Simulation Results for HTS Cables in Real Grid Situations: Downtown Chicago and California's Path 15

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Background

- RAND recently completed a study of the potential impact of HTS power technologies on the U.S. power grid, with emphasis on mitigation of transmission constraints
  - Simulations were aimed at quantifying the reliability and transfer capacity benefits possible with HTS cables in realistic situations;
  - Study also included one-to-one comparisons between energy use and life cycle cost of HTS and conventional power technologies.

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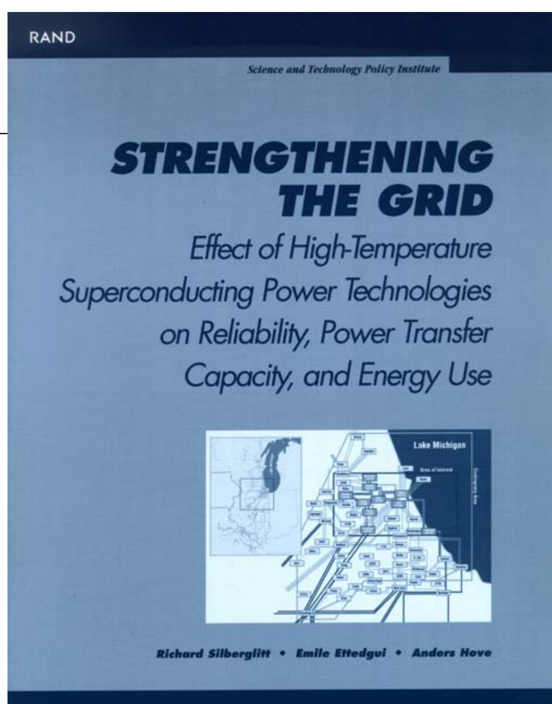

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Major conclusions of the RAND HTS Study

- Significant transmission constraints exist in many areas of the U.S., resulting from increased demand, increased power transfers, and very small increases in transmission capacity over the past several years, and have contributed to decreased reliability and price differentials.

- High-temperature superconducting underground cables provide an attractive retrofit option for urban areas that have existing underground transmission circuits and wish to avoid the expense of new excavation to increase capacity.

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Major conclusions of the RAND HTS Study (Cont.)

- When operated at high utilization, HTS cables provide energy savings benefits compared with conventional cables per unit of power delivered. Whether or not the life cycle costs are also lower depends upon the cost of electricity.

- HTS cables can provide a parallel transmission path at lower voltage to relieve high-voltage transmission constraints. Long-distance HTS transmission circuits will however require periodic cooling stations and sufficient manufacturing capacity for HTS wire.

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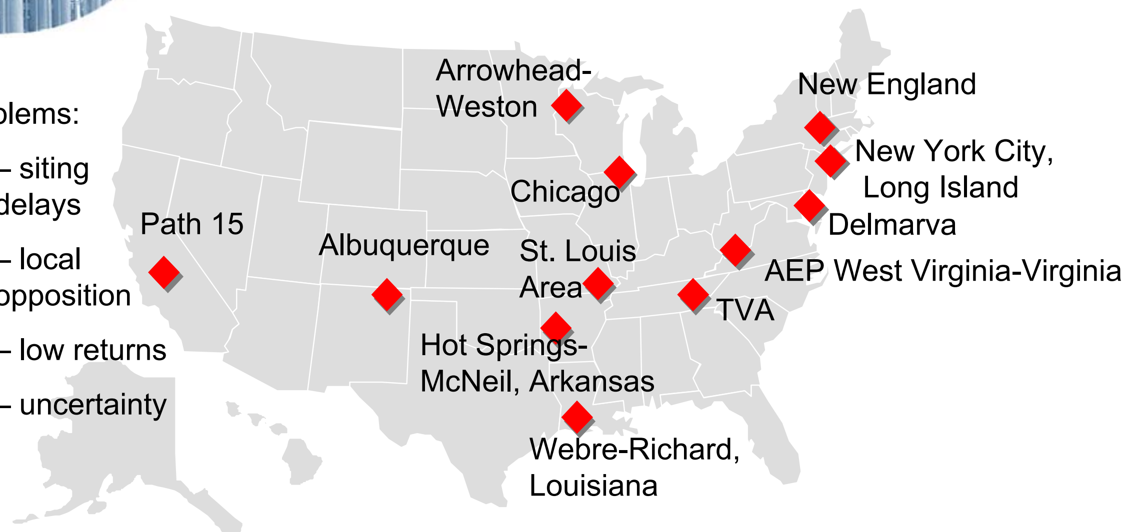
Major U.S. transmission constraints

•Problems:

- siting delays
- local opposition
- low returns
- uncertainty



Major transmission bottlenecks as identified in NERC reports, TLR log files, POST studies, press accounts, and national energy reports

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HTS cable benefits

- Lower impedance and higher ampacity than conventional transmission lines at same voltage.
- Can add power capacity within same space to relieve stress and increase power transfer capacity.
- Can reduce need for high voltage equipment.
- Underground parallel paths can reduce vulnerability.

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Simulation of real-world HTS applications

- Rand partnered with PowerWorld to conduct power-flow analysis of HTS cables in realistic grid situations
- PowerWorld Simulator provides visualization of power flows based upon input on generators, loads, transmission lines, transformers, and other power grid-connected equipment.
- Simulator uses data on peak loads reported on FERC Form 715.
- Required data on HTS cable resistance, capacitance, and inductance was provided by Pirelli.
- Two cases were studied: downtown Chicago and CA Path 15.

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Goals of the power flow simulation studies

- Investigate effect on power flow of lower impedance and higher ampacity of HTS cables.
- Quantify the improvement in reliability of high voltage electric networks that can be obtained with HTS cable substitutions or additions.
- Determine the additional electric demand that a given geographical area could support using HTS cables.
- Present specific examples of the manner in which HTS cables may be utilized in realistic grid situations to increase reliability, reduce vulnerability, and increase available transfer capacity.

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Methodology of the power flow simulation studies

- Select an area and analyze the base case power flow using recent peak load data as submitted to FERC (Form 715).
- Identify candidates for HTS cables (stressed lines).
- Study the selected area after implementing HTS cables and evaluate the new power flow.
- Compare reliability through contingency analysis.[1]
- Analyze transfer capability.

[1]These simulations do not include operating measures that utilities can use to deal with contingencies, e.g., adjusting phase shifters, opening or closing breakers, changing local generation profile, or employing demand-side management.

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Carrying out the (N-1) contingency analysis

- Define the **contingency area** and compile a list of elements (single lines and transformers) in the smaller **area of interest**.
- Monitor violations[1] that occur for all the elements in the full simulation with one element outage in the contingency area.
- Select elements in the area of interest with the greatest number of violations and the highest overload for all the contingencies.
- Replace those elements with HTS cables using resistance, capacitance, and inductance data provided by Pirelli.

[1]Transmission lines and transformers: loading>100% MVA rating
Buses: voltage ±10% of nominal voltage [0.9 or 1.1 per unit (p.u.)]

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First study—downtown Chicago

- 890 MW load in concentrated area with majority of power injection via one 345 kV substation.
- Meeting increasing demand in this area is difficult because of transmission network constraints.
- The constraining elements include 138 kV underground cables.
- Total load for simulation is 19,000 MW and 7000 MVAR. Contingency analysis includes 133 transmission lines.

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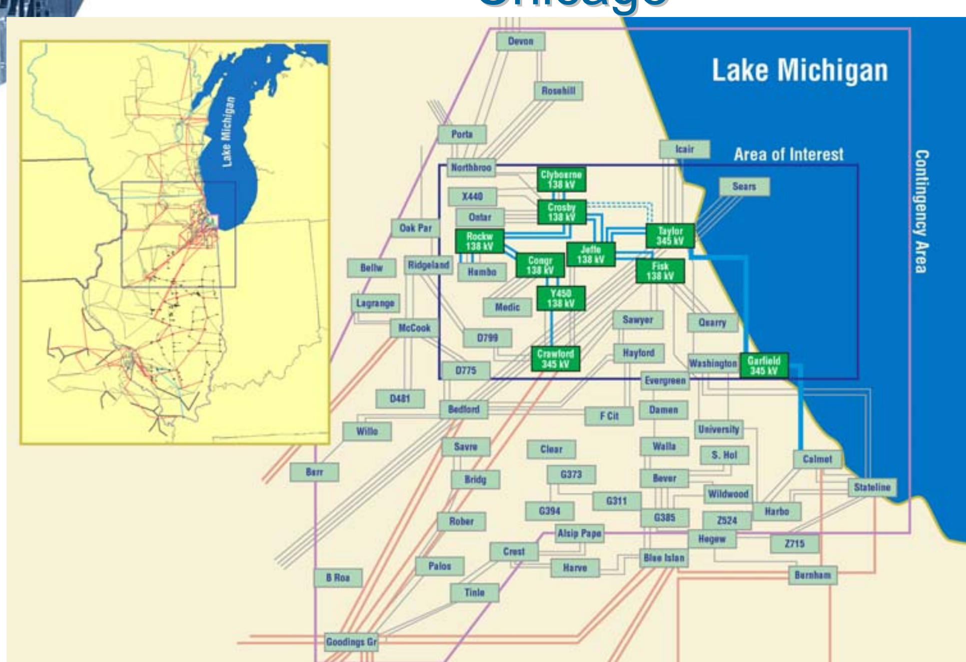
Overview of downtown Chicago



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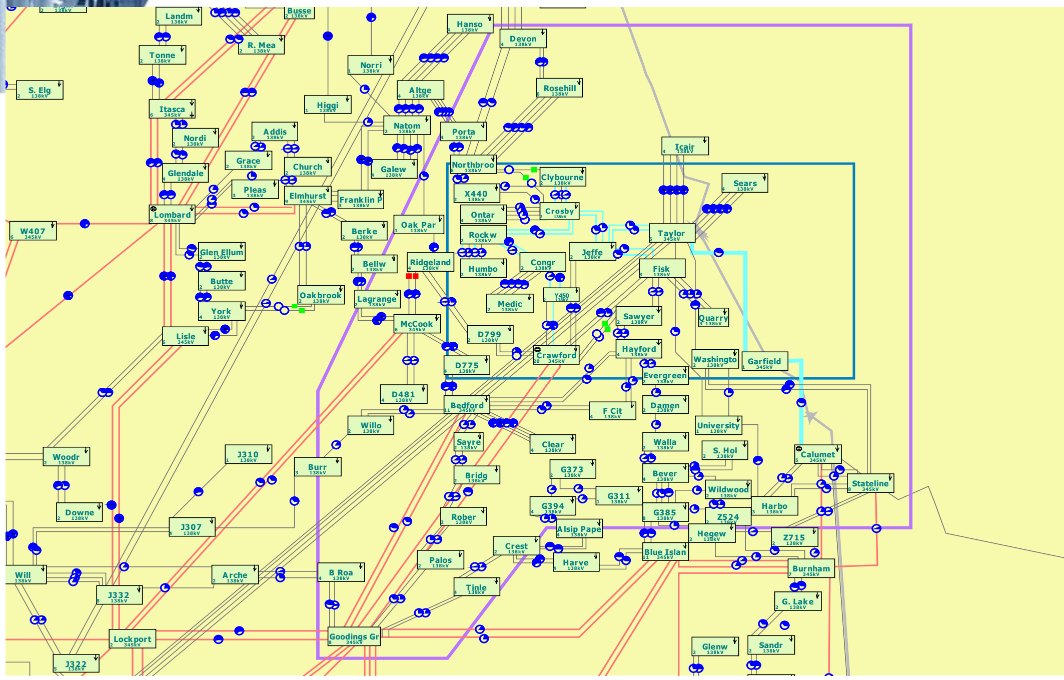
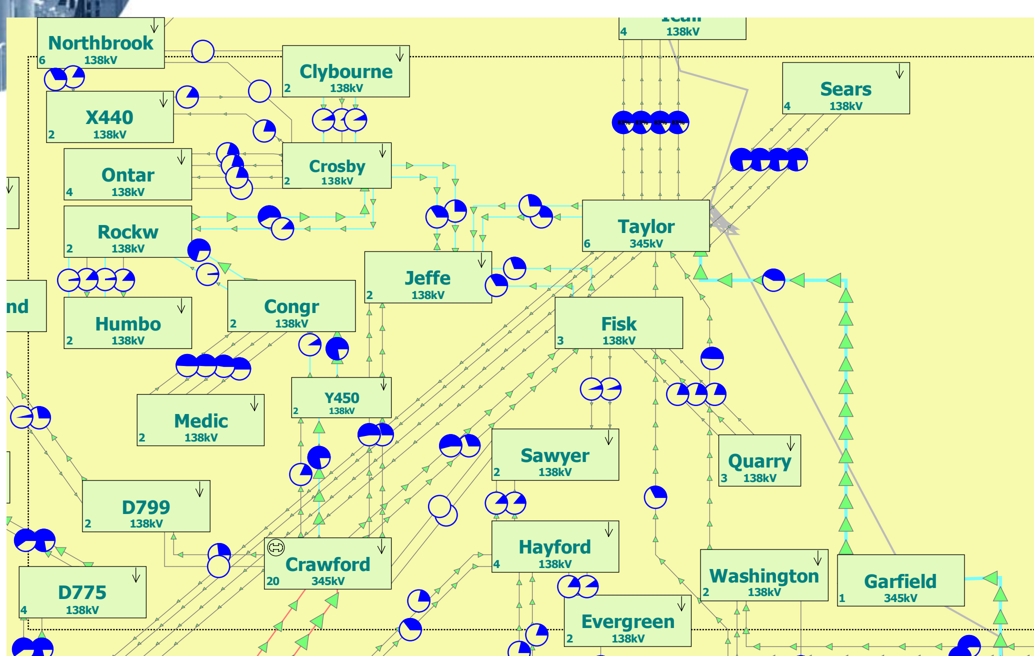
Downtown Chicago's transmission network



Power flows in the area of interest



Results of the contingency analysis

- Installing 11 HTS cables (plus 8 parallel HTS cables to maintain system symmetry and 1 HTS cable to avoid a base case overload) improves power flows.
- The number (37 vs. 105) and severity (max 109% vs. max 164%) of violations decreases.
- Violations never occur in the HTS cables used for the analysis.
- Power transfer into area of interest can increase up to 41% while maintaining fewer violations than the base case.

HTS Cables Provide Increased Transfer Capacity for the Same Level of Reliability

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Chicago case with just two HTS cables

- Contingency analysis revealed that most severe contingencies resulted from heavily loaded paths through the Crawford substation.
- Either (1) addition of HTS cables connecting Taylor and Crosby or (2) substitution of HTS cables for conventional cables connecting Jefferson and Crosby provided a parallel path through Garfield, reducing loading on paths through Crawford.
- Violations reduced from 91 in Base Case to 43 (Case 1) or 73 (Case 2) and average overload from 118% in Base Case to 107% (Case 1) or 108% (Case 2).
- Most severe contingencies (>130%) eliminated in both cases.

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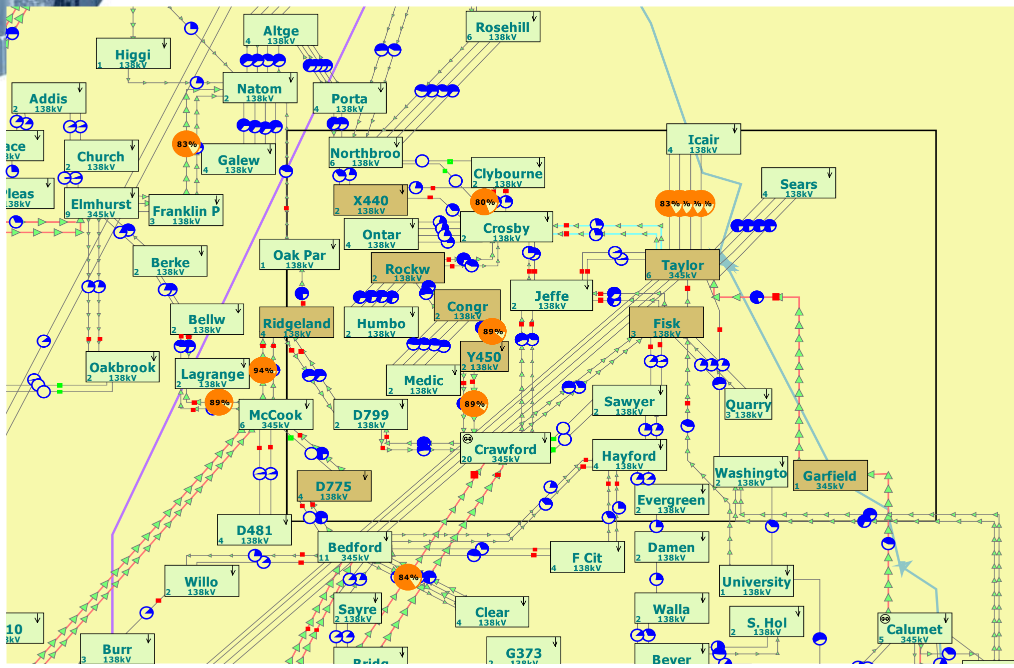
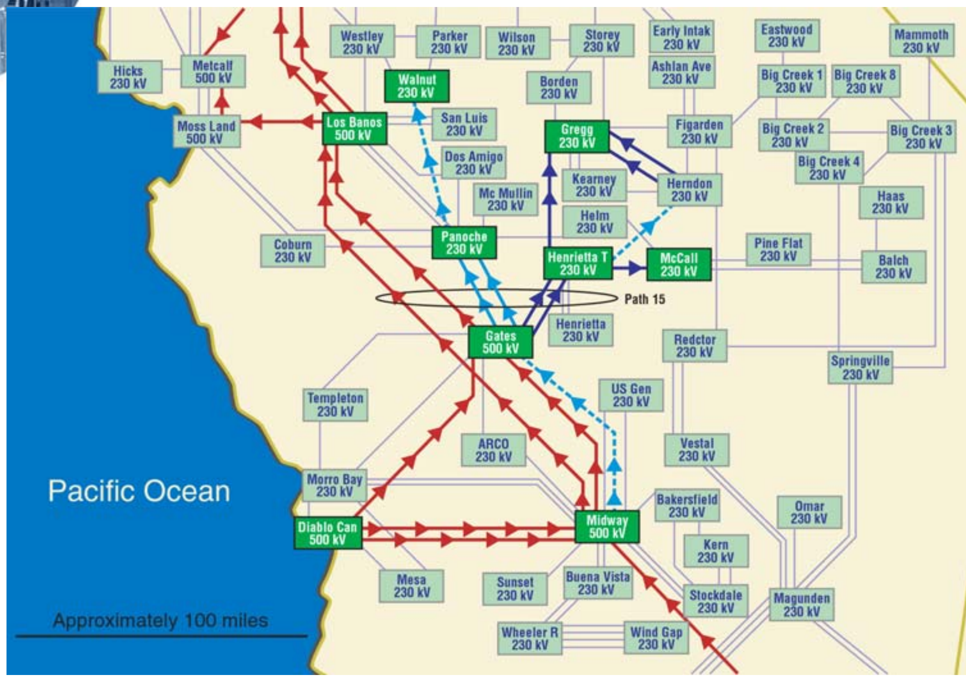
Power flows with new HTS path from Taylor to Crosby



Second study—California's Path 15

- Path 15 consists of 2 500 kV transmission lines and 4 230 kV transmission lines that have been identified as constraining power flows from Southern California to Northern California.
  - Implicated in January 2001 rolling blackouts in San Francisco.
  - Often determines price differential between north and south.
- Most of flow goes through heavily loaded 500 kV lines.
- $300M project to increase transfer capacity by 1500 MW using conventional technology has been announced by DOE.

Overview of CA Path 15



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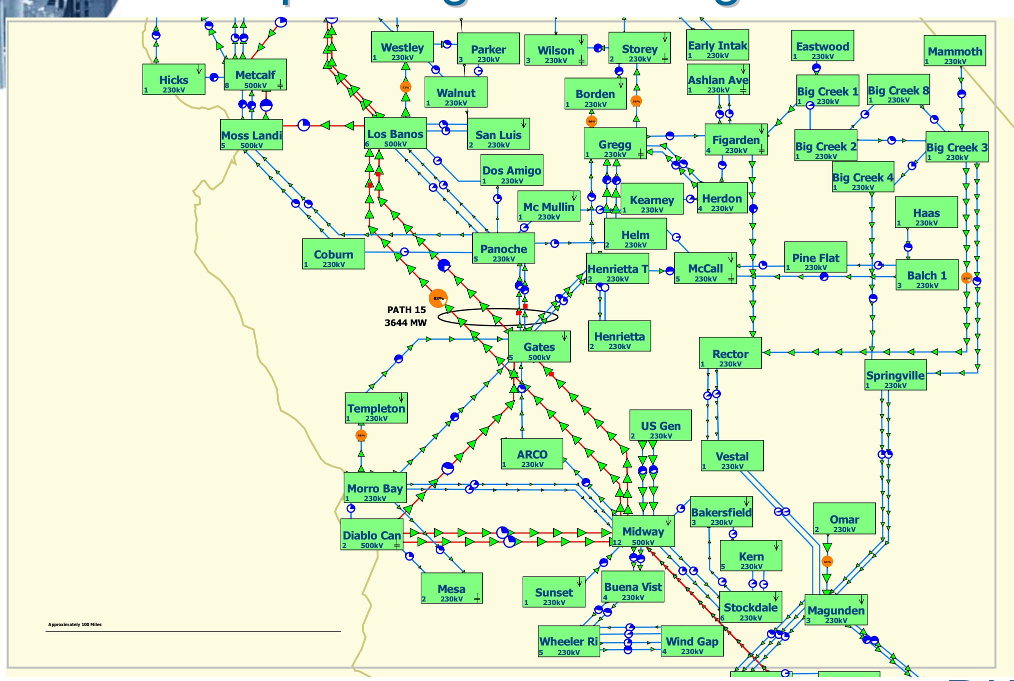
A portion of the California power grid showing Path 15



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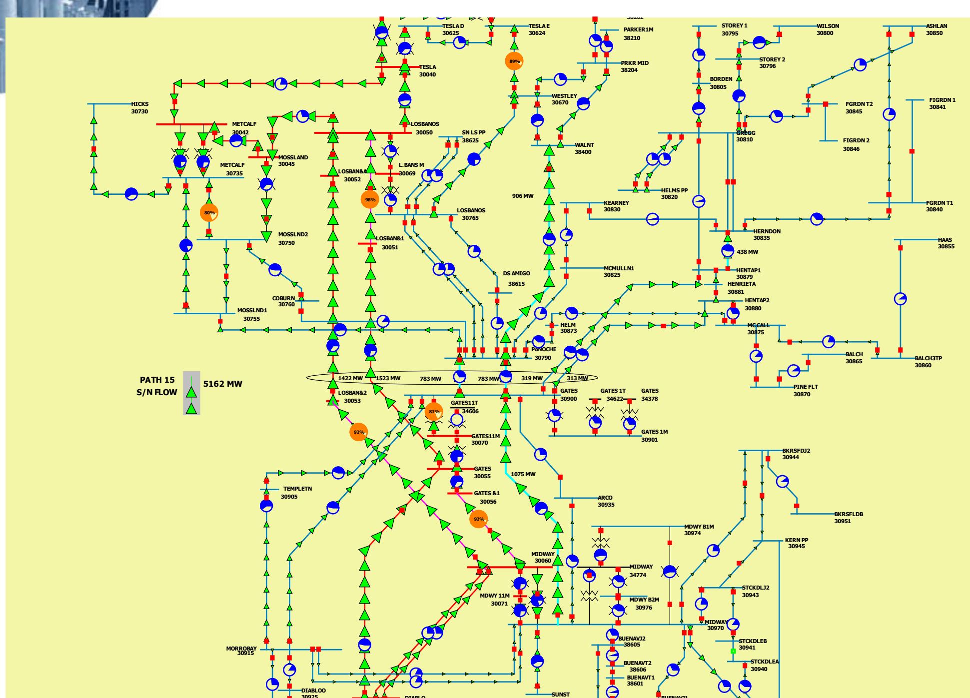
HTS cable approach for Path 15

- Note that 500 kV lines are heavily loaded, while 230 kV lines and 500 kV to 230 kV transformers are under-utilized.
- Construct new 230 kV path to allow additional north to south (N/S) power transfer.
- Result: 5 HTS cables[1] (3 additions and 2 substitutions) provide approximately 1500 additional MW from N/S at same level of reliability.

[1]These HTS cables are much longer than is currently feasible, but demonstrated benefit of the lower voltage parallel path is valid and generalizable.

Power flows in Path 15 with 5 HTS cables



Conclusions from power flow simulations

- HTS cables can provide increased reliability or increased power transfer capacity at the same level of reliability.

- HTS cables can provide (underground) parallel paths (at lower voltage) to relieve stress on heavily loaded transmission paths and reduce vulnerability.

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