



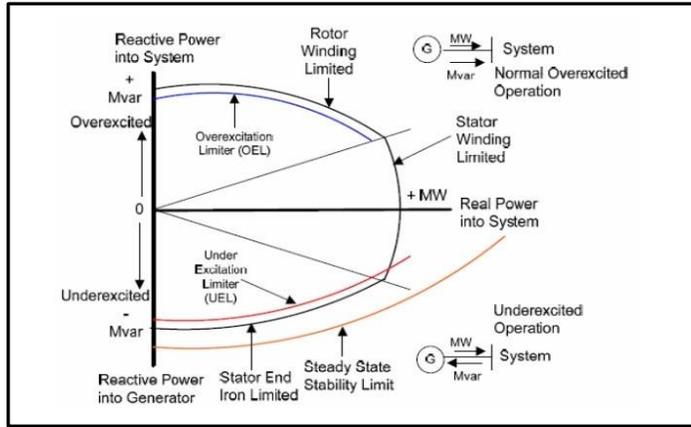
# High Voltage Direct Current (HVDC)

Voltage Source Converters (VSC) | Technology Solutions for Integration of Renewable Resources

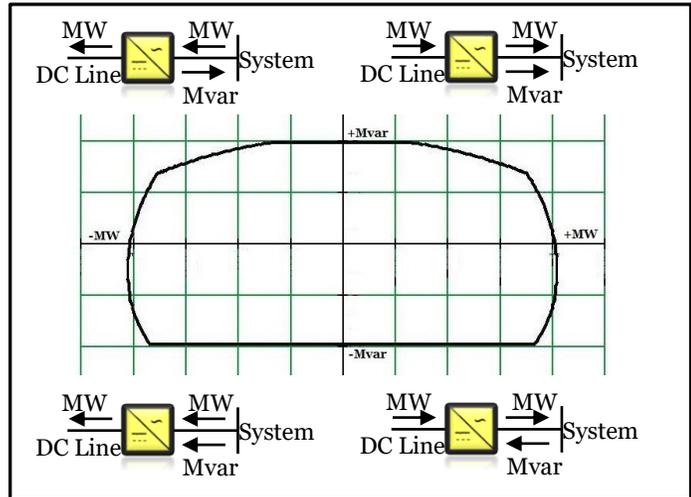
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# Why Consider HVDC over Conventional AC Transmission?

## Performance Characteristics | Reactive Power Support and Black-Start



Typical P-Q Curve for Fossil Fuel based Generators

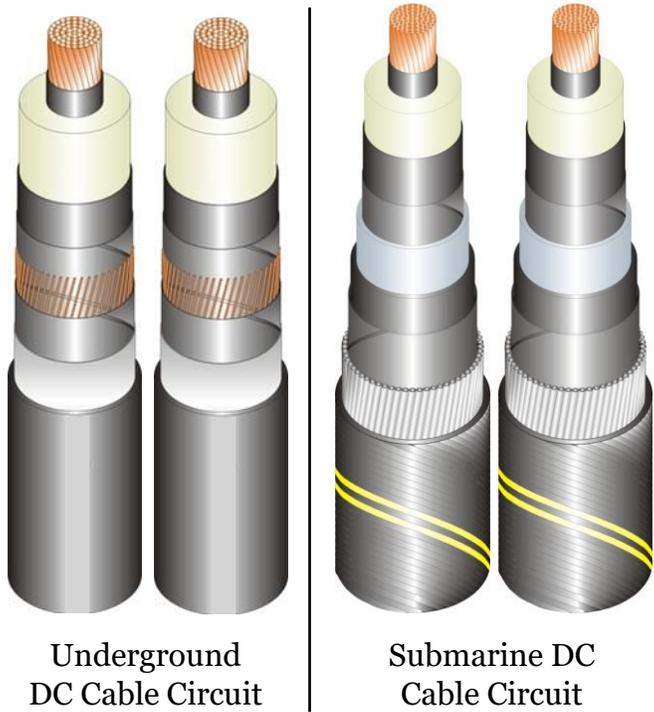


Typical P-Q Curve for VSC Based HVDC Stations

- Voltage source converter (“VSC”) based HVDC links can deliver renewable energy from remote renewable wind, solar and hydroelectric resources and make such deliveries appear to the grid as supply from a local generator sited at the receiving end of the transmission corridor.
  - ❖ **No Inadvertent Power Flows:** The HVDC converter stations control the power flow on an HVDC link to the desired dispatch and there is no risk of inadvertent flows overloading other parallel transmission lines.
  - ❖ **Improved Grid Performance:** VSC based HVDC stations provide dynamic and continuous reactive power support (approx. ±50% of real power capacity rating) for real power transfers in both directions on the DC line.
  - ❖ **Improved Grid Resilience:** VSC based HVDC stations are capable of quickly black-starting the AC grid at the receiving end of the DC transmission corridor using power supply from remote generation resources located at the sending end of the line.

# Why Consider HVDC over Conventional AC Transmission?

## Transmission Technology Deployment | New Invisible High-Capacity Transmission Lines



- The practical length of a high-voltage AC cable link is limited by the 60 Hz charging current caused by the inherent electrical capacitance of the cable
  - ❖ The cable capacitance increases linearly with the length of the cable
  - ❖ HVDC cables only carry charging current during initial energization of the circuit
- Continued R&D over the past two decades have produced high-capacity polymer (XLPE) insulated DC cables that facilitate construction of very long and invisible high-capacity transmission lines.
  - ❖ New transmission lines onshore can be all underground or a hybrid of overhead and underground construction to mitigate siting issues and public concerns
- Underground segments can be sited in existing infrastructure corridors (e.g., existing overhead line corridors, roads, railroads, pipelines, etc.) to avoid disturbing or impacting previously undeveloped land.

<b>1999</b> Sweden 160 kV ( $\pm 80$ kV) 50 MW 43 miles UG	<b>2002</b> Australia 300 kV ( $\pm 150$ kV) 220 MW 112 miles UG	<b>2012</b> Ireland-Wales 400 kV ( $\pm 200$ kV) 500 MW 46 miles UG 116 miles subsea	<b>2007-2009</b> Type and PQ tests 640 kV ( $\pm 320$ kV) up to 1100 MW	<b>2015</b> Germany 640 kV ( $\pm 320$ kV) 800 MW 60 miles UG 47 miles subsea	<b>2016</b> Sweden-Lithuania 600 kV ( $\pm 300$ kV) 700 MW 31 miles UG 248 miles subsea	<b>2017</b> Germany 640 kV ( $\pm 320$ kV) 916 MW 56 miles UG 28 miles subsea	<b>2014-2018</b> Type and PQ tests 1050 kV ( $\pm 525$ kV) up to 2000 MW
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