



Technology Session 1: Power Delivery Infrastructure

Overview Presentation: Jerry Heydt, Arizona State University

Discussion Panel: Flora Flygt, Strategic Planning and Policy Advisor, American Transmission Company; **Jim McCalley**, Iowa State University; **Robert Saint**, Principal Engineer, National Rural Electric Cooperative Association; **Peter Sauer**, University of Illinois at Urbana/Champaign

Discussion Facilitator: Ward Jewell, Wichita State University

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Challenge areas for this session include:

- National transmission overlay
- Transmission alternatives (e.g., HVDC, AC, six-phase, alternative conductor technologies)
- Microgrids
- Distribution network infrastructure
- Large scale energy storage - interactions with power delivery infrastructure
- Distributed vs. centralized generation – interactions with power delivery infrastructure
- Demand response – interactions with power delivery infrastructure

Transmission

Distribution

**Robustness through
hardware
enhancement**

**Robustness through
smart design and
operation**

Transmission alternatives

Reasons for transmission expansion

- Load growth
- Integration of wind and solar generation into the grid
- Alleviate transmission bottlenecks
- Connect asynchronous regions

Load growth

- Nearly flat in the last three years
- Central city growth
- Thermal limits could be alleviated, especially without extended outage of existing facilities

- Long distances encountered (e.g., Dakota – East)
- Modest concentration of generation
- Security limits, phase angle stability issues

Integration of renewables

Transmission alternatives

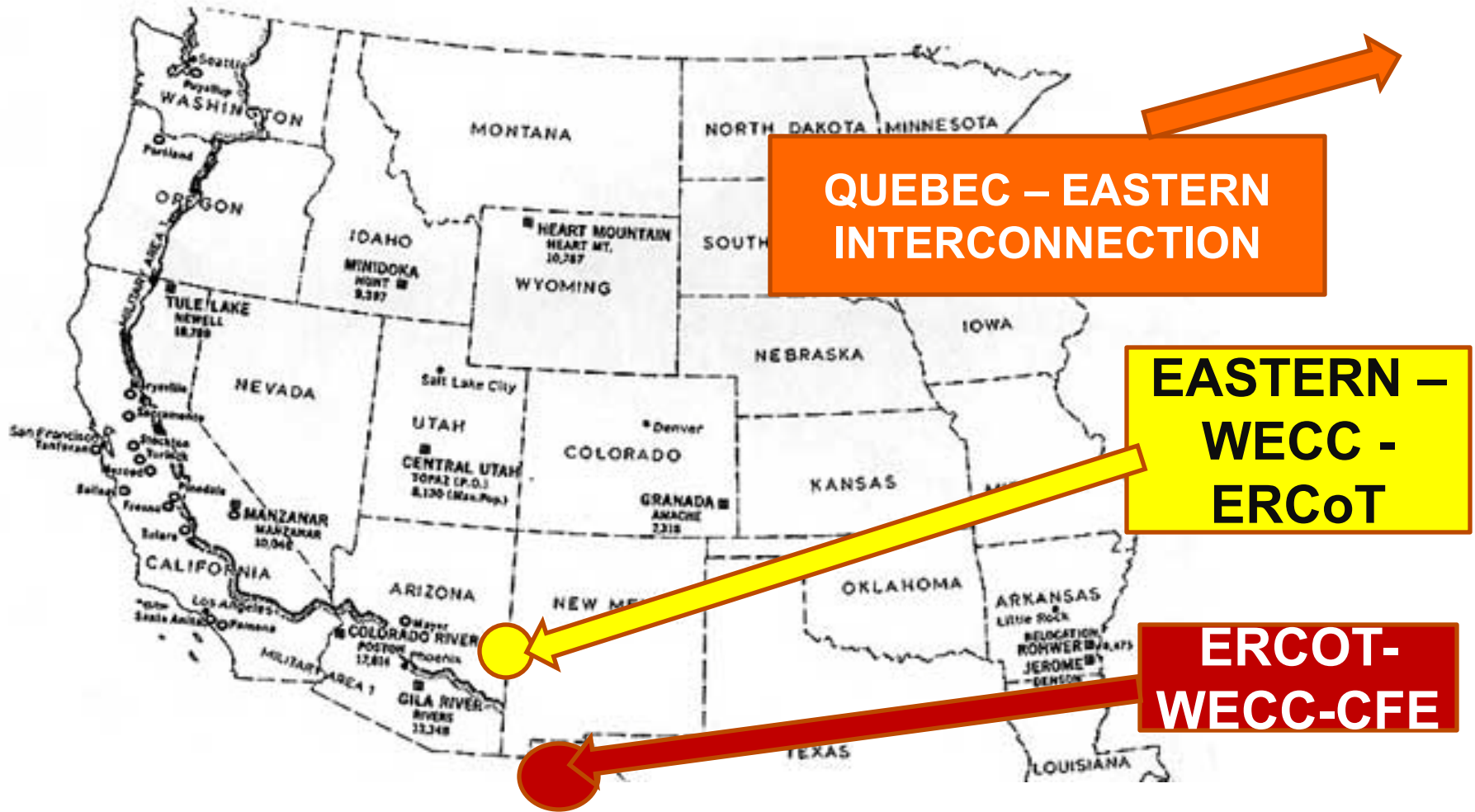
Alleviate transmission bottlenecks

- Alleviate overlapping RASs in critical paths
- Reduce exposure to $N-2$ contingencies

- The Tres Amigas project, merchant substation joining the Eastern, ERCOT, and WECC interconnection
- Other 'sweet spots' exist (e.g., near El Paso joining ERCOT-WECC-CFE)

Connect asynchronous regions

Transmission alternatives



Asynchronous interconnection 'sweet spots'

What are the challenges in developing the fundamental building blocks of the future grid?

Systems issues

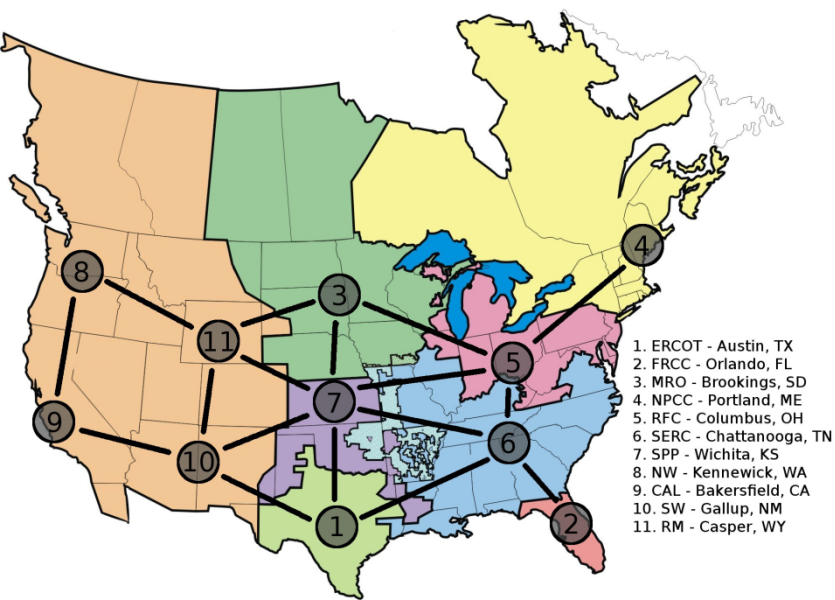
- Making the system theory robust enough to accommodate worst case scenarios, but cost effective enough to justify implementation
- Utilization of system theory that can accommodate *very different* scenarios and components – e.g., *uncertainty in infrastructure*
- Forecasting credible ‘what if’ scenarios

Economic and socio-political issues

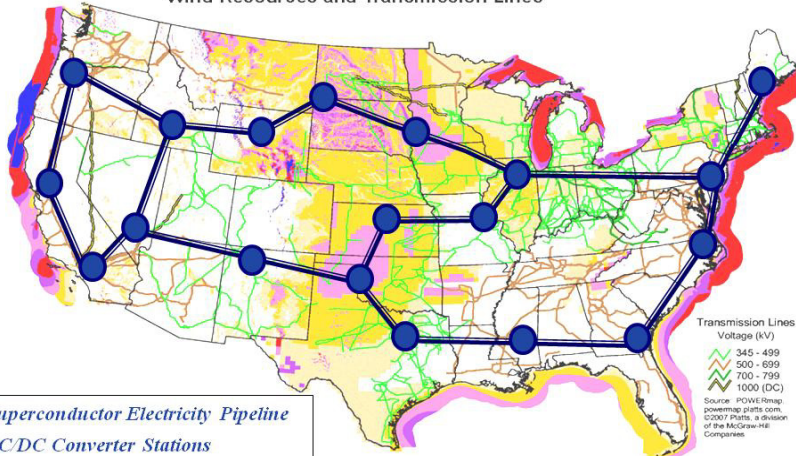
- Optimally investing in technologies for the future, e.g., road mapping transmission expansion
- Accommodating the present needs without sacrificing the effectiveness of future designs
- Managing the needs of each stakeholder / a multiobjective optimization – overcoming the cost / benefit specifics problem: who benefits, who pays?

Example: coordinate growth of wind, solar, nuclear, geothermal, biomass, clean-coal, and natural gas generation to 2050

The possibility of a transmission overlay that is consistent with other energy overlays: the subject of a sub-thrust in the PSERC Future Grid Initiative



Wind Resources and Transmission Lines

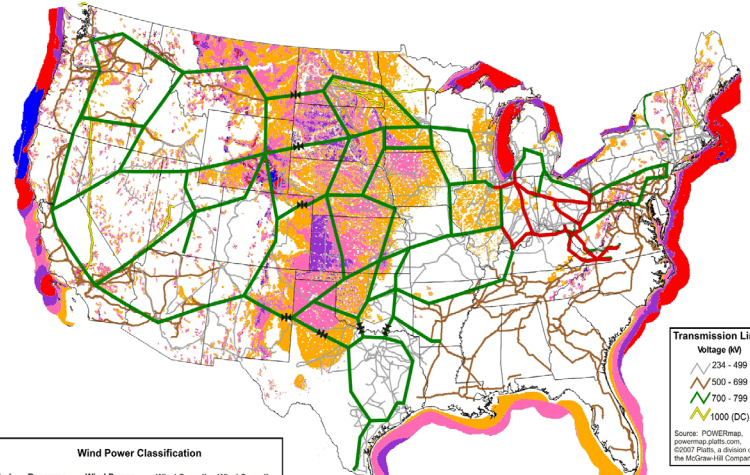


Superconductor Electricity Pipeline
AC/DC Converter Stations

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ²	Wind Speed ^a at 50 m mph	Wind Speed ^a at 50 m m/s
2 Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3	
3 Fair	300 - 400	6.4 - 7.0	14.3 - 15.7	
4 Good	400 - 500	7.0 - 7.5	15.7 - 16.8	
5 Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9	
6 Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7	
7 Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8	

^a Wind speeds are based on a Weibull k value of 2.0

U.S. Department of Energy
 National Renewable Energy Laboratory
 NREL
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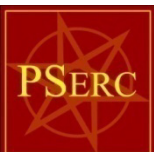
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This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

Conceptual 765 kV Network

- Existing 765 kV
- New 765 kV
- AC-DC AC Link

Source: American Electric Power (AEP)



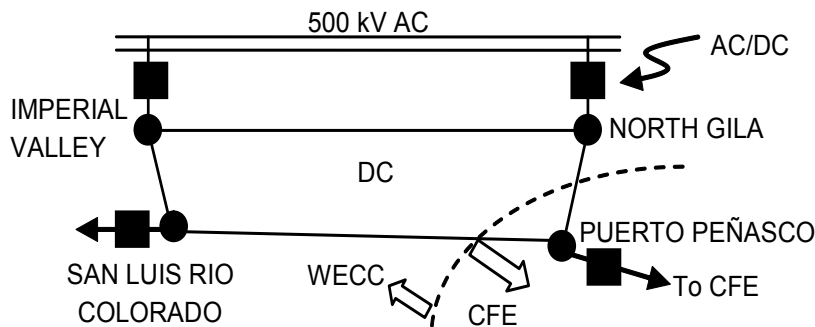
A transmission overlay design

- Design U.S. national transmission overlays
- Develop associated design process to facilitate growth of wind, solar, nuclear, geothermal, biomass, clean-coal, and natural gas generation to 2050
- Assess value of each overlay design
- A project in the PSERC Future Grid Initiative spearheaded by Drs. McCalley and Aliprantis at Iowa State University

Transmission alternatives

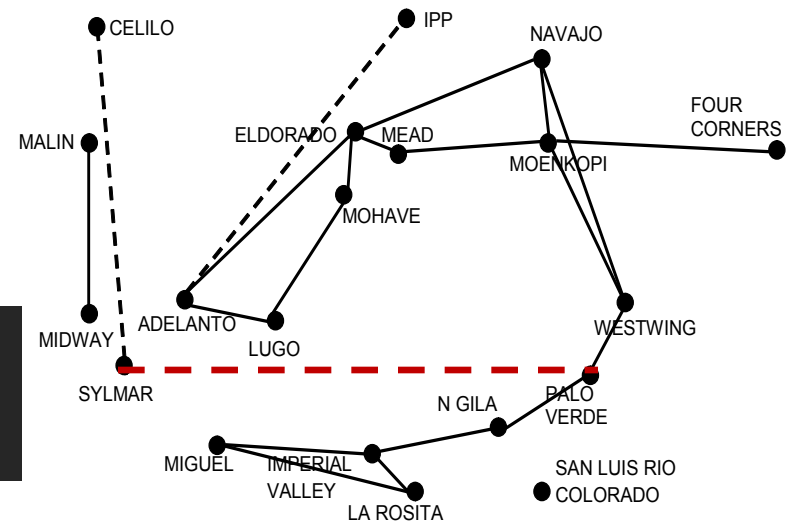
Innovative concepts

- **HVDC, particularly multi-terminal and networked**
- High temperature, low sag (HTLS) conductors
- Compact phase spacing
- Electronic connection, FACTS (again)
- Widespread placement of synchrophasor instrumentation (PMUs)



A DC 'network' at the US-Mexico border

Conversion of the PDCI to a three terminal HVDC system



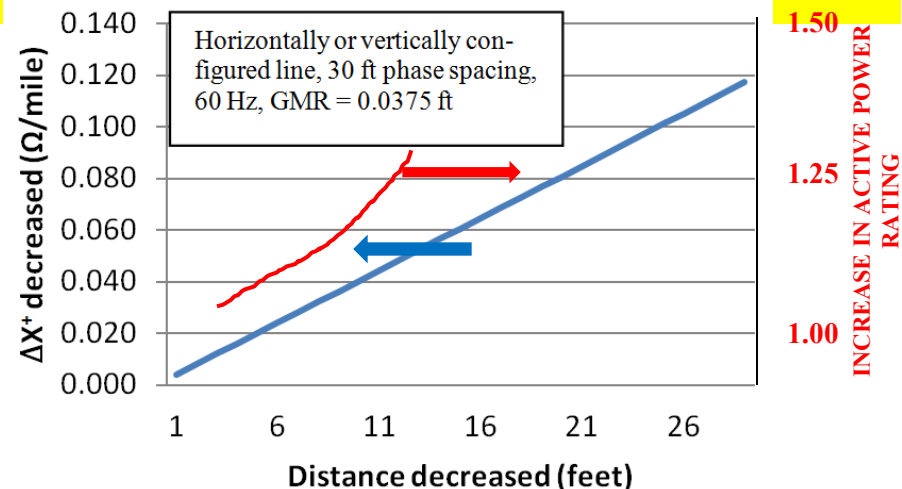
Transmission alternatives

Innovative concepts

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HTLS has the salient advantage of approximately double ampacity. The positive sequence reactance of typical HTLS lines is slightly (~1 – 3%) lower than conventional conductors of the same size. There is little advantage from the point of view of improvement of phase angle stability. HTLS has the advantage of rapid construction (e.g., use of existing towers in reconductoring projects). The main disadvantage is cost.

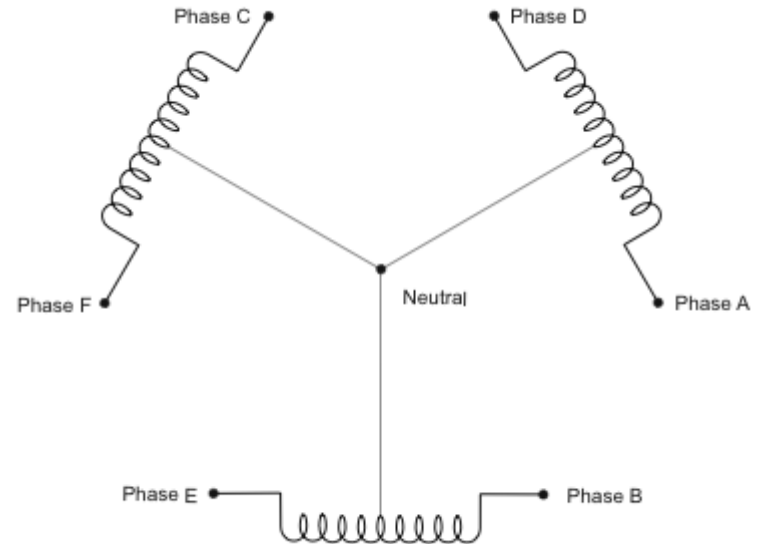
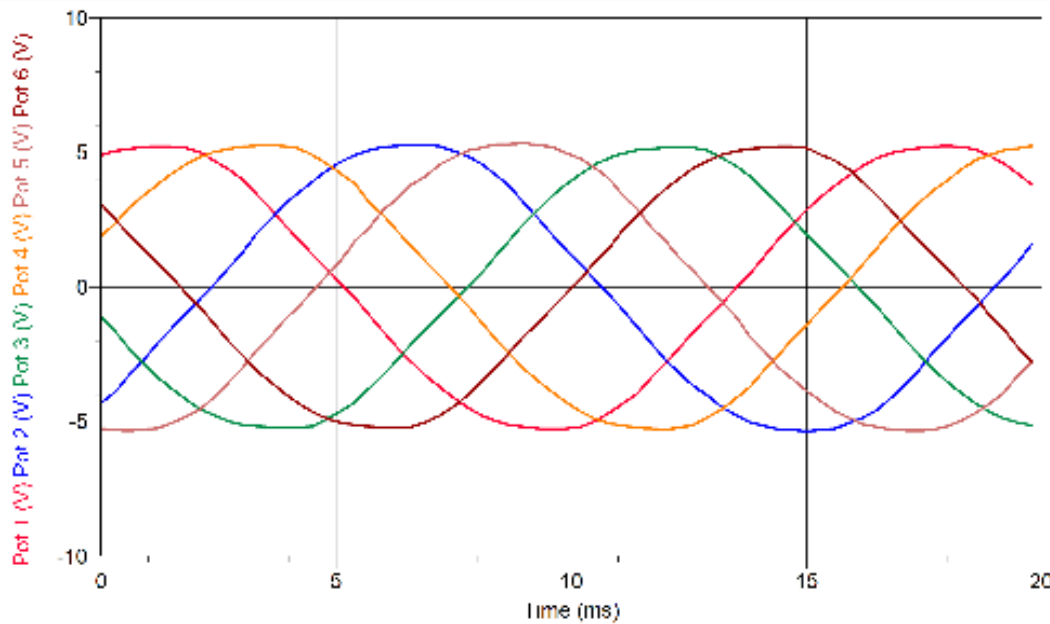
Compact phase spacing (e.g., reduction of ~30' phase spacing to 15' or even 9') has an advantage of reduced positive sequence reactance ($x^+ = x_s - x_m$). This can give higher security limits for long lines. The disadvantages include failure to comply with some industry and accepted state standards, safety issues in live line maintenance. Compact spacing can be combined easily with HTLS.



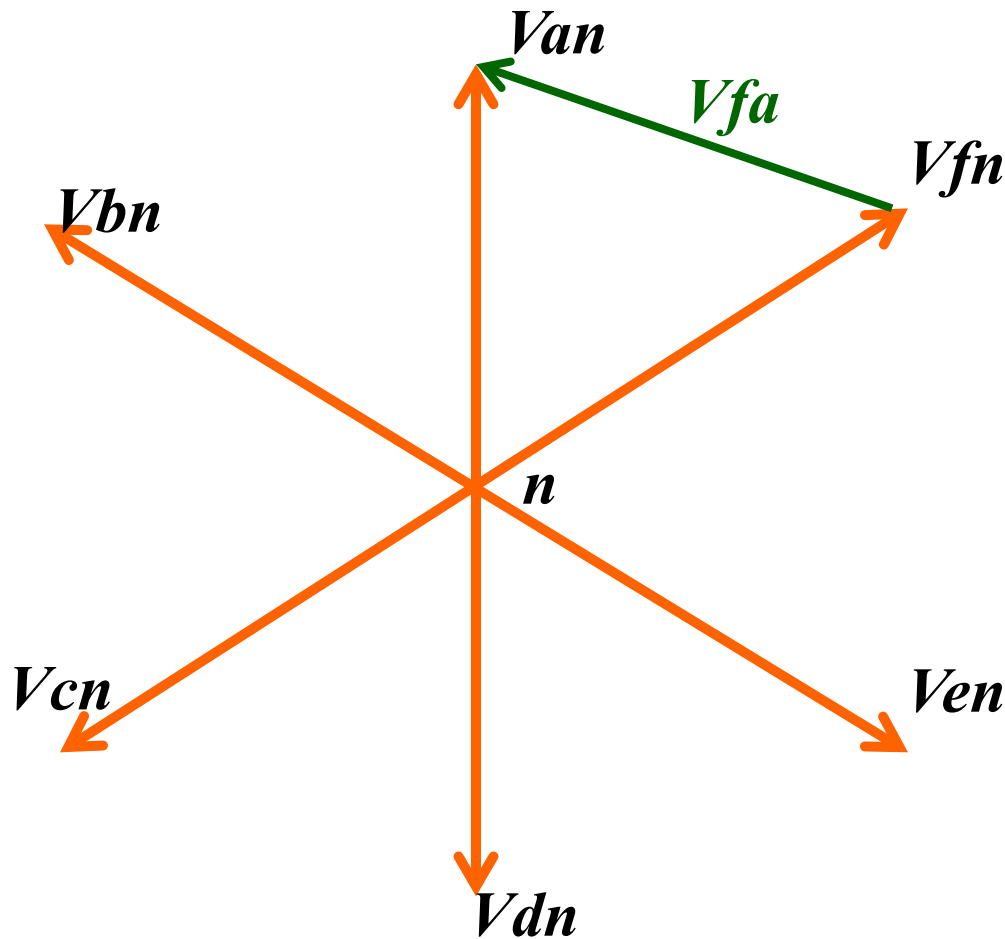
Transmission alternatives

Six phase transmission

- Phase to phase voltage is equal to line to neutral voltage
- Narrower right of way
- Enhanced mutual coupling between phases
- The polyphase form of the symmetrical component transformation nonetheless has a 'positive sequence' that is



Transmission alternatives



Six phase line distinct advantages over a double circuit three-phase:

- Less right of way requirement
- Lower positive sequence reactance per mile
- Less insulation requirement
- Higher active power transmission capability
- Ease in interface with three phase systems
- Lower power quality impact for rectifier / inverter facilities

And some disadvantages:

- More complex transformer connections and specially constructed transformers
- Greater exposure to line-ground faults
- More complex protection issues

In the long term, even higher phase order may be realized with advantages of bulk power transmission

Reserve zones: the calculation of generation reserves for systems with high penetration of renewable resources

How to determine generation reserve zones?

System
operations
issue

- Network partitioning
 - Mathematical extension to islanding models
- Generator clustering

Define a zone as a cluster of generators with a specific reserve requirements (*instead of a network partition*)

Clusters need not be separable, may overlap and generators may belong to more than one cluster

Ability to replicate “Interruptible Imports” and RMR units

Deliverable: mathematical formulation to determine optimal generator clusters to supply reserve

Implications in the design of future transmission systems

Wide area controls

Innovative control concepts

- Using HVDC
- Electronic controls, FACTS
- **Widespread placement of synchrophasor instrumentation (PMUs)**
- Wide-area control techniques for future power system with large portion of renewable power generation and a large number of Phasor Measurement Units
- Algorithms for voltage stability, oscillatory stability and angle stability controls – formulation and test results on test cases

System
operations
issues



A research area spearheaded by Dr. Venkatasubramanian at Washington State University

Large scale energy storage

- **Pumped hydro**

- Deployed on a gigawatt scale in the U.S. (20 GW at 39 sites and installations range from 50 MW to 2100 MW).
- Sites store 10 hours or more, making the technology useful for load leveling

- **Compressed air energy storage (CAES)**

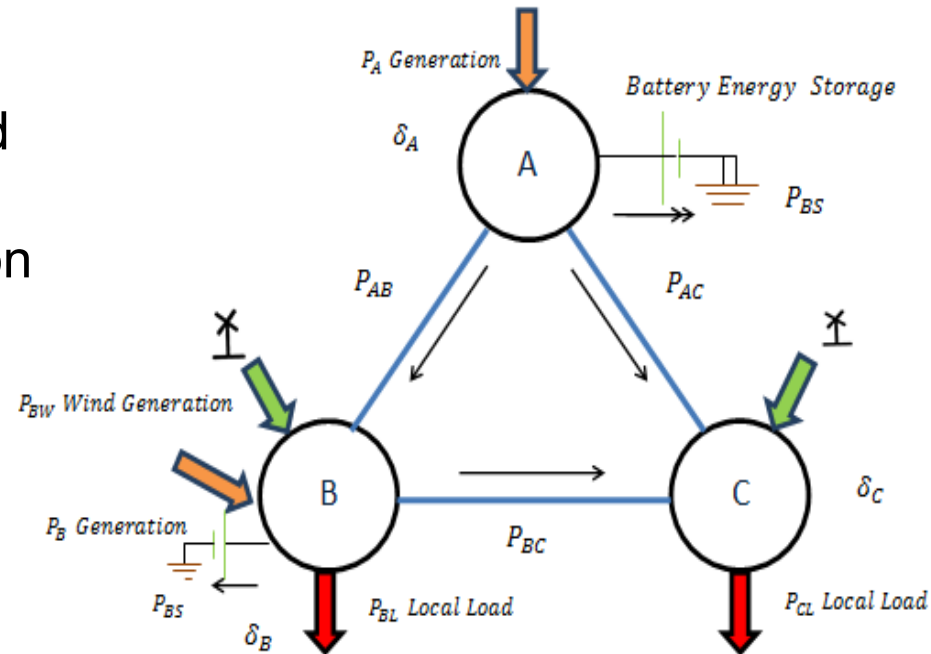
- Appropriate load leveling because it can be constructed in capacities for 100 to 300 MW.
- Can be discharged in 4 to 24 hours
- Usually combined with combustion turbines.

- **High energy batteries**

- Two types
 - high temperature batteries (sodium sulfur battery)
 - liquid electrolyte flow batteries
- Disadvantages: expensive, short lifetime

Large scale energy storage

- Store energy in the off peak period, discharge during the peak
- Reduces load in critical circuits
- Better enables 100% utilization of wind resources
- In a 6 GW system, tests show reduction of operating costs by 2.5 to 10%
- High speed ramp rates – useful for reserve margin especially with wind energy systems
- Substantial DoE research effort



A research effort by G. Heydt at Arizona State University

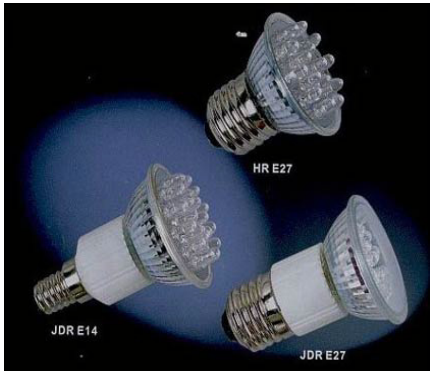
- No large scale demonstration without substantial subsidy
- Difficult to obtain a positive benefit / cost ratio for any **one** advantage obtained
- Some storage requires specialized circumstances (e.g., pumped hydro geography)
- No strong acceptance by industry

Distribution system characteristics

Higher levels of electronically processed loads

- Higher distribution primary voltages (e.g., 35 kV primaries)
- Fast acting electronic controls
- Rooftop residential photovoltaic impact
- Increased residential sector
- Innovative protection and fault detection

- Presently, studies show that distribution loads are about 30% electronically processed (e.g., ASDs, electronic lighting, rectifier loads)
- Expected to reach ~50% by 2020
- Main growth: industrial drives, electronic lighting, computer / IT loads (rectifiers)

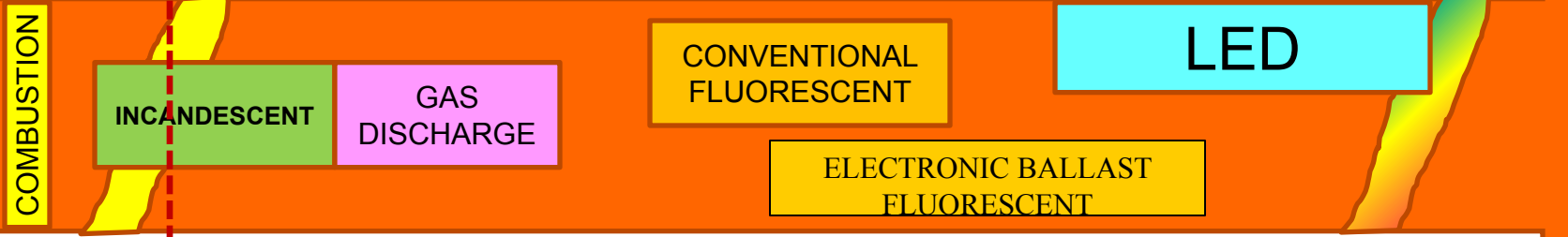


Lighting is estimated to be 20 to 25% of the total electrical demand

12.6 lm/w

EFFICACY IN LUMENS / WATT

0.3 10 20 30 40 50 60 70 80 90 100 110 683



0.02 1 2 3 4 5 6 7 8 9 10 11 55

RELATIVE EFFICACY (BASE = 12.6 LUMENS / WATT)

Theoretical



Distribution system challenges

- Higher distribution primary voltages (e.g., 35 kV class, to reduce losses)
- Greater reliance on networked primaries – in inner cities as well as less load-dense areas
- Utilization of underground circuits , balancing mean time to failure and repair time (especially in storm prone areas)
- Revisiting tried-and-true standards to allow distributed generation (including reactive power resources), and distributed energy storage
- Judicious use of electronic controls (hybrid solid state transformer , fault interrupter)
- Consideration of higher distribution secondary voltages (e.g., such as 240 V outside of North America)
- Nonstandard frequencies in distribution secondaries for electronic lighting

Challenge areas: summary

- National transmission overlay coordinating all energy resources
- Utilization of transmission alternatives and hardware (e.g., HVDC, AC, six-phase, higher phase order, alternative conductor technologies)
- Microgrids
- Distribution network infrastructure and standardization
- Large scale energy storage - interactions with power delivery infrastructure
- Distributed vs. centralized generation – interactions with power delivery infrastructure
- Demand response – interactions with power delivery infrastructure

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