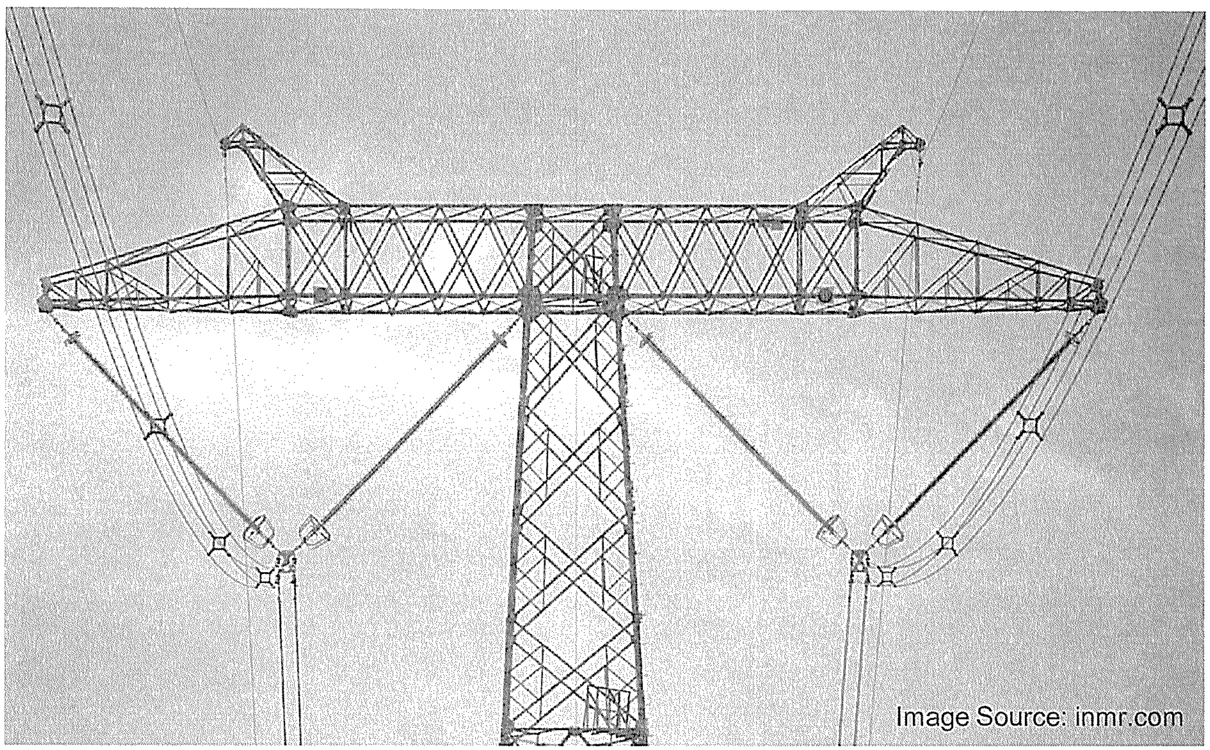
For 1650 MW
of Load Diversity $2.3 B
In estimated benefits

For 550 MW of
Frequency Response
Generation Pooling
$2B in estimated Benefits
Benefit/cost ratio
0.96-1.14
Without
Wind or Energy Arbitrage

Questions?

Contact: Dale Osborn
Phone: (651) 632-8471
E-mail: dosborn@misoenergy.org

Conceptual Interregional HVDC Network

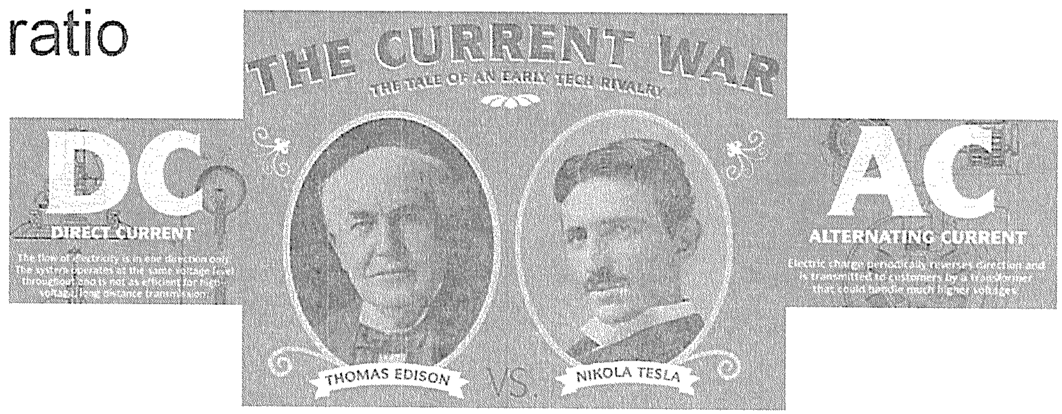


October 16th, 2014

Dale Osborn
David Orser
Maire Waight

HVDC Network Study

- **Objective: Determine the value of connecting multiple regions of the U.S. with an HVDC* network**
- **Potential benefits**
  - 30 GW of displaced peaking generation
  - Revenue of $45.3 billion
  - 1.25 Benefit-Cost ratio



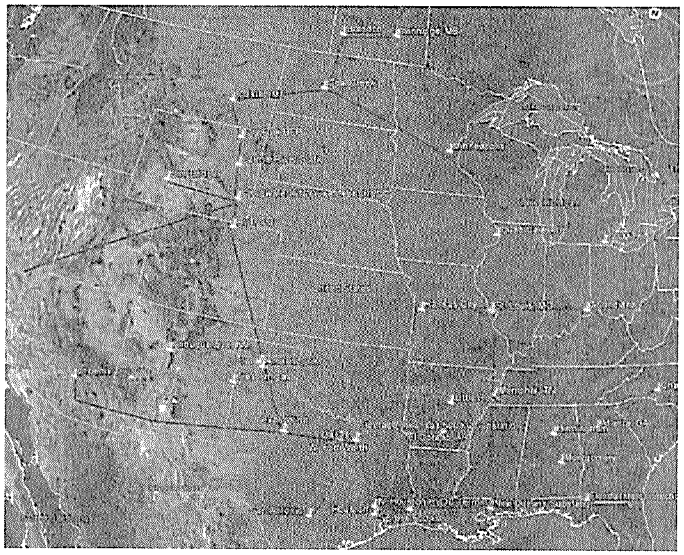
*HVDC - High Voltage Direct Current

How is this study different?

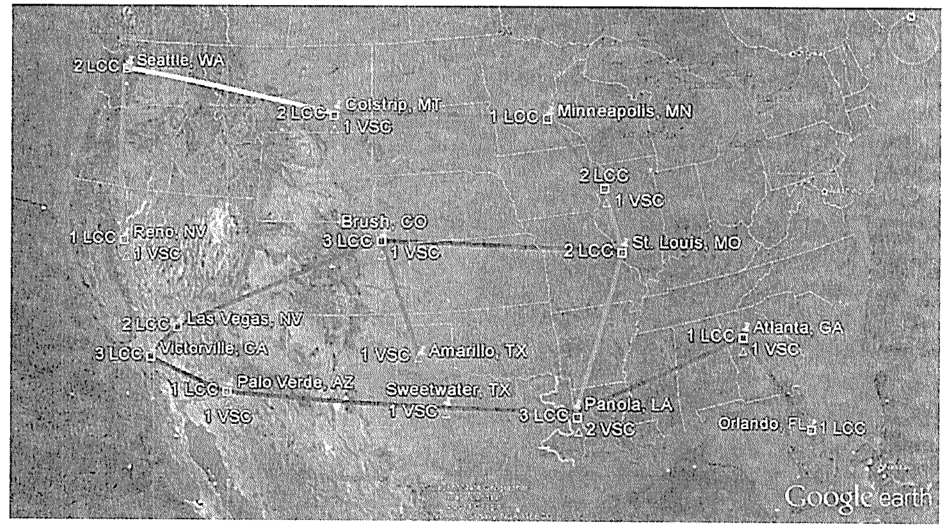
- **Energy vs. Capacity**
  - Most power transmission planning today deals largely in energy
  - Capacity – Supplying power during <u>peak load</u>
    - ~zero energy (E = P*(10 hours / 1 year) ~= 0)
  - Peak capacity is supplied by peaker units
    - High $/Whr
    - High capital cost, low fuel cost
    - Is it possible to increase utilization % of these units?

HVDC Sketch Differences

Jan 8th, 2014



Oct 16th, 2014



- Bottom Up Topology
- Based first on Frequency Response
- 2012 load data
- 23,000 MW of diversity and renewables

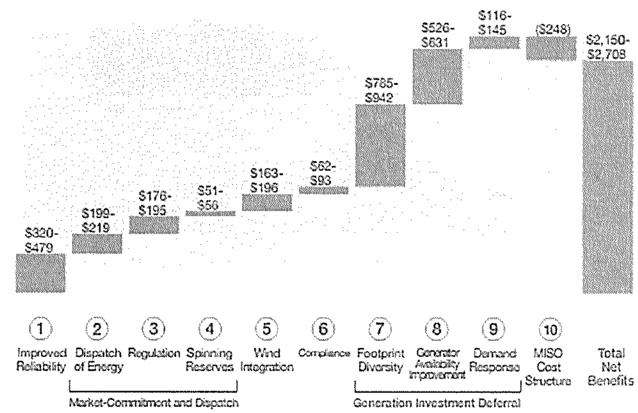
- Top Down Topology
- Based first on Load Diversity
- 2006-2012 Load Data
- 70,100 MW of diversity and renewables

Increased scope by ~33% of MISO total load

HVDC High-Level Value Drivers

- Load Diversity
  - Interregional transport of capacity (near zero energy)
- Frequency Response
  - Enhanced power system reliability through frequency support
- Wind/Solar Diversity
  - Reduced variability of renewable resources
- Other benefits
  - Transport of high-value energy for renewable portfolio standards' requirements
  - Bulk transport of energy

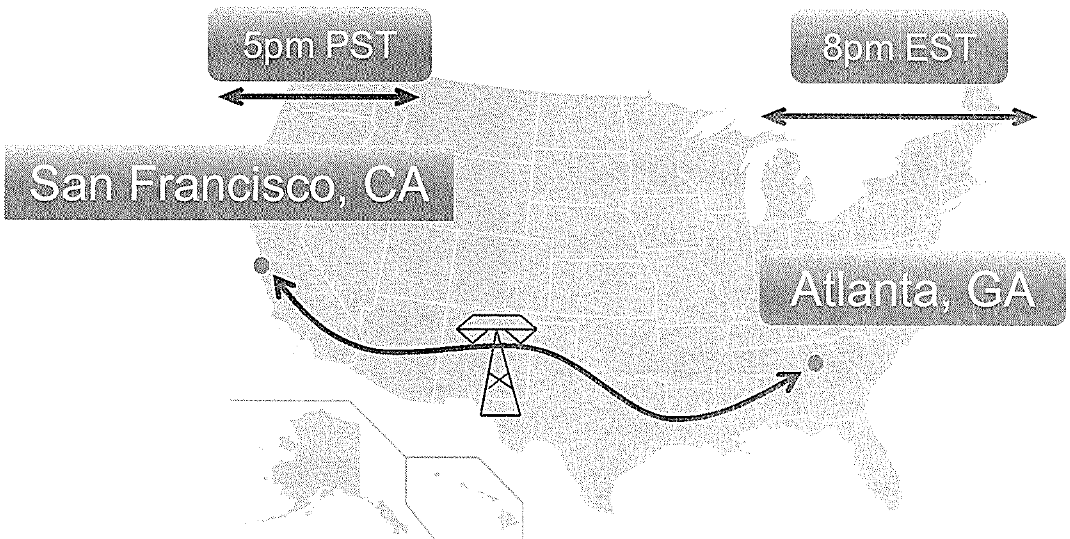
MISO Value Proposition



HVDCnet Value Drivers	
Load Diversity	46%
Frequency Response	22%
Wind/Solar Diversity	5%
Other Benefits	27%

Load Diversity

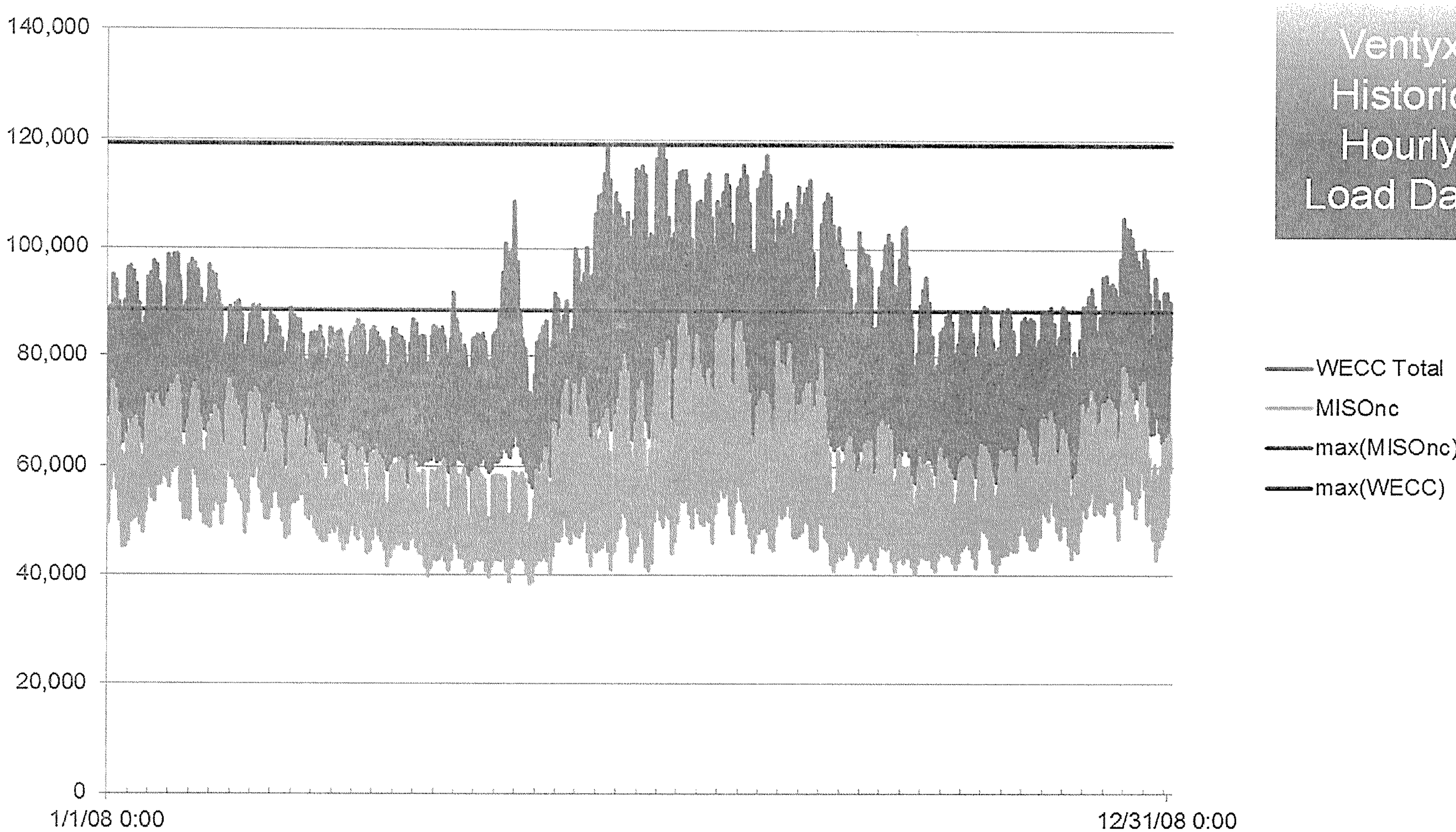
- **Load Diversity** – Differences in the load profiles between two regions



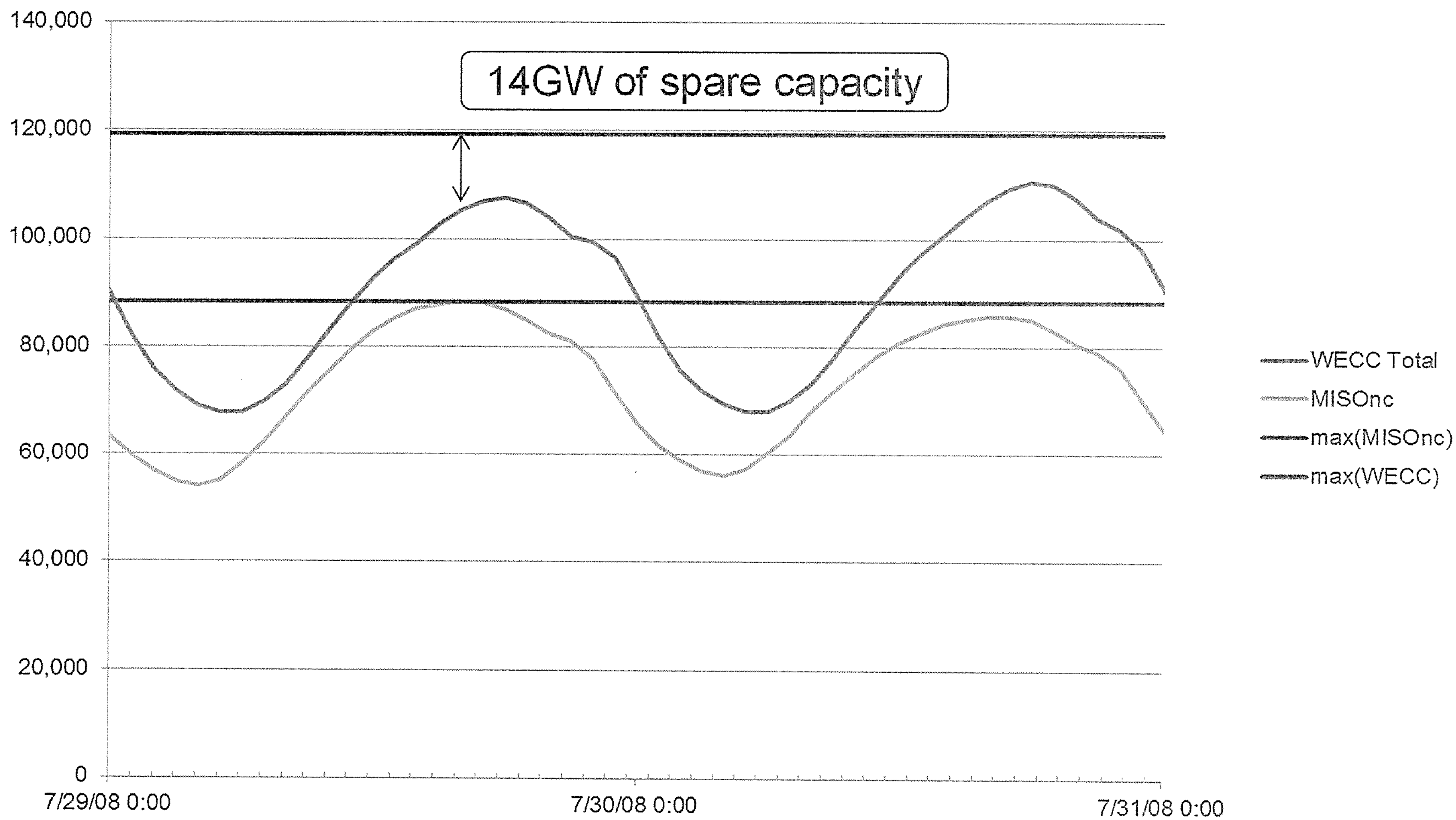
  - Value → Spare capacity displaces generation
  - Sources → Time, industry, climate, weather, ...
  - Greatest value with greatest distance

2008: MISO vs. WECC (year)

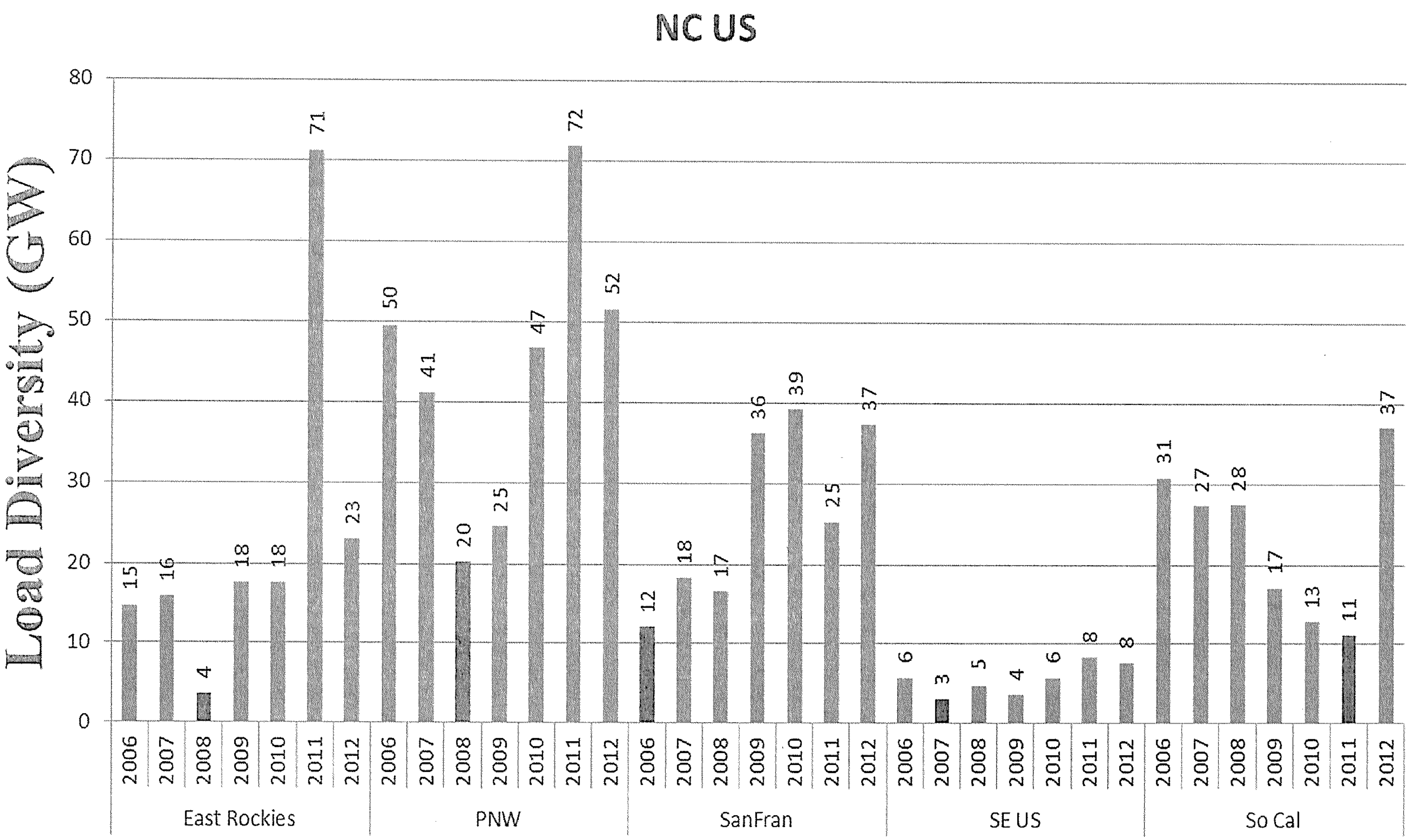
Ventyx Historic Hourly Load Data



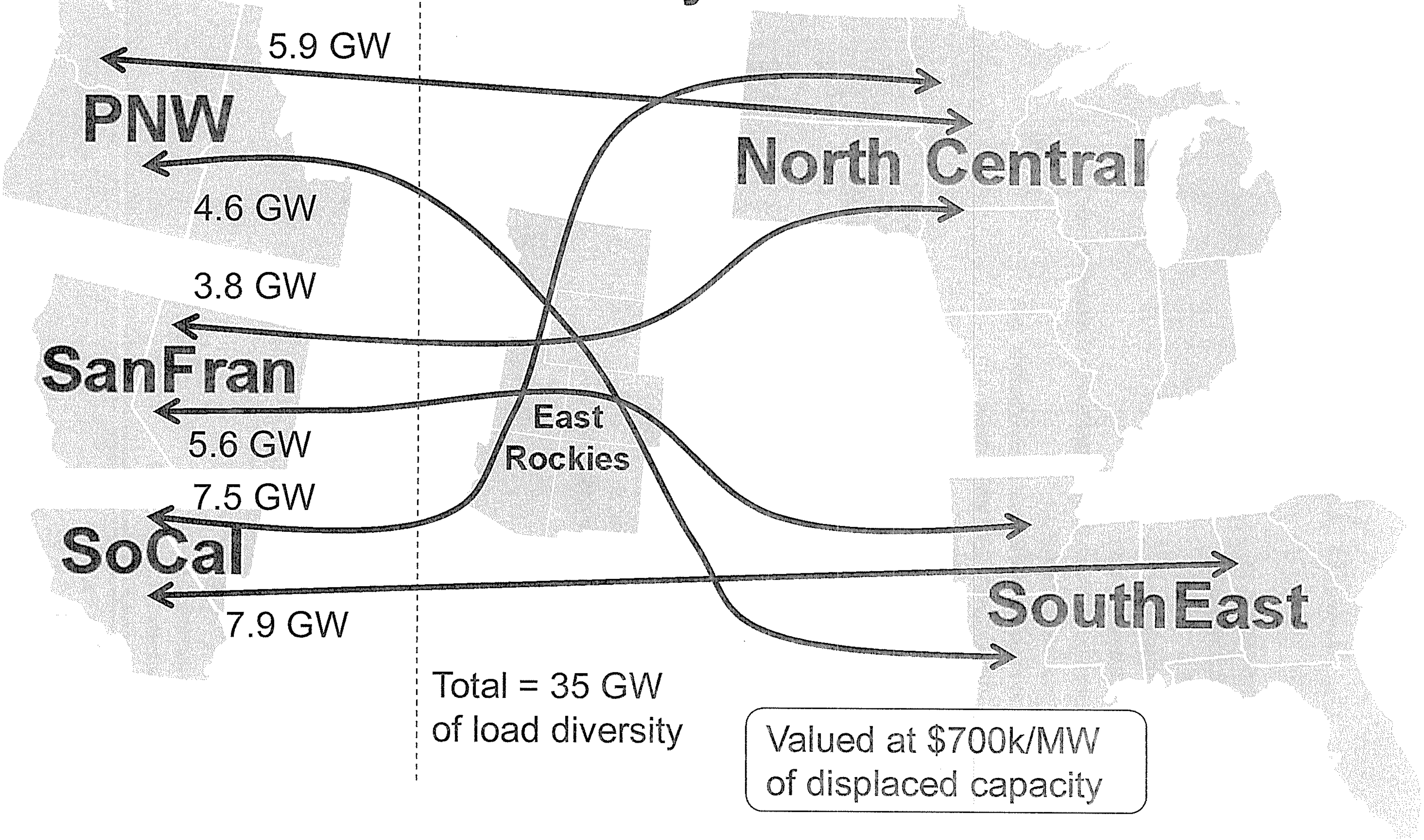
2008: MISO vs. WECC (@ MISO peak day)



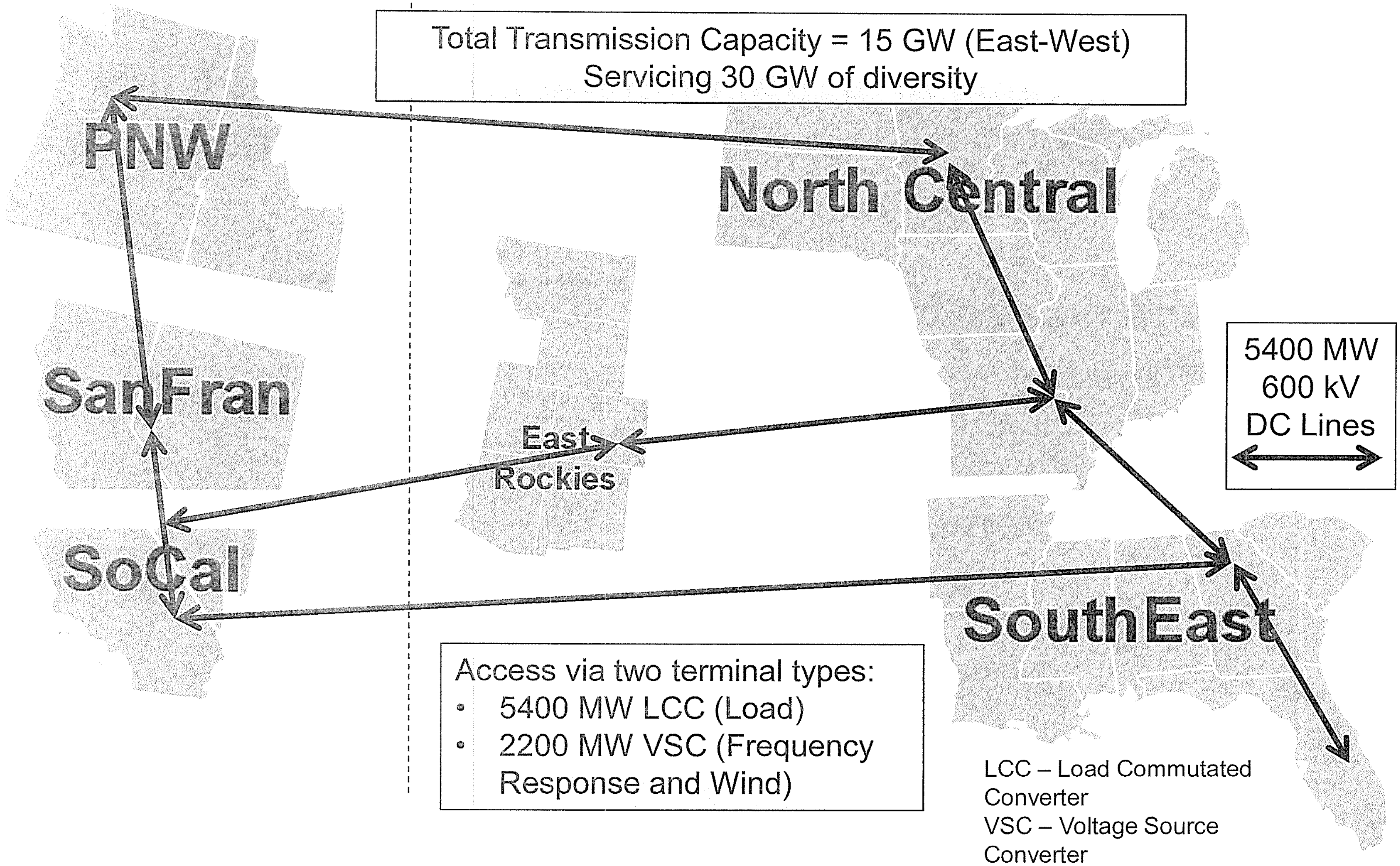
North Central U.S. Spare Capacity



Load Diversity Between Areas



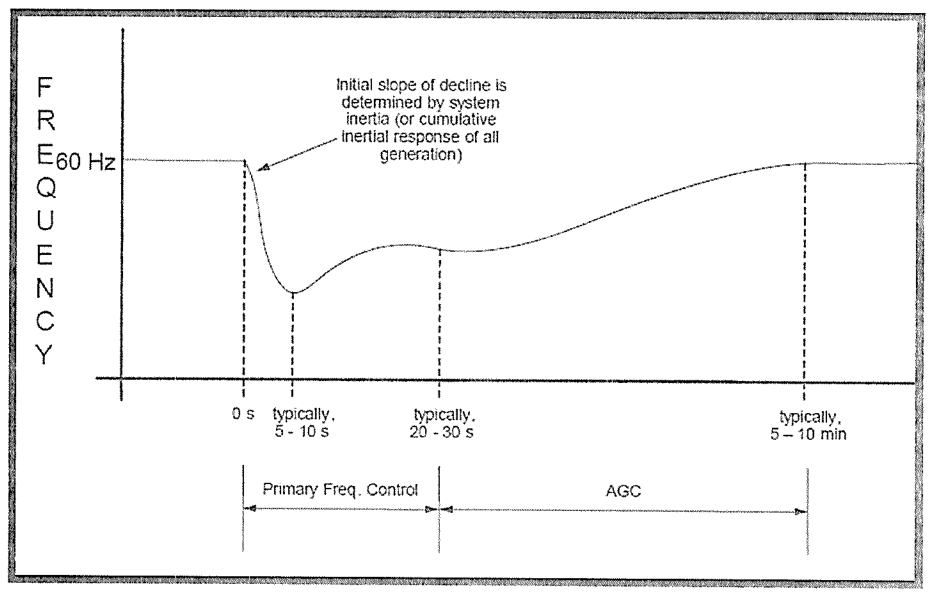
HVDC Network Sketch



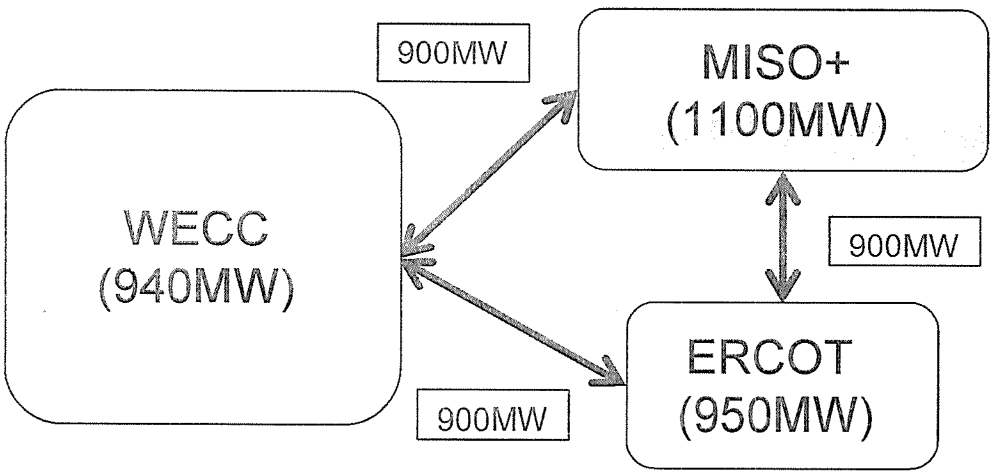
Frequency Response

- **Potential value in distributing Resource Contingency Criteria (RCC) between HVDC network participants**

- **Benefit comes from:**
  - $700,000/MW from capital cost of capacity
  - $13/MWh from frequency response premium



Frequency Response

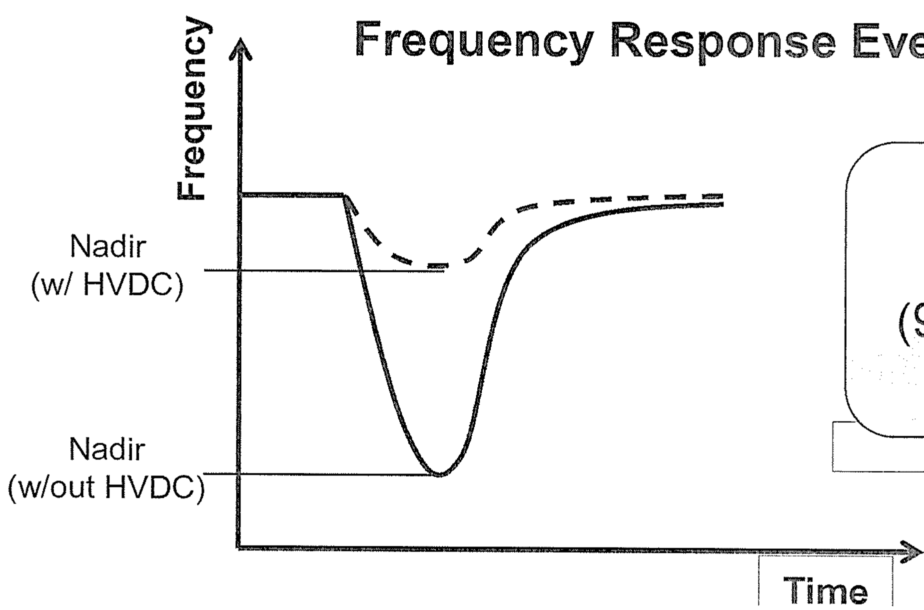


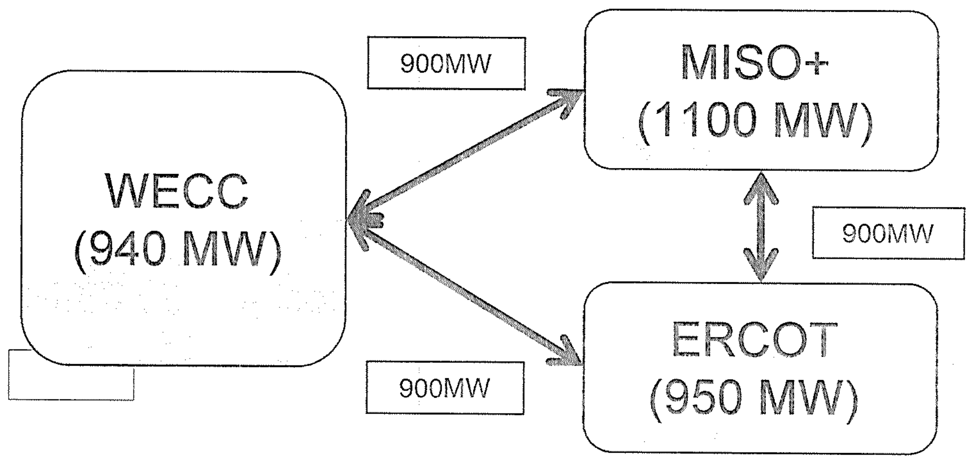
Zone	Reserves (MW)
East	4500
→ MISO+	2900
WECC	2740
ERCOT	2750

- **Sharing frequency response reserves through interregional secure power transmission**
  - ~950 MW of local reserve, ~2750 total reserves
  - 2x900 MW of secure transmission
  - Net benefit 5400 MW of displaced capacity (3x1800 MW)
- **Approximately 1 in 30 years there will be an outage in two regions simultaneously**

Frequency Response (cont.)

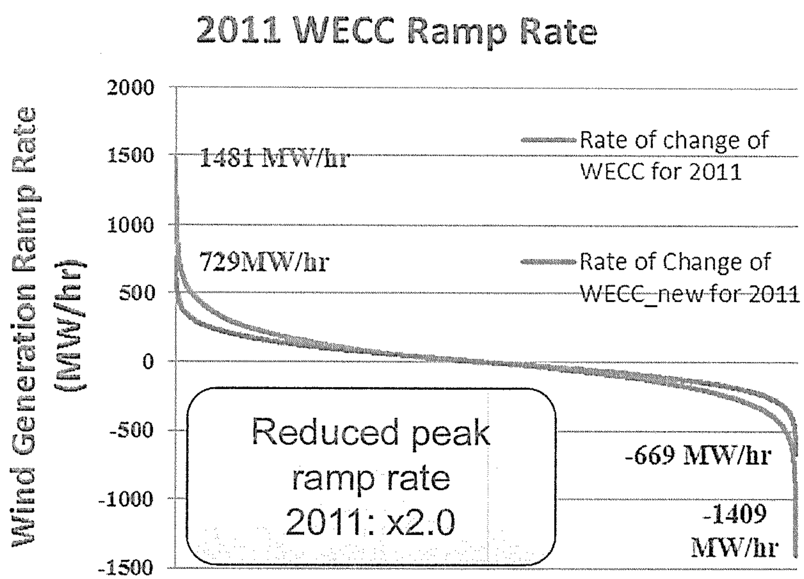
- **Improved frequency response performance**
  - Current governor control responds in 3-5 seconds
  - VSCs allow for response in 0.1 seconds
  - Raises frequency event nadir

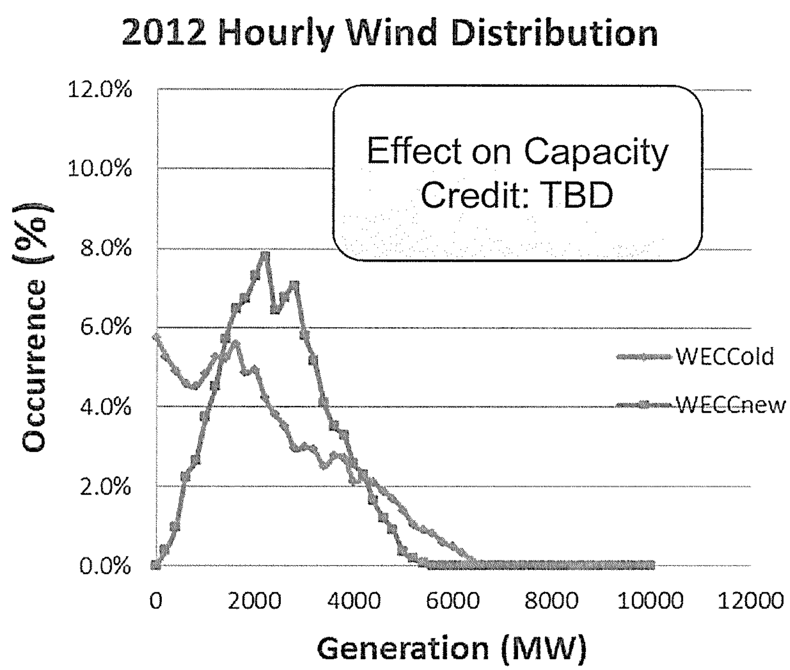




Wind Energy Benefits for WECC

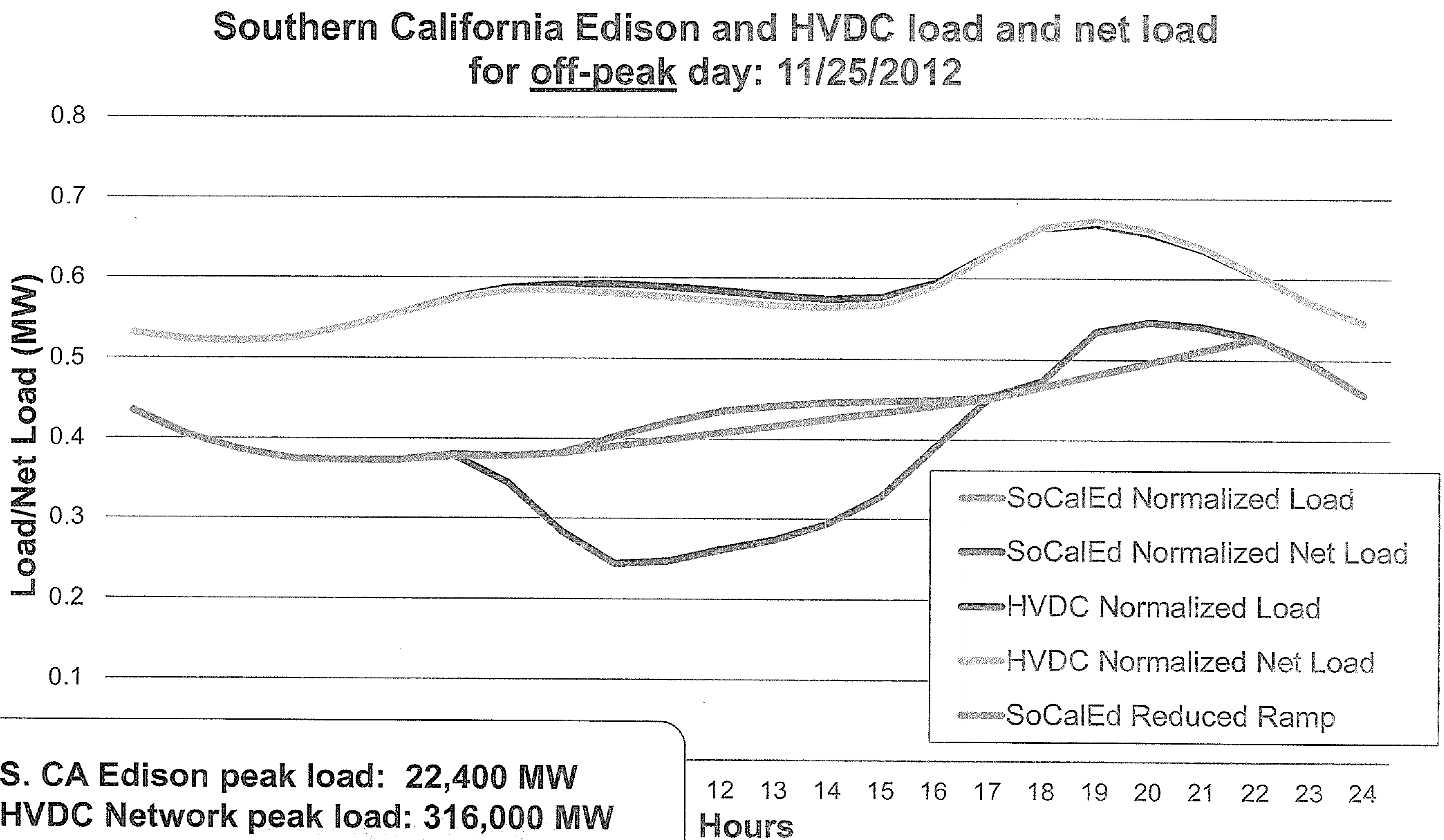
- Add all wind generation across MISO, ERCOT, and WECC
- Re-distribute wind based on peak capacity





- Benefits
  - Reduced ramp rate
  - Reduced variability (and thereby potentially increased capacity credit)

High Solar Generation Impact



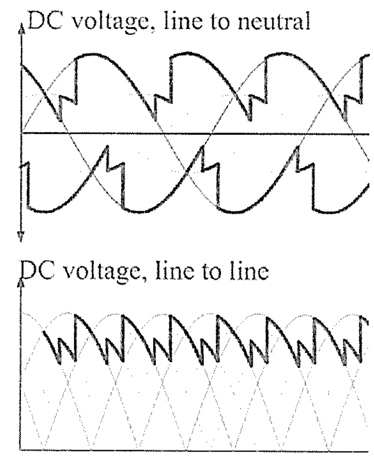
S. CA Edison peak load: 22,400 MW
HVDC Network peak load: 316,000 MW

“Other Energy Based Benefits”

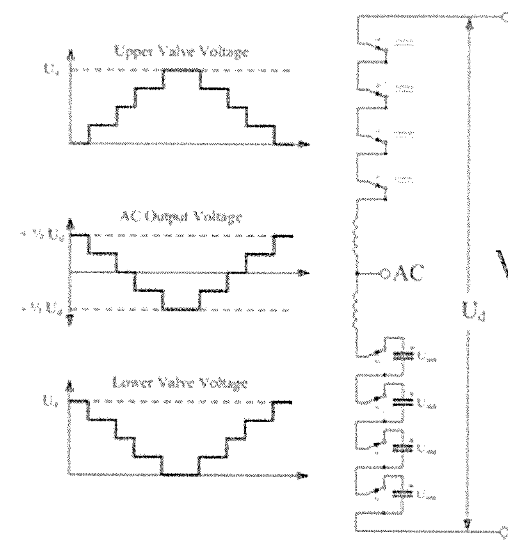
- **Energy Arbitrage across the network**
  - $3/MWhr
- **Wind and Solar for Renewable Portfolio Standards**
  - $4/MWhr
- **Split transmission of renewables in the mid-west and south-west**
  - Up to $30/MWhr
  - More details later this session
- **(not counted) Secondary load diversity mining**
  - North-South Links, Rockies, SPP, and …
  - $700k/MW

HVDC Terminal Types

- **Line Commutated Converter (LCC)**
  - Widely deployed today
  - Lowest $/MW for bulk transport
  - LCCs are “Slow” with >10 sec. reversal times
- **Voltage Source Converters (VSC)**
  - A few standard VSCs in service today (Michigan Straits, San Francisco, Spain)
  - Black start capability
  - Full four quadrant operation (voltage regulation to zero schedule)
  - Fast response (frequency regulation)
  - Reversible and controllable ramps (load following, renewables)



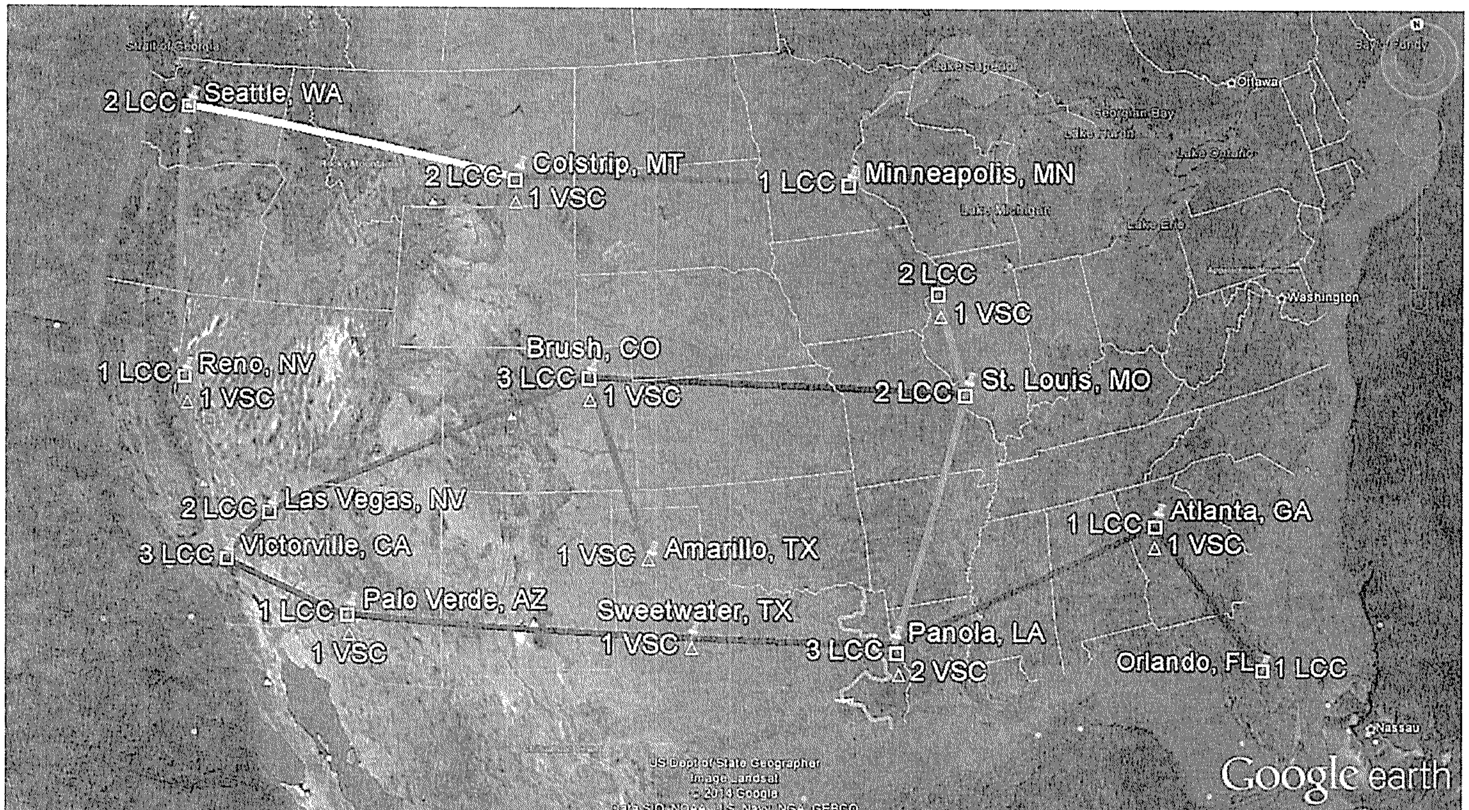
LCC



VSC

VSC-MMC graphic by: Clampower [CC-BY-SA-3.0], Wikimedia Commons

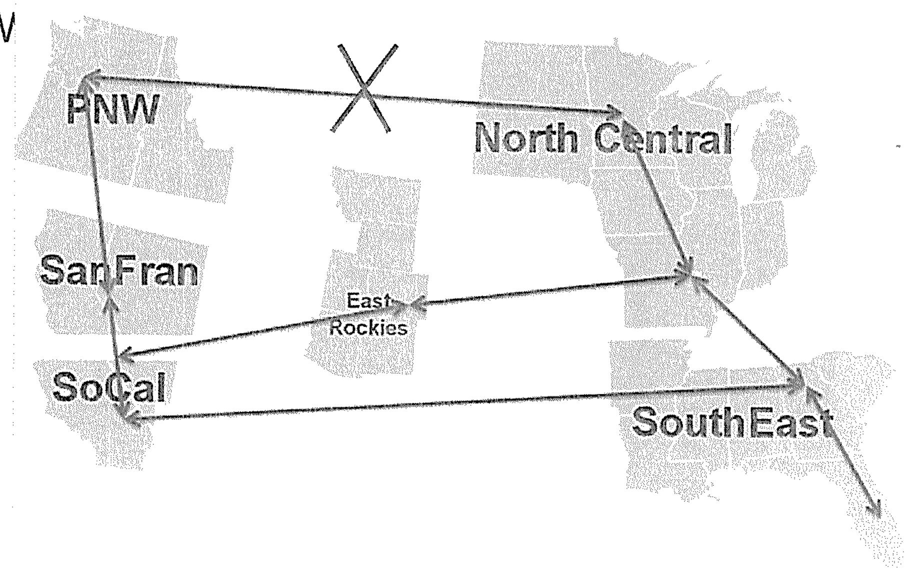
Conceptual HVDC Network Sketch



- Max three terminal LCC links in concept network
- VSC taps in parallel (Frequency Response and Regulation)

Contingency Analysis

- **Network includes 3 lines = 16.2 GW (east-west transmission)**
  - N-1 fault event = 10.8 GW of transmission
    - → 5.4 GW Contingency (MSSC - Most Severe Single Contingency)
- **Alterative:**
  - HVDC Lines have overload capacity (115% for 20+ mins)
  - 5000MW scheduled, 400 MW reserved capacity
  - N-1 Capacity of 2x6.25 GW = 12.5 GW
    - → **2.5 GW Contingency (MSSC)**
- Additional mitigation is possible with spare AC capacity between some terminals (north-south)
- Expansion of network to >3 links will further reduce the MSSC



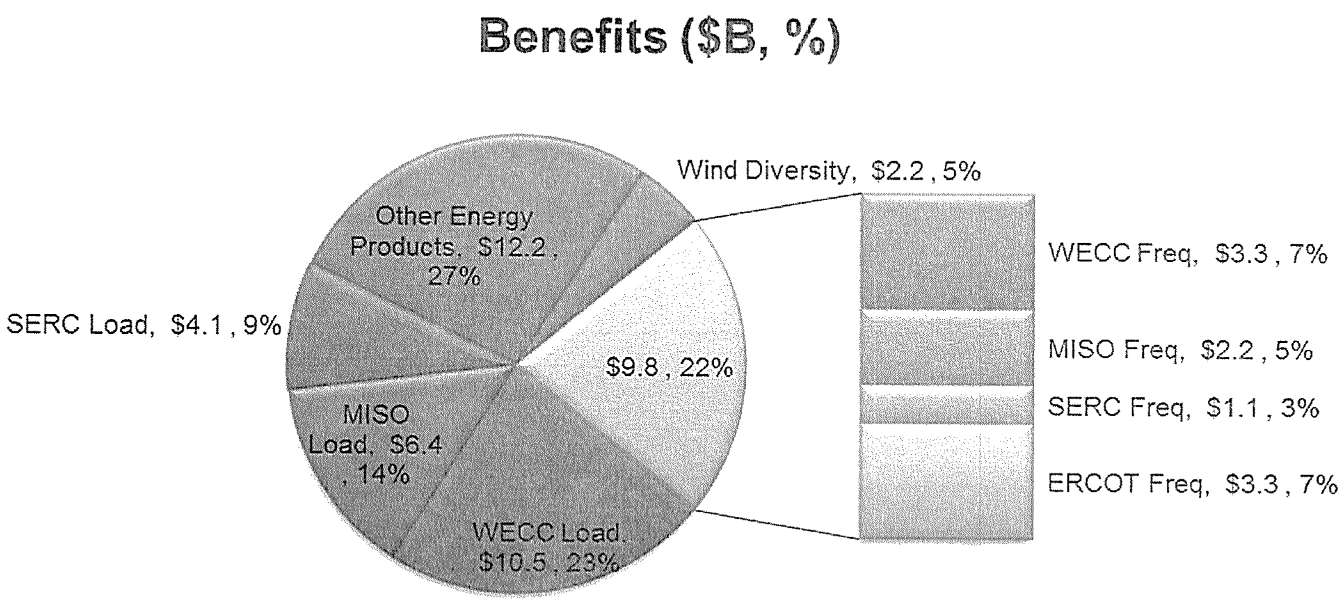
Cost / Benefit

Cost	Units	$/Unit	Total
Line	7654 Miles	$3 Million/Mile	$23.0 Billion
LCC	22 Terminals	$472 Million/Terminal	$10.4 Billion
VSC	10 Terminals	$285 Million/Terminal	$2.9 Billion
		Grand Total	**$36.2 Billion**

Benefit	Total	
Load Diversity	$ 21.0 Billion	46%
Frequency Response	$ 9.8 Billion	22%
Wind Diversity	$ 2.2 Billion	5%
Other Energy Based Benefits	$ 12.2 Billion	27%
Grand Total	**$45.3 Billion**	

Benefit/Cost Ratio	**1.25**

Costs allocated by % of benefits



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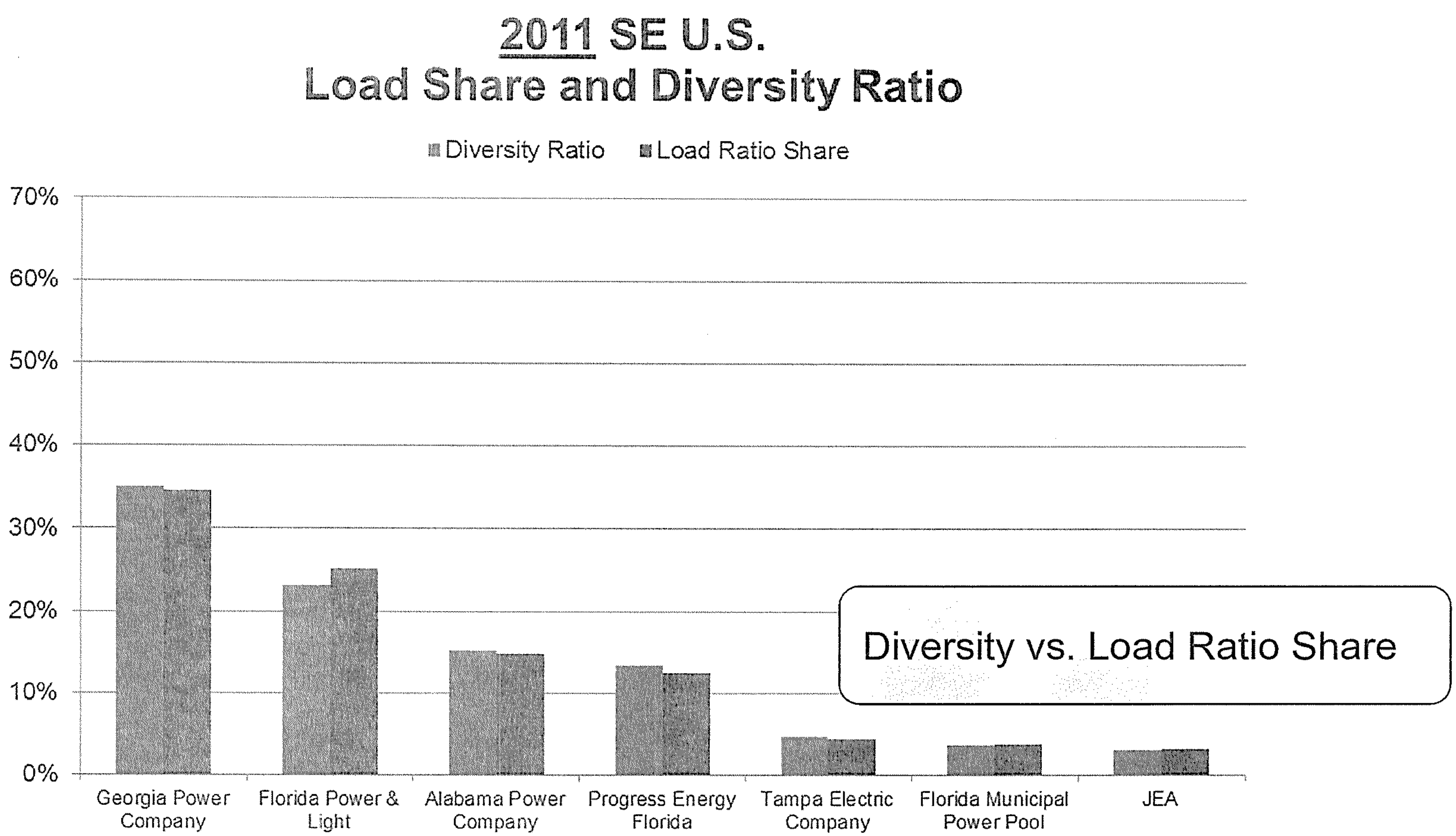
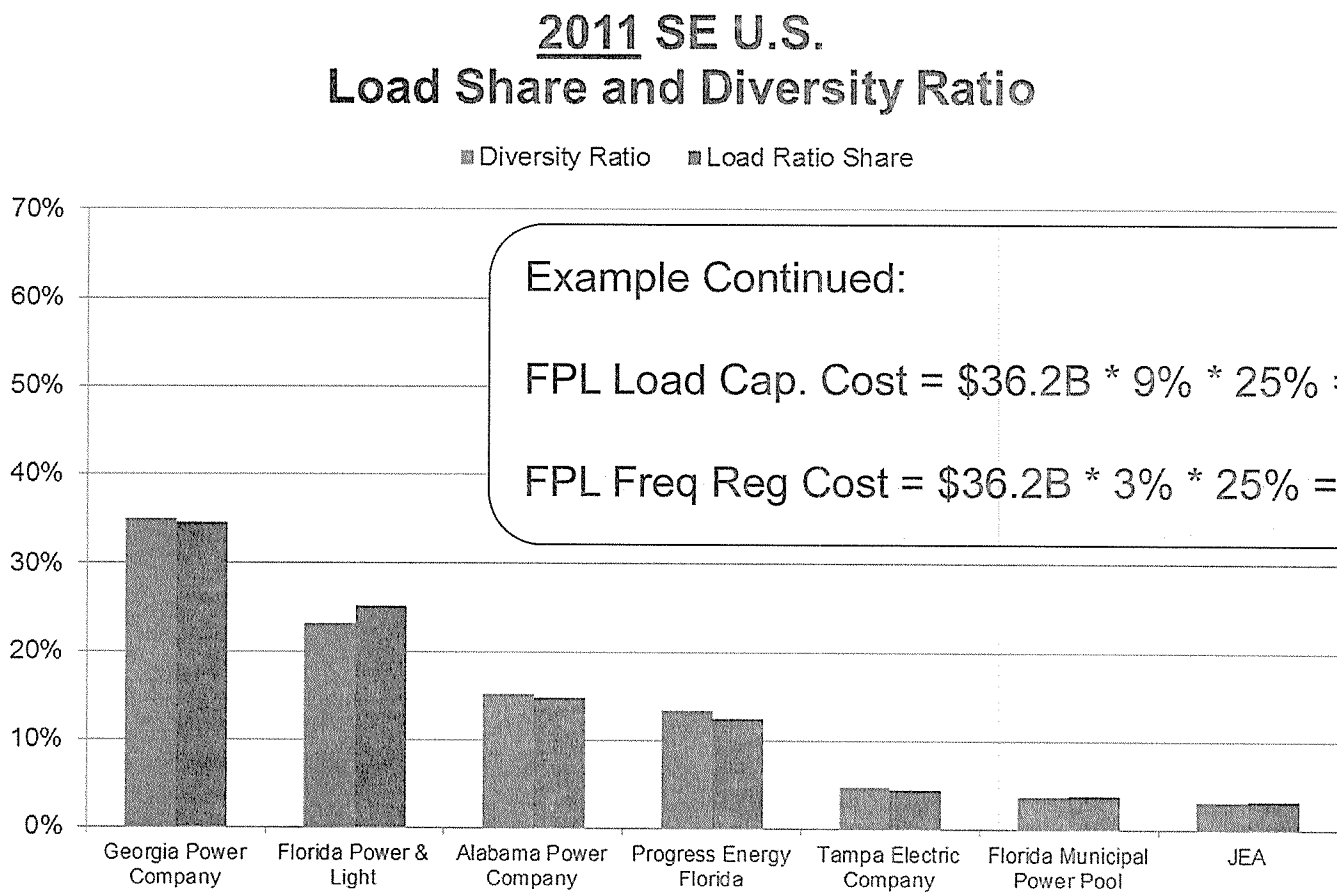
SERC Load Cap. Cost = $36.2B * 9% = $3.3B

SERC Freq Reg Cost = 36.2B * 3% = $1.1B

Diversity vs. Load Ratio Share



Diversity vs. Load Ratio Share

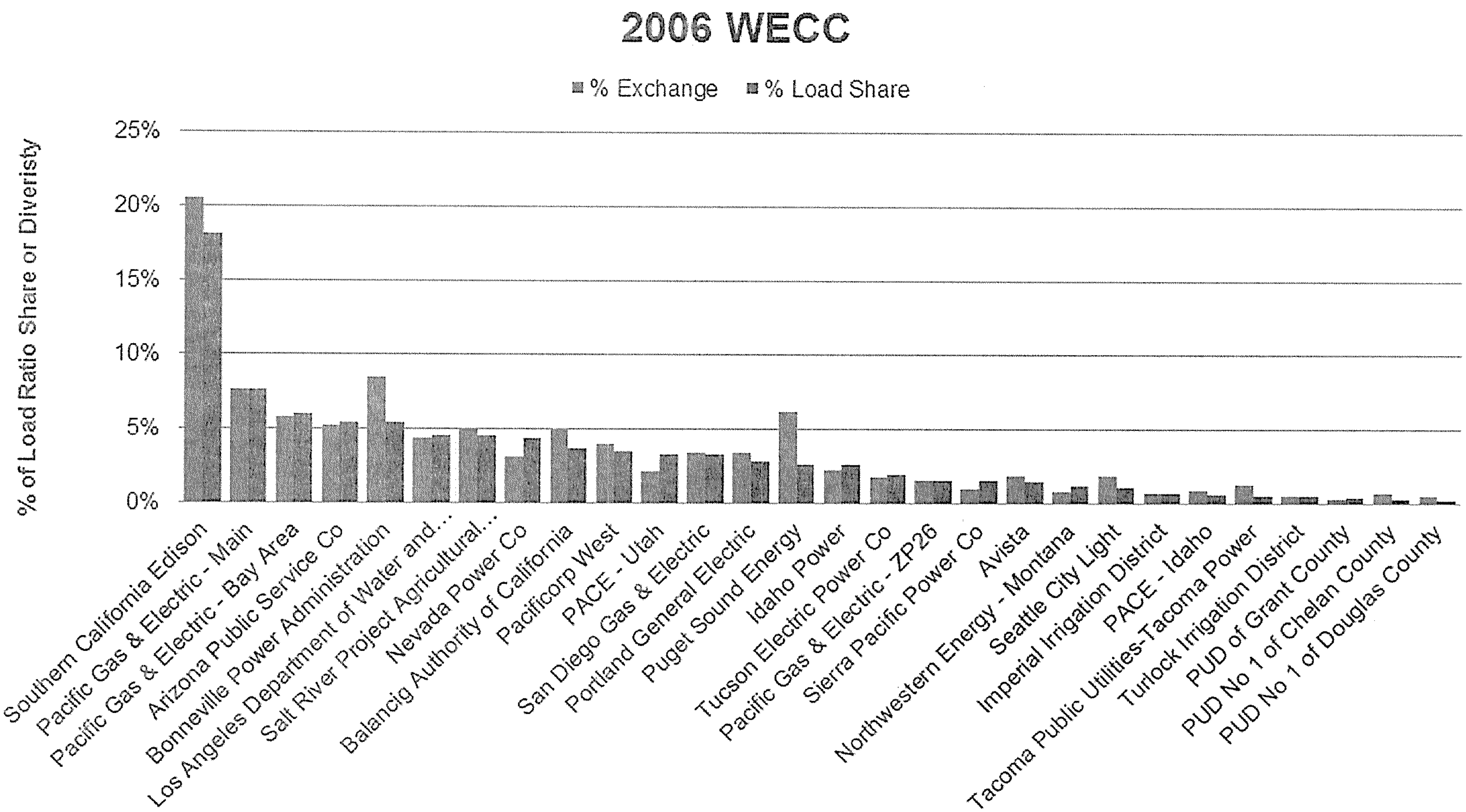


Example Continued:

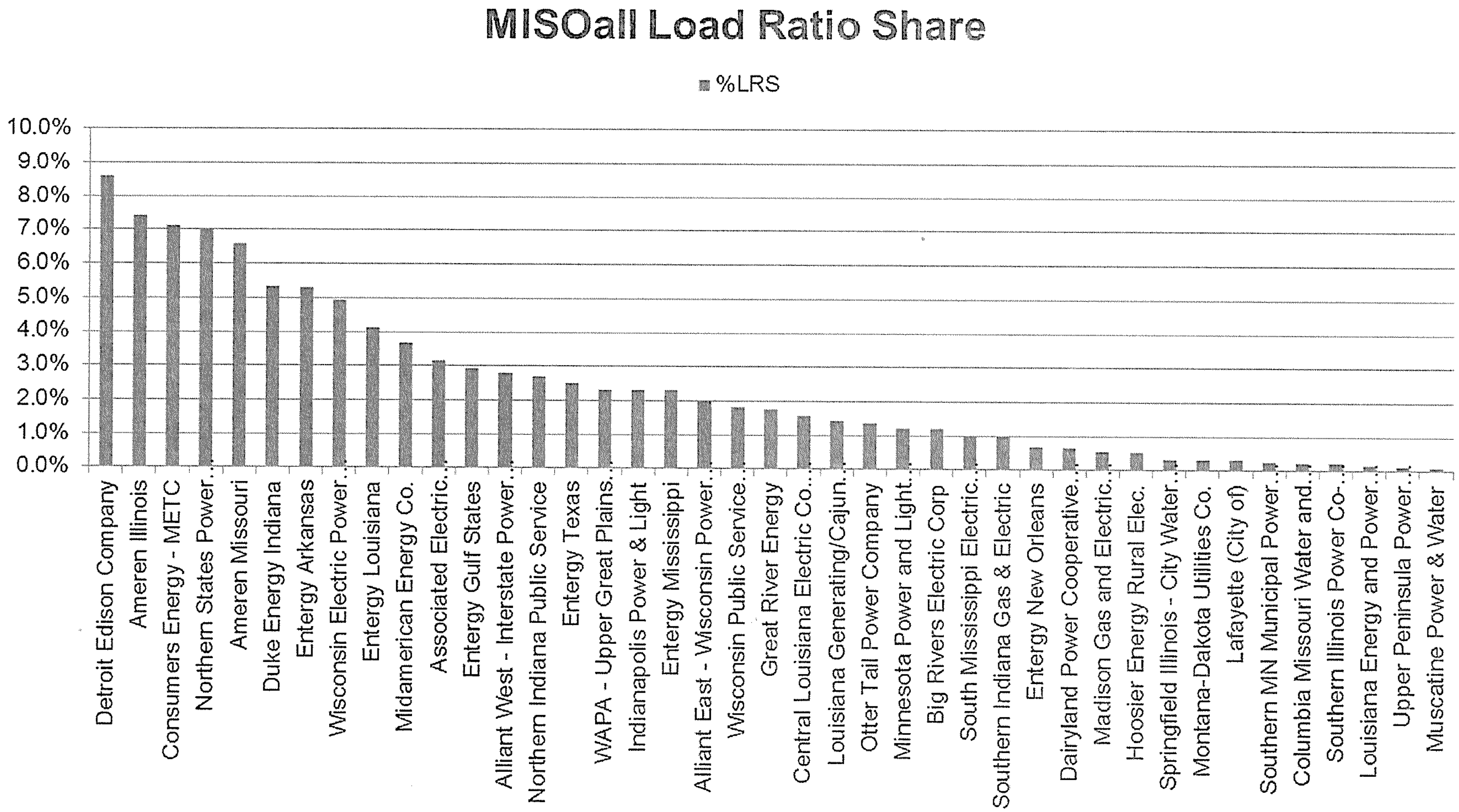
FPL Load Cap. Cost = $36.2B * 9% * 25% = $815M

FPL Freq Reg Cost = $36.2B * 3% * 25% = $270M

WECC Load Ratio Share and Diversity

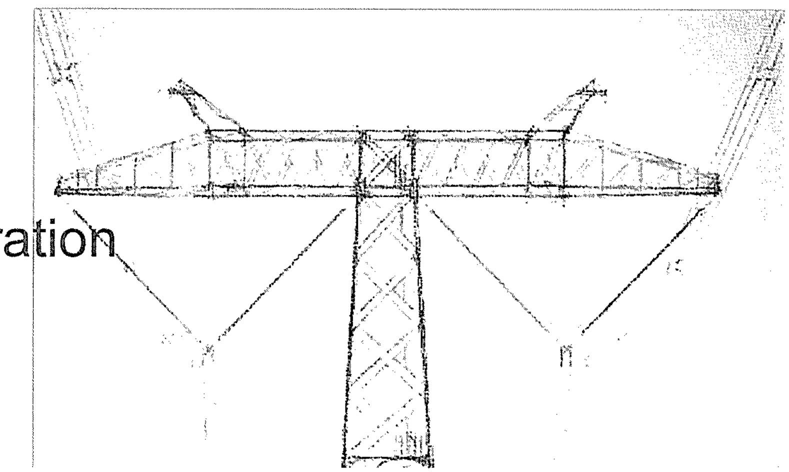


MISO Load Ratio Share



HVDC Network Study Findings

- An interregional HVDC network may provide benefits in excess of costs
- Utilizing capacity and frequency response sharing substantially reduces the cost burden to justify transmission
- Utilizing loop and overload allows lines >MSSC



- Potential benefits
  - 30 GW of displaced peaking generation
  - Revenue of $45.3 billion
  - 1.25 Benefit-Cost ratio

Questions?

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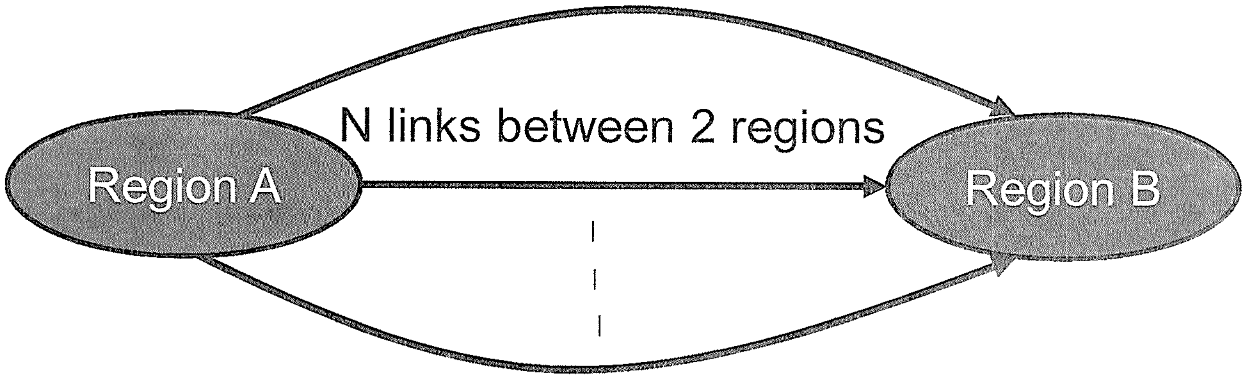
Phone: (651) 632-8588
E-mail: dorser@misoenergy.org

Backups/Alternative Slides

(N-1) Contingency Analysis



- **Maximum Scheduled Power**

(with 5400MW lines and 2700MW MSSC)

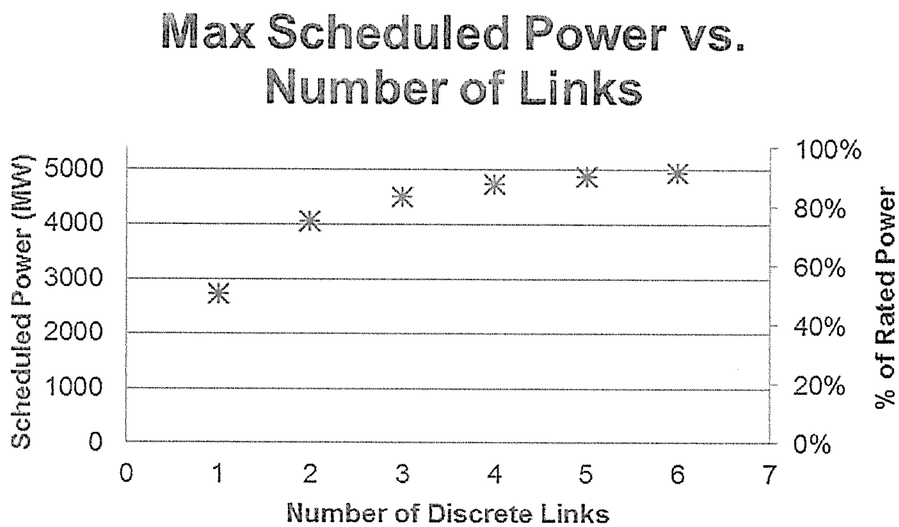
  - 1 link → 2700 MW
  - 2 links → 4050 MW
  - 3 links → 4500 MW

MSSC - Most Severe Single Contingency

(N-1) Contingency Analysis Cont.

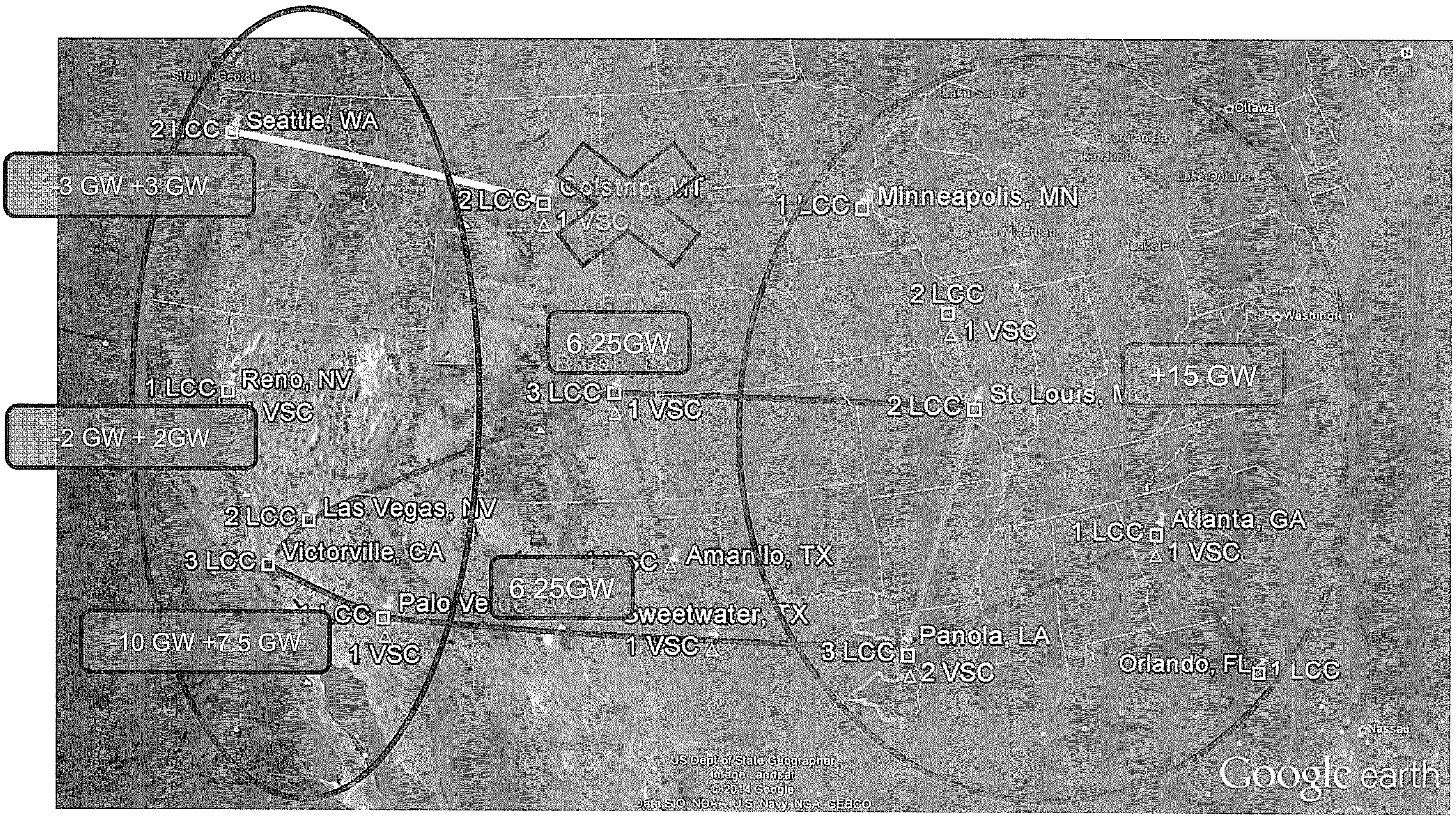
- Power Scheduled per Line
  - $P_{sch}/N = (N*P_r - C)/N$

N = number of links
P_r = Rated Power
P_{sch} = Scheduled Power
C = Most Severe Single Contingency



N	Psch/N	% of Pr
1	2700	50%
2	4050	75%
3	4500	83%
4	4725	88%
5	4860	90%
6	4950	92%

Contingency Example (cont.)



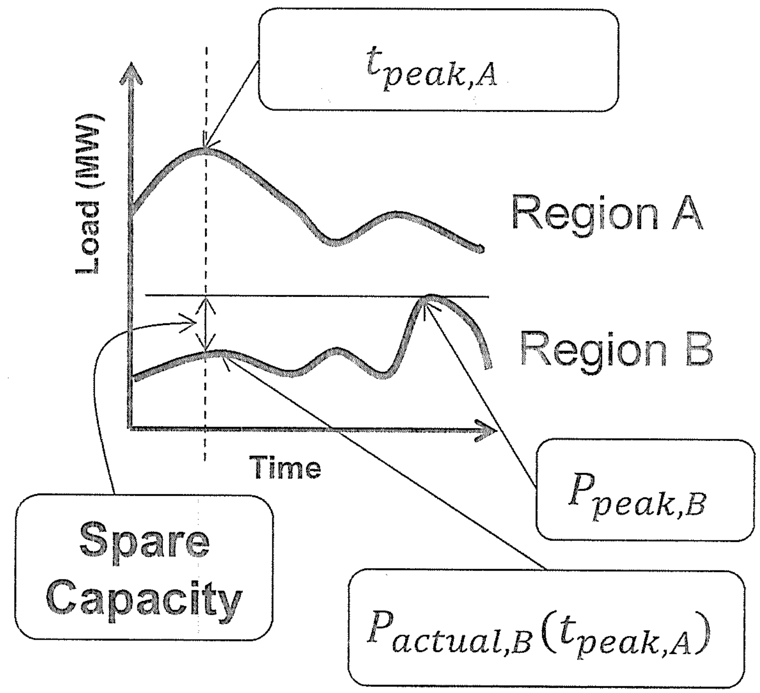
Future Work on HVDC Network

- Wind diversity
  - Capacity credit
  - Energy value
- Solar diversity
- Energy market value
- Collaborate with key partners and stakeholders
  - Joint studies with peer regional bodies

Calculating Load Diversity: Methodology

- Start with hourly load data from Ventyx
- Find the <u>spare capacity</u> of region B at region A's peak load

  $P_{peak,region} - P_{actual}(t_{peak,region})$
- Find the minimum available spare capacity over 7 years (2006-2012)



Ventyx data are obtained from FERC Form 714 Part III Schedule 2 reporting

Ancillary Benefits

- **HVDC terminal locational advantages**
  - Can be placed anywhere, not just at seams
    - Near wind, provide voltage support
    - Near loads, reduced congestion
  - Asynchronous and schedulable to meet needs (no loop flows!)
- **Overload Capability**
  - HVDC converters and lines can be overloaded for short periods of time (longer than a FR event)
  - Can help alleviate faults within HVDCnet or external events

2008: MISO vs. WECC (summer)