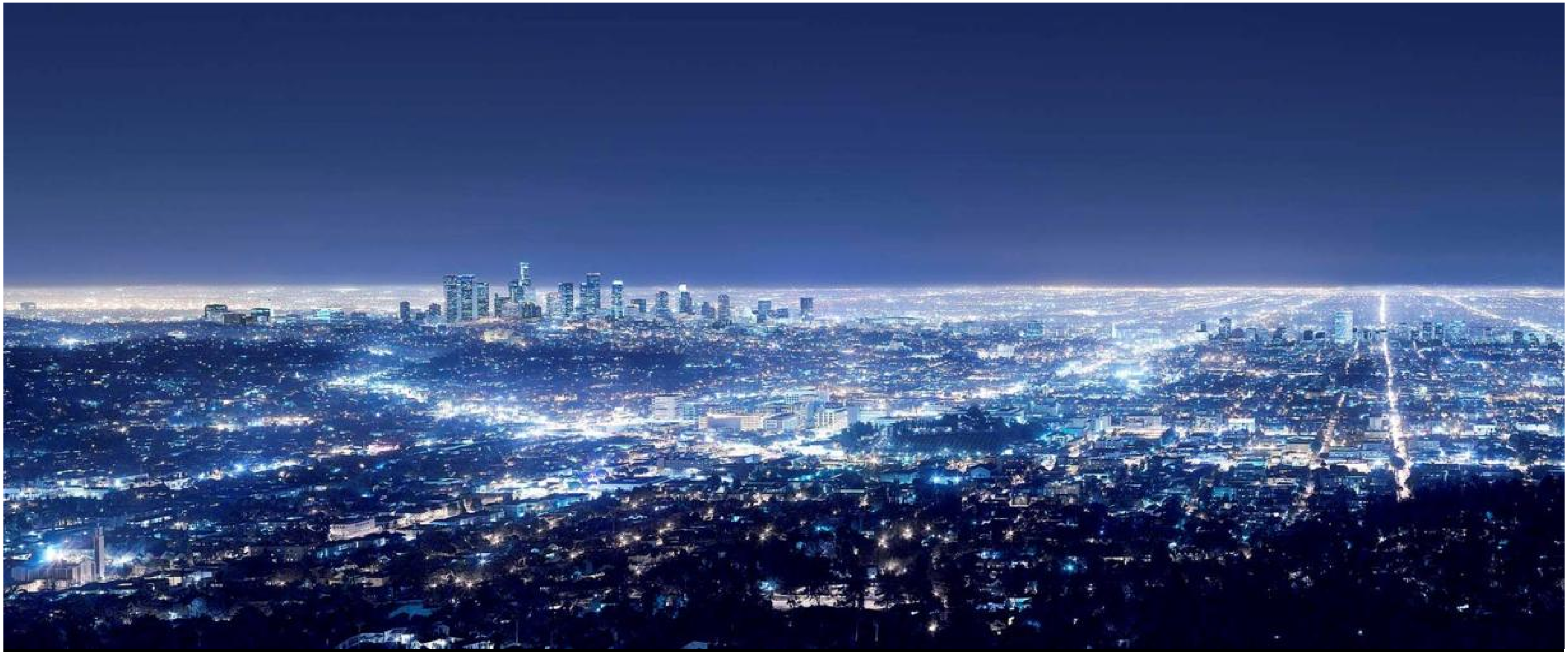

Transmission Grid Reinforcement with Embedded VSC-HVDC

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Outline

- Introduction
- HVDC-Light Transmission Technologies
- Embedded VSC-HVDC for AC Grid Reinforcements
- WAMS Enhanced VSC-HVDC Systems
- Conclusions

HVDC Light ©, the ABB product name of VSC-HVDC transmission

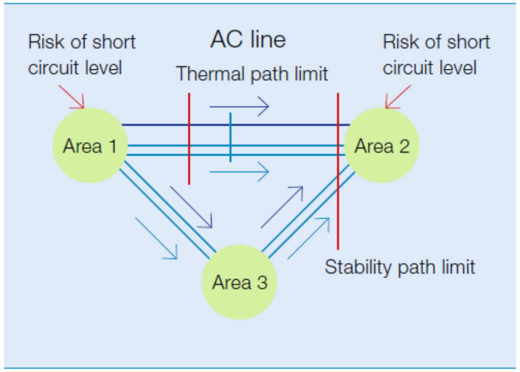
Introduction

CIGRE working groups, e.g. B4.65; C4/B4/C1.604

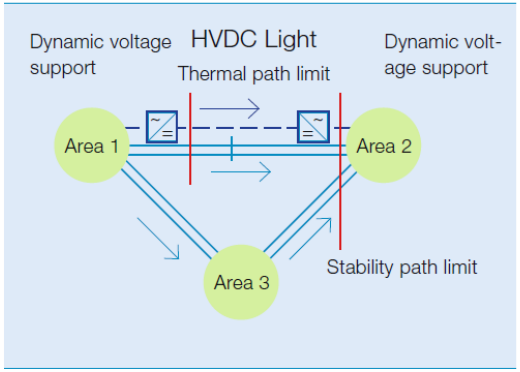
“An embedded HVDC system is a **DC link with at least two ends being physically connected within a single synchronous AC network**. With such a connection, it can perform not only the basic function of bulk power transmission, but also, importantly, some additional control functions within the AC network such as power flow control, voltage control, system stability improvement and the mitigation of system cascading failure.”

Introduction

- Expansion needs of regional grids
  - Increased bulk power transmission
  - Reliable integration of large-scale renewables
  - Flexible control of network power flow
- Issues with AC expansion options
  - Environmental constraints
  - Voltage or transient instability problems
  - Risk of increased short circuit levels
  - Unaccepted network loop flows
- Future transmission infrastructure
  - Advanced transmission technologies
    - Embedded HVDC, FACTS
  - Hybrid AC/DC grid structure



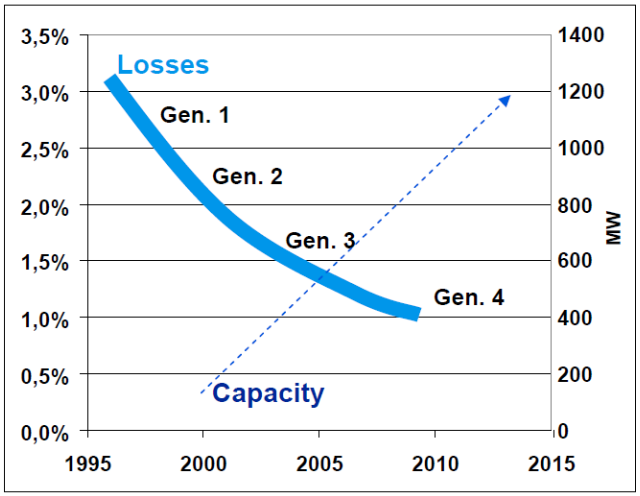
Regional grid reinforcement with conventioal AC options



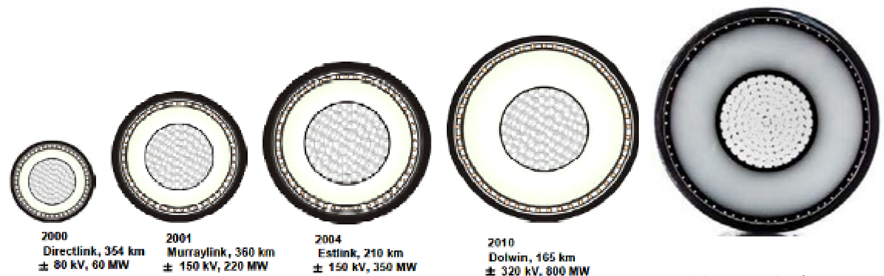
Regional grid reinforcement with VSC-HVDC

HVDC-Light Transmission Technologies
Evolution since 1997

Reduce losses



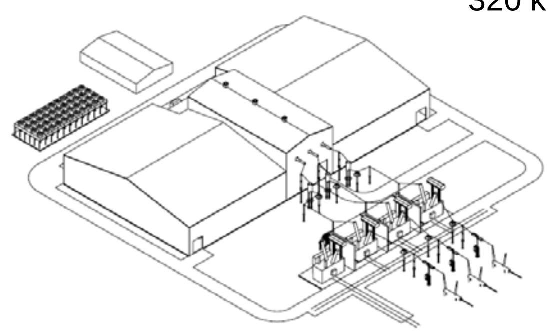
Increase capacity



2014, ±525 kV,
up to 2.6 GW

Compactness

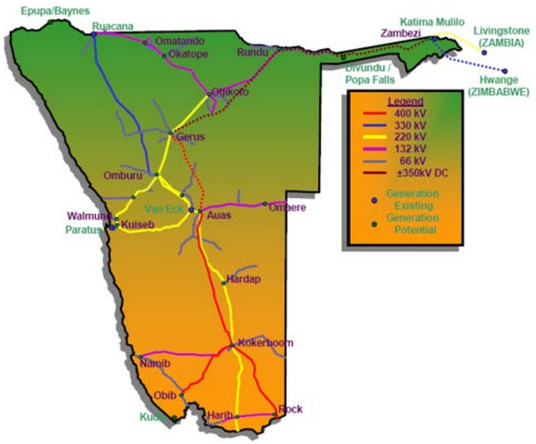
150 x 100 m
320 kV, 1000 MW

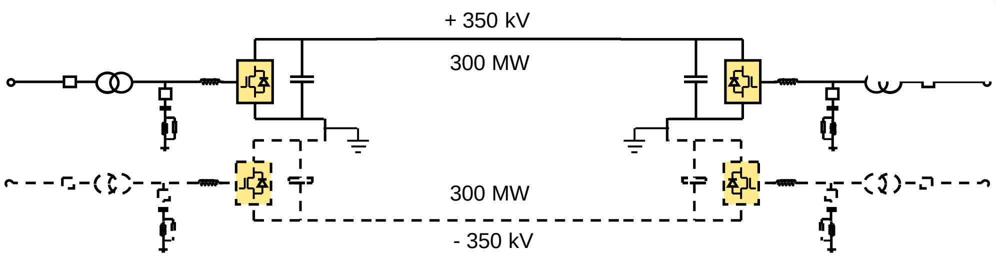


Recent : Dolwin beta offshore wind connection 916 MW, ±320 kV, 2 x 135 km cable system

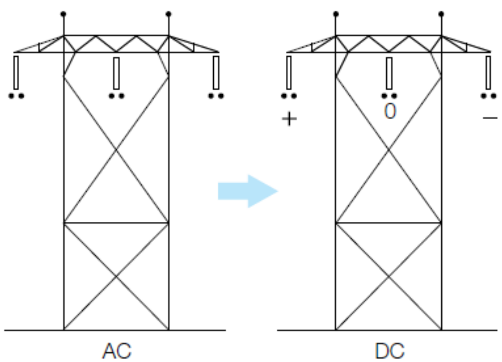
HVDC-Light Transmission Technologies
Overhead link and AC/DC line conversion

- Caprivi Link
  - 300 MW, 350 kV monopole with ground electrodes
  - 970 km overhead DC line
  - Stabilize connected weak power networks
  - Expandable to 600 MW, ± 350 kV bipole



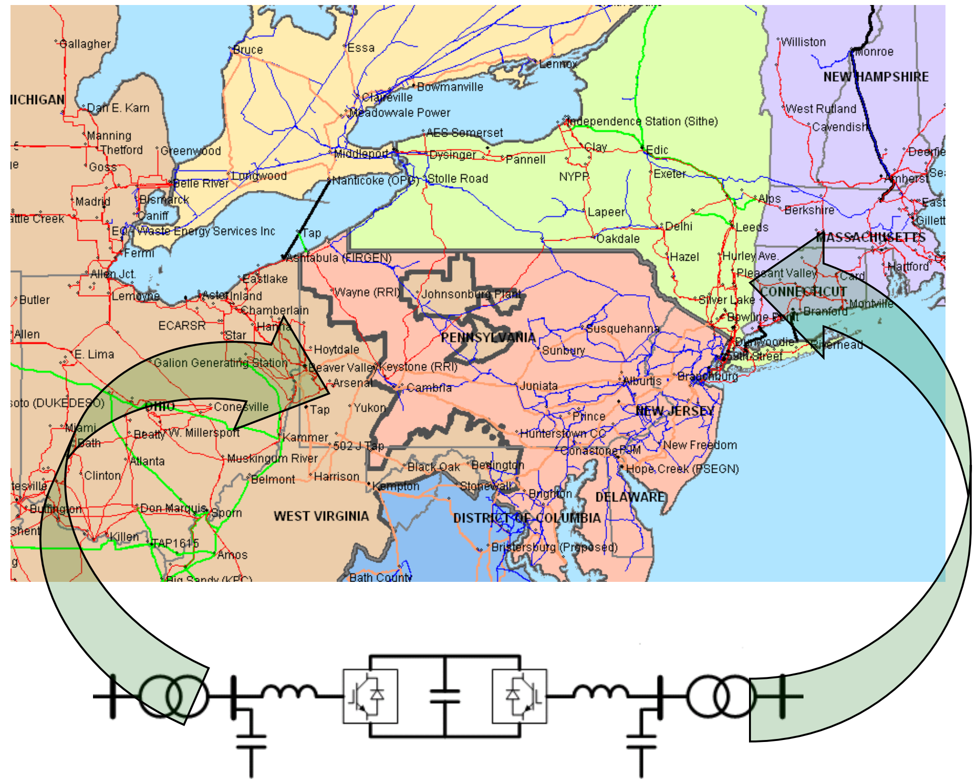


- Potential benefits of AC/DC line conversion
  - Capacity gain of 50%~100% or higher by conversion of three phase AC line to bipole or tripole DC transmission
  - Capacity gain of 100% or higher by conversion of double circuit AC line to three symmetric monopole DC transmission



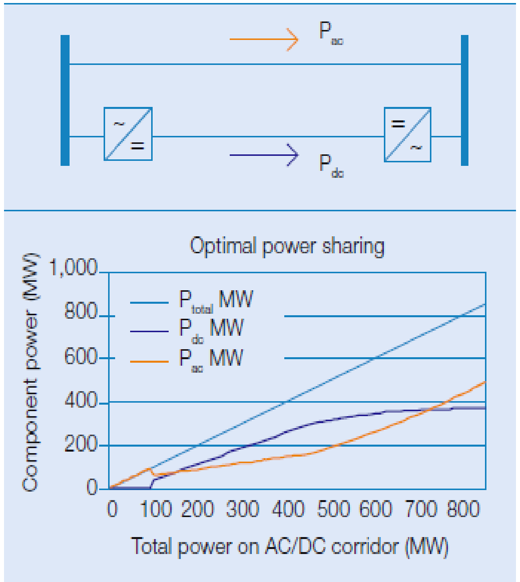
Embedded VSC-HVDC for AC Grid Reinforcements

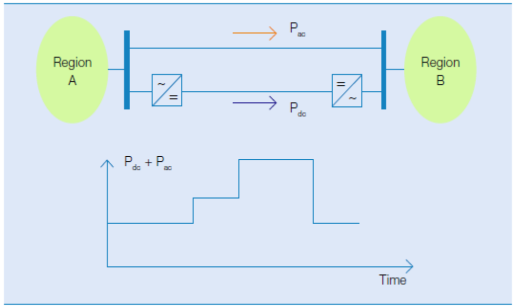
- VSC-HVDC provides necessary features for embedded applications in meshed AC grids
  - Increased transfer capability
  - Flexible power flow control
  - Improved system dynamic performance
  - Feasible multi-terminal configurations for more flexibility

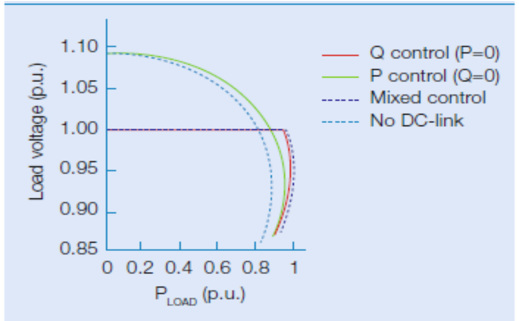


Embedded VSC-HVDC for AC Grid Reinforcements
Transfer capability enhancements

- VSC-HVDC link can effectively transmit the rated power bypassing congested AC network.
- Optimal power-sharing to minimize the losses of hybrid AC/DC corridor.
- Precise power flow control by contractual agreement simplifies the pricing of inter-region power transfers and prevents undesired flows.
- Increase voltage stability constrained transfer limit beyond DC link power ratings.







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Embedded VSC-HVDC for AC Grid Reinforcements
Infeed to Large Urban Areas

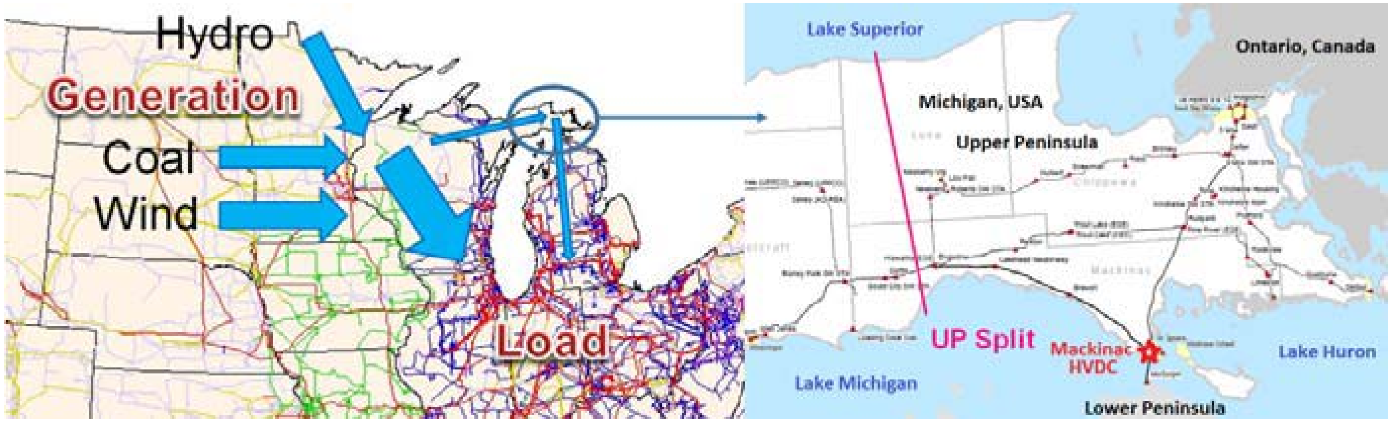
- Large urban grids are characterized by
  - High concentration of critical loads
  - High reliance on external power supply
  - High demands for reliability and power quality
- Operation Issues
  - Inadequate into-city and intra-city delivery capability
  - Inadequate voltage support at load centers
  - Increased levels of short-circuit currents
  - Increased concerns on grid resiliency
- Direct HVDC infeed could provide low-cost and reliable power injection to urban grid load centers bypassing AC network constraints.

Cross-Sound link between Connecticut and Long Island (±150kV, 330MW, 40km)

The Cross Sound link improves the reliability of power supply in the Connecticut and New England power grids, while providing urgently needed electricity to Long Island.

Embedded VSC-HVDC for AC Grid Reinforcements
HVDC as a Flow Control Device

- Mackinac is a HVDC Light® 200 MW BtB operating as a flow control device embedded in the ac system between Michigan's Upper (UP) and Lower (LP) Peninsula
- HVDC Light® offers the following combined features:
  - Control the flows regardless of future system changes
  - Operate under any system short circuit conditions
  - Provide continuous and dynamic MVArs for voltage regulation
  - Quickly adjust real power in response to system contingencies



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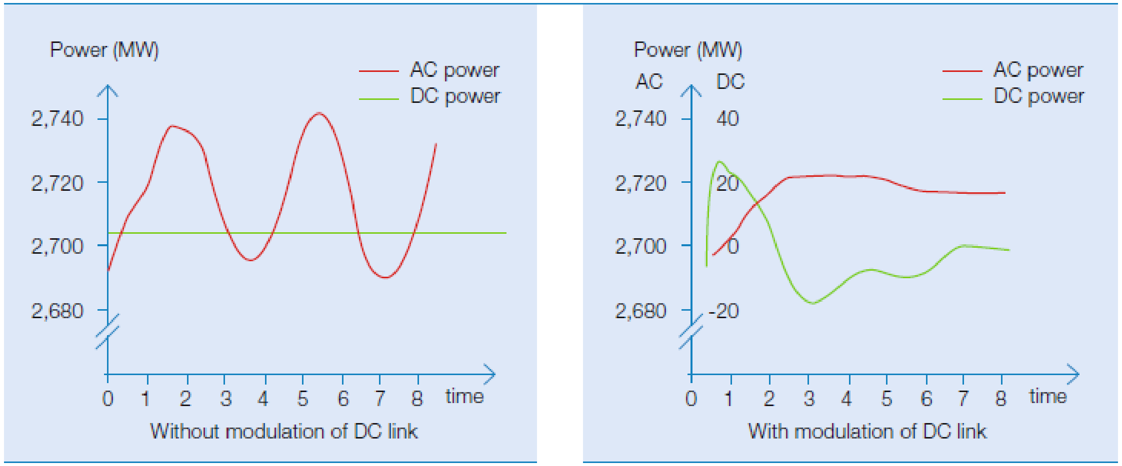
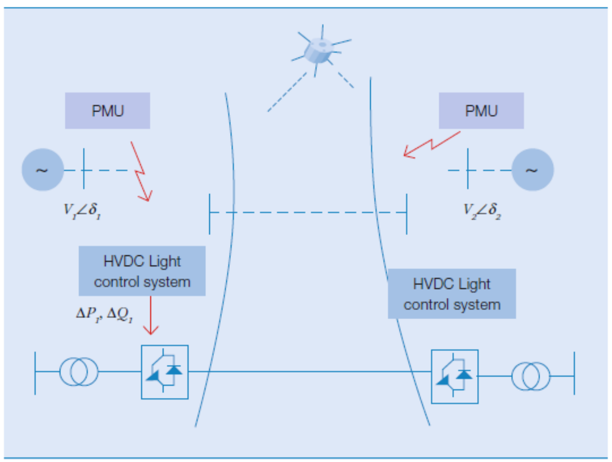
System Aspects of VSC-HVDC
Power oscillation damping (POD)

- Embedded VSC-HVDC could damp both local and inter-area modes of power oscillations
- Damping control schemes could be implemented based on different feedback signals such as modulated active power signals or modulated reactive power signals or any desired ac quantity based on observability analysis
- In some cases, P and Q could be modulated concurrently to achieve a more effective means of damping oscillations.



WAMS Enhanced VSC-HVDC Systems
Expanding system benefits of HVDC

- WAMS could enhance the performance of VSC-HVDC systems with necessary remote measurements to initiate effective dynamic and post-contingency controls individually or cooperatively
  - Improve network transfer capability
  - Mitigate post-contingency violations
  - Counter electromechanical disturbances
    - Small signal power oscillations
    - Large angle swings (transient stability)



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Conclusions

- VSC-HVDC is emerging as a robust and economical alternative for regional transmission grid reinforcements.
- Embedded VSC-HVDC applications, together with WAMS, could significantly improve overall system performance.
- Technology is under continued development for higher voltage, higher efficiency and more flexibility.
- Operational features of VSC-HVDC are becoming more and more important to System Operators.

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