Under what conditions is HVDC conversion a *cost effective* way to increase transmission capacity conversion in an existing HVAC corridor?

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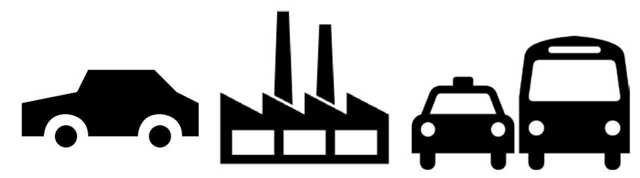
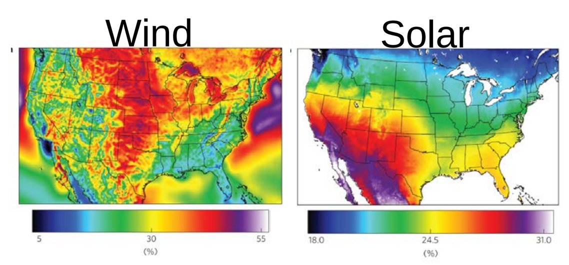
Motivation

Transmission expansion will be necessary for decarbonization



- Electrification could double electricity demand by 2050 due to industrial and transportation loads
- Renewable resources are often located in remote regions, away from population centers
- ~50% to ~120% expansion in electricity transmission capacity likely needed for decarbonization[1]



Wind and Solar power potential in the US [2]

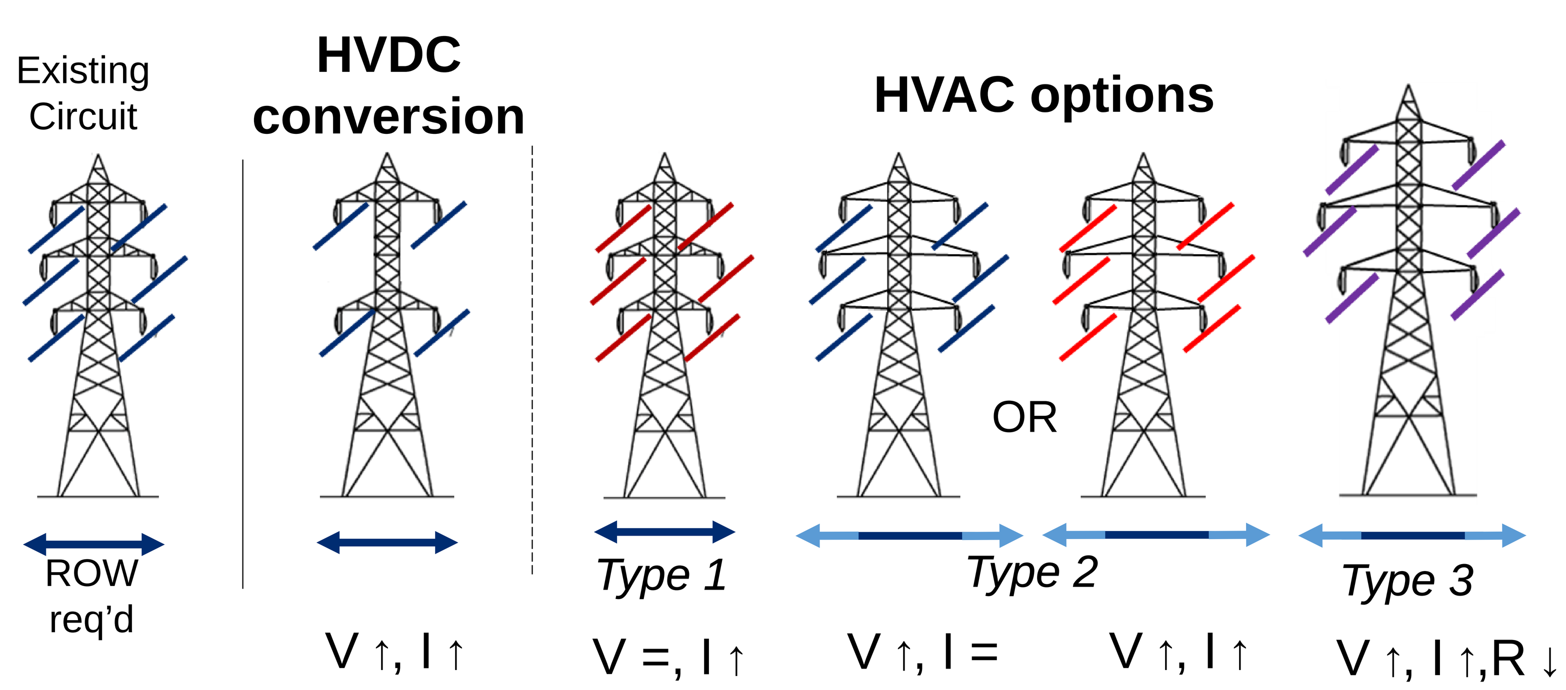
Siting new transmission lines in the US is increasingly difficult

- Multiple levels of conflicting regulatory bodies: local through federal
- Courts reject FERC siting power created in 2005 EPAct for "National Interest Electric Transmission Corridors"

Maximizing potential of existing corridors could speed the energy transition

- HVDC conversion can transmit 3.5X power in the existing right-of-way (ROW)
- UltraNet project in Germany using HVDC conversion to increase renewables in grid

Corridor Upgrades Compared



	HVDC	HVAC Type 1	HVAC Type 2	HVAC Type 3
Voltage Level	+/- 500 kV	345 kV (existing)	500 kV	500 kV
Structures	Modified	Existing	Modified	Replaced
ROW	Existing	Existing	Expanded	Expanded
Conductors	Existing	Higher perf, similar weight	Existing OR Higher Perf, similar weight	Larger, heavier

Methods

HVDC costs dominated by converter station (scales with power), HVAC costs by conductors (scales with distance)

$$Cost_{total} = Cost_{power}P_{MW} + Cost_{distance}D_{miles} + Cost_{losses}$$

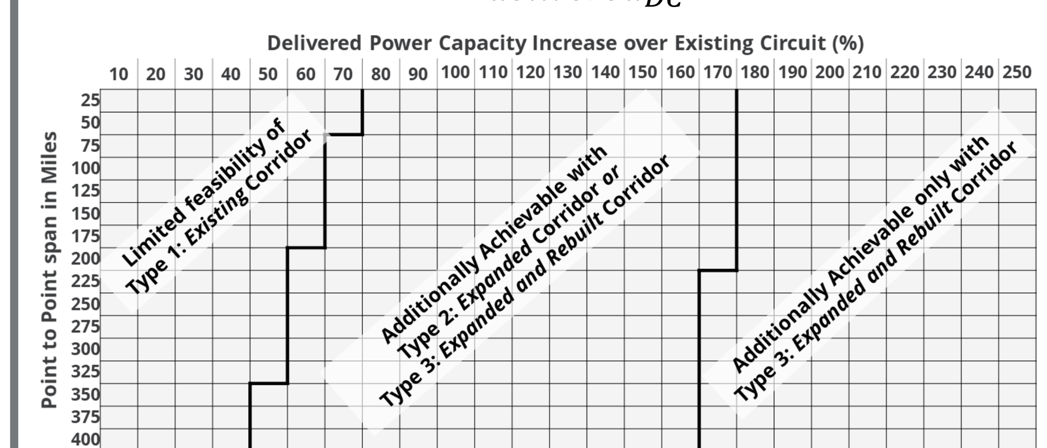
	Power Costs	Distance Costs	Electrical Losses
	Util. & Industry est.	*Industry est.*	*EIA wholesale \$/MWh*
HVDC	Converter Station	n/a	Ohmic, Conversion
HVAC Type 1: Existing Corridor	Transformer	conductors	Ohmic
HVAC Type 2: Expanded Corridor	Transformer	ROW: n/a / conductors	Ohmic
HVAC Type 3: Expanded and Rebuilt Corridor	Transformer	ROW, conductors, structures	Ohmic

- Uncertainty included as +/- 10% cost of each capital expenditure (not losses)
- Construction/Equipment costs modeled as undiscounted, year 0 capital expenditures
- Losses modeled as NPV of 30 years of peak losses, 5% discount rate

Some HVAC types limited in achievable distance and power increase configurations

- *Delivered* power is compared: resistance losses increases with current and distance

$$P_{delivered_{AC}} = 2\sqrt{3}VI - 6I^2R$$
$$P_{delivered_{DC}} = 4VI - 4I^2R - L_{conversion}$$



- HVDC can achieve all the compared configurations
- HVAC performance primarily limited by losses
- Current (I) and resistance (R) determined by conductor manufacturer software

References

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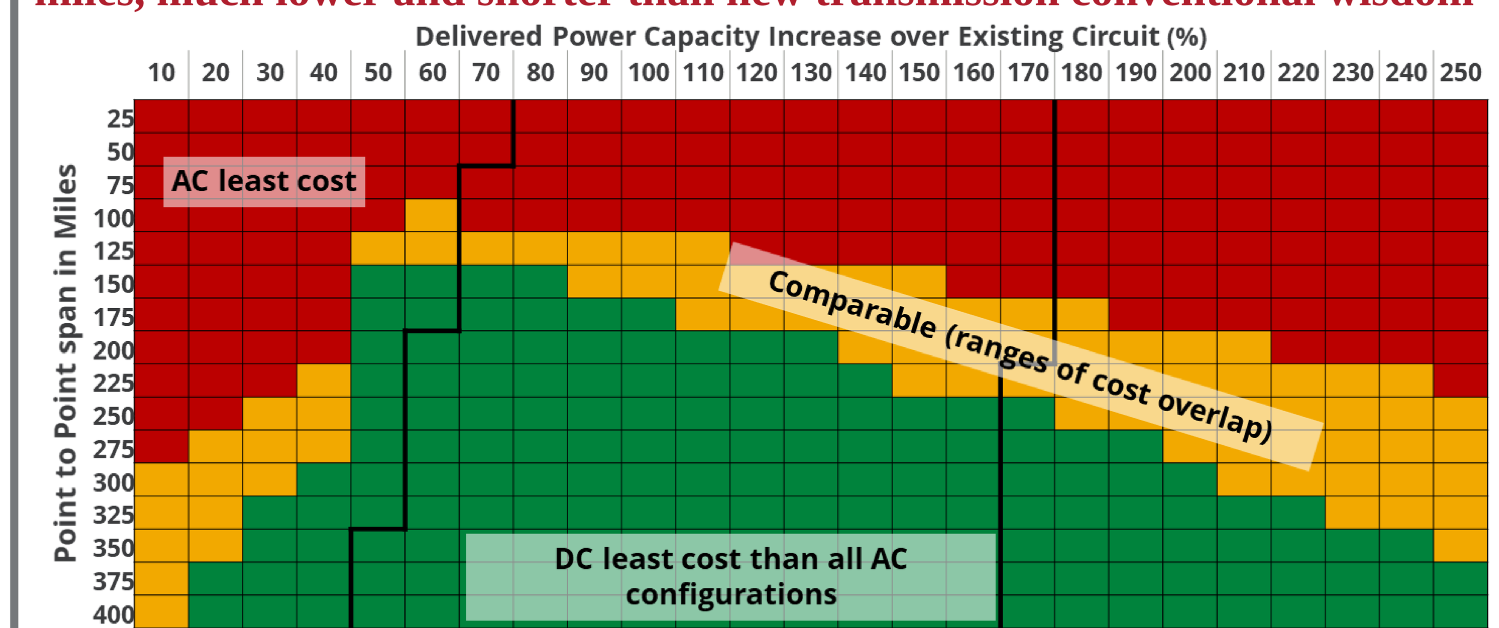
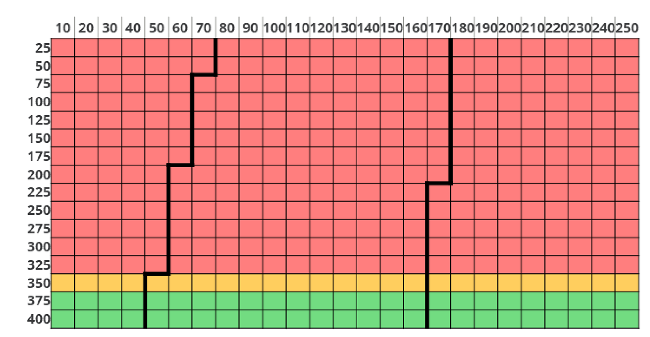
Results & Implications

HVDC least or comparable cost at 50%-150% power increases and over 150 miles, much lower and shorter than new transmission conventional wisdom

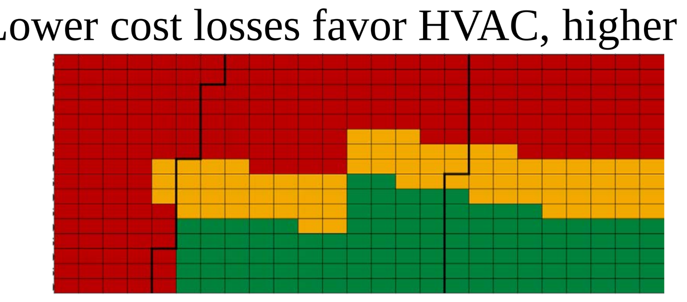


Cost comparison for HVDC conversion vs. HVAC upgrades

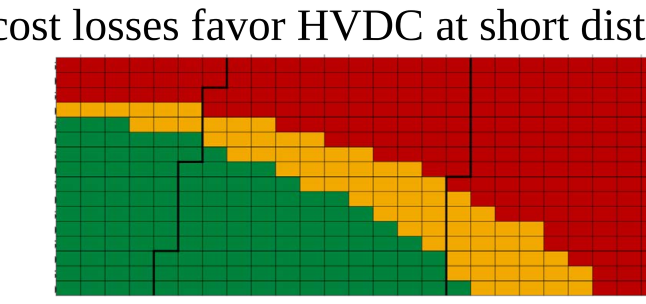


Convention wisdom on HVDC breakeven distances: cost effective >350 miles

- Lower cost losses favor HVAC, higher cost losses favor HVDC at short distances



Losses: \$5/MWh



Losses: 75/MWh

HVDC conversion is technologically and economically feasible; should be included in industry and academic analyses

- Federal regulation focuses primarily on new transmission
- Not included in utility transmission planning software, limiting fair market consideration
- May impact recommendations if incorporated into decarbonization optimizations
- Lowering conversion costs (capital costs and energy losses) and increasing flexibility of HVDC operational configurations may support energy transition

Costs of permitting, regulatory approval, delay, and public response expected to further favor HVDC

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