CIGRE US National Committee
2021 Grid of the Future Symposium

Reactive Power Compensation Considerations for Offshore AC Networks

Tapan Manna (USA)

BURNS McDONNELL

October 18, 2021

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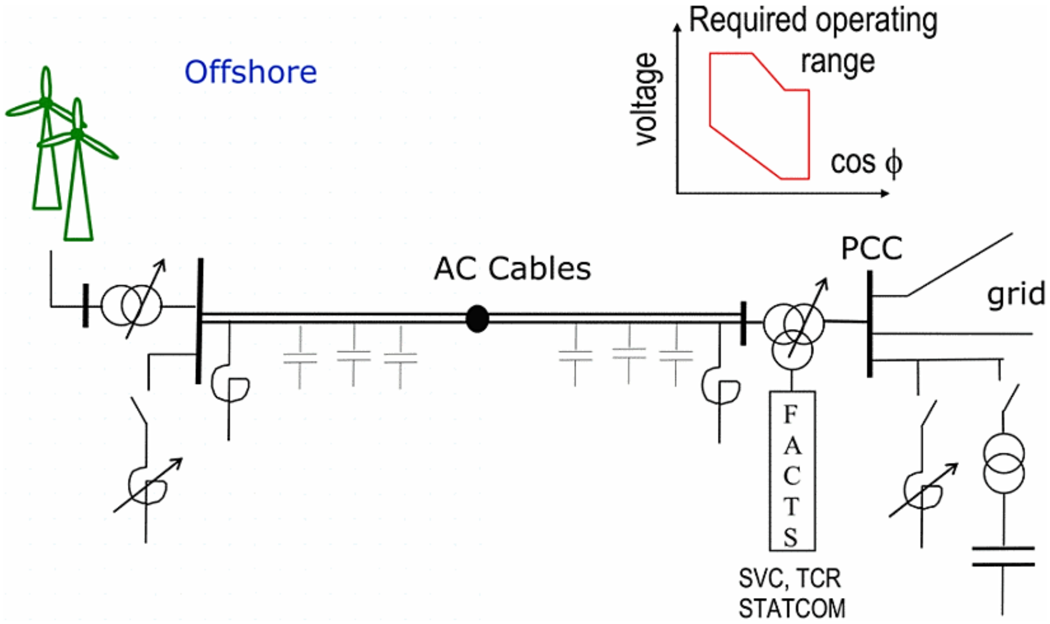
Background

- Wind energy is the fastest-growing power generation resource.
- Offshore wind farms are integrated into bulk power grids at the onshore PCC through the AC submarine cable.
- Stability of system network operation with a large penetration of wind energy has been one of the most important concerns.
- Reactive power is generally produced or absorbed by major reactive components of wind power plant (WPP).
- To keep the grid operating voltage within acceptable margins, an optimal cost-effective reactive power compensation is necessary.

Topological Structure of an Offshore Wind Farm

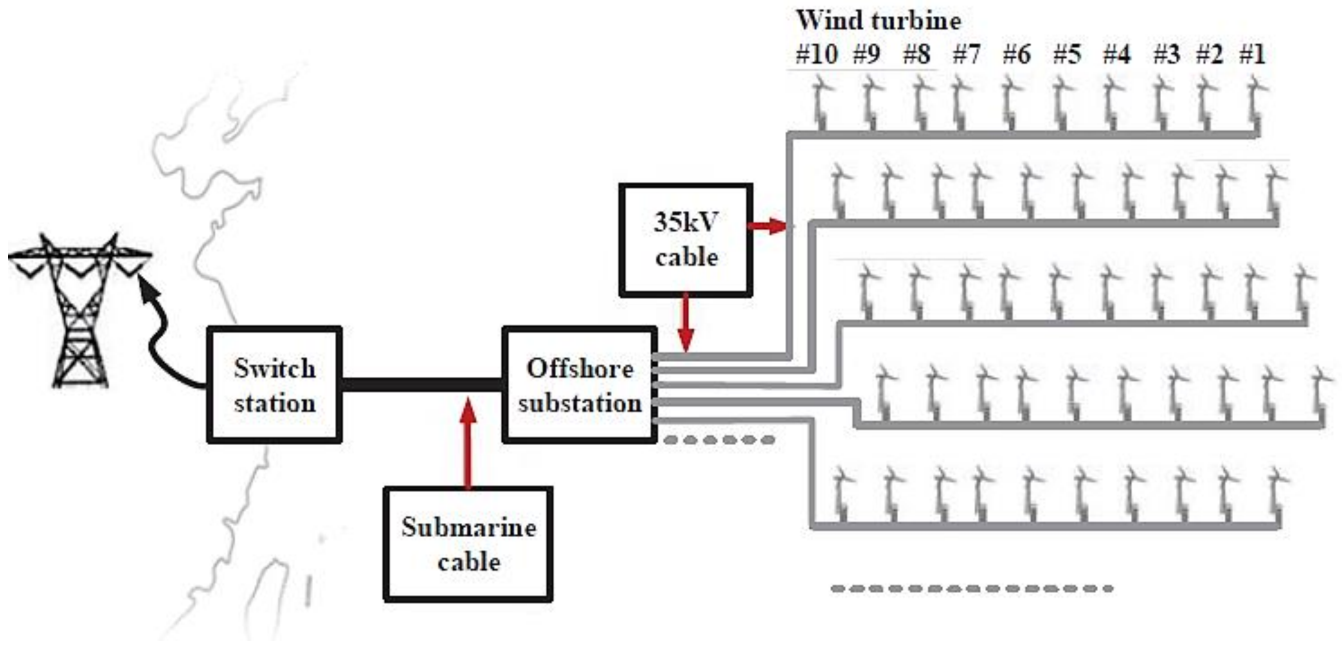


General layout of an offshore wind farm

Source: CIGRE TB 610-2015

Source: M. Wilch, et al., “Reactive Power Generation by DFIG Based Wind Plants with AC Grid Connection,” *IEEE Lausanne Power Tech Conference*, Lausanne, Switzerland, July 1-5, 2007

Topological Structure of an Offshore Wind Farm (Cont'd)

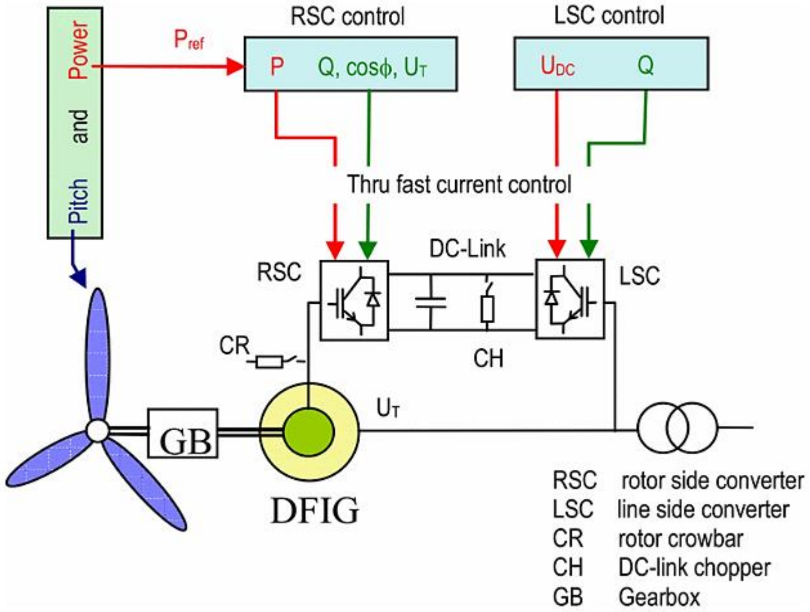


Array cables and offshore substation

- Array cables – radial and branched connection
- Configurations of turbine
- Several busbars and transformers
- Voltage level U_m = 35 kV
- MV switchgear

Source: L. Yan, et al., "Research on Reactive Voltage Characteristics and Control Strategy of Offshore Wind Farm," *12th IET International Conference on AC and DC Power Transmission (ACDC 2016)*, Beijing, China, May 28-29, 2016

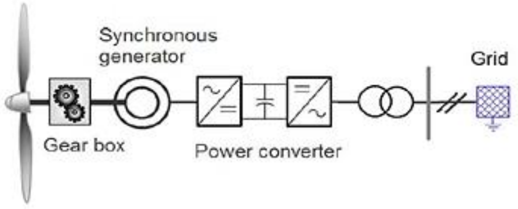
Configuration of Wind Turbine Generators



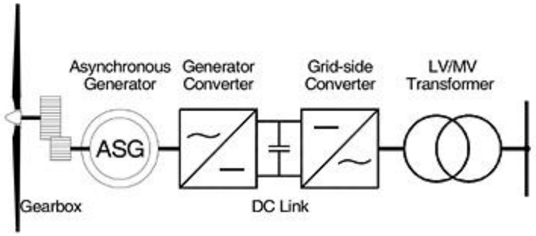
- Doubly Fed Induction Machine (DFIG)
- Partial power converter processes rotor power

Configuration of a WT equipped with DFIG

Source: M. Wilch, et al., “Reactive Power Generation by DFIG Based Wind Plants with AC Grid Connection,” *IEEE Lausanne Power Tech Conference*, Lausanne, Switzerland, July 1-5, 2007



a)



b)

- WT equipped with SG/ASG and full load power converter
- DC link allows power to flow between SG/ASG and asynchronous systems

a) WT equipped with a synchronous generator
b) WT equipped with induction generator and full-scale frequency converter

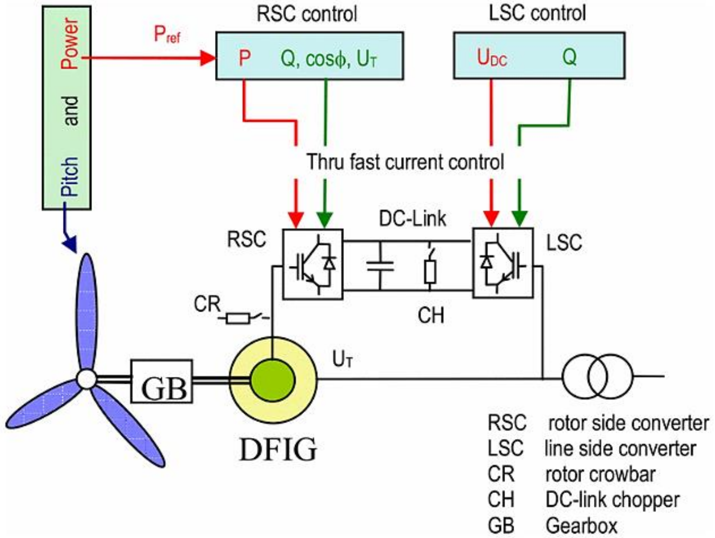
Sources a): H. Guo, et al., “Stability Studies of Offshore Wind Plants,” *5th International Conference on Critical Infrastructures (CRIS)*, Beijing, China, Sept. 20-22, 2010
b): W. Wiechowski, et al., “Selected studies on offshore wind farm cable connections - challenges and experience of the Danish TSO,” *IEEE PES General Meeting*, Pittsburg, PA, USA, July 20-24, 2008

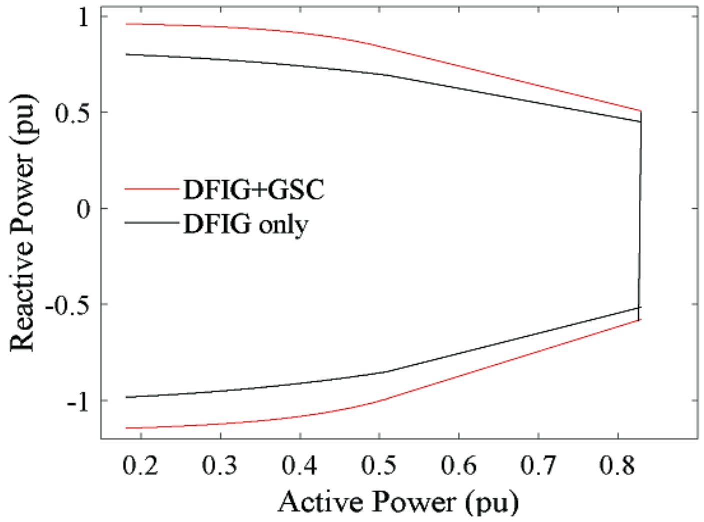
Control Capability of Wind Power Plants

Offshore wind power plants (WPPs)' controls:

- Active power/ frequency control
- Reactive power/ voltage control
- Low voltage ride-through (LVRT)/ fault ride-through

WPP controls can coordinate the P and Q response of multiple wind turbines (WTs) and thus make the plant control function as a single integrated power generation source.



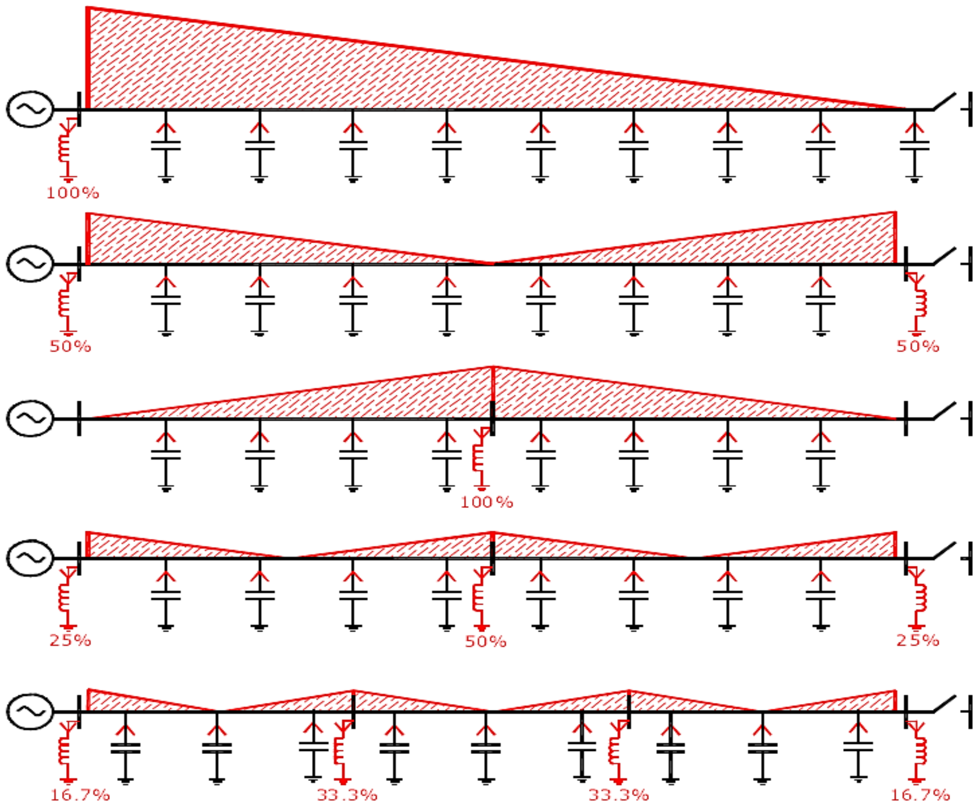


VAr Capability with and without GSC/LSC

Source: Md. N. S. Shabbir, et al., "Analytical Approach-Based Reactive Power Capability Curve for DFIG Wind Power Plants," *IEEE IAS Annual Meeting*, Detroit, MI, Oct. 10-16, 2020

Reactive Power Contribution by AC Cables

- Cable itself is a VAr source (capacitive) that contributes reactive power into the grid. Switching a long HVAC cable can cause overvoltage if not properly compensated.
- AC cables are characterized by many times as large shunt capacitance compared to overhead lines.
- The resulting charging current will limit the remaining cable ampacity for active power transfer, increase the active power losses and increase the voltage along the line.
- Charging current is voltage dependent, the higher the voltage, the faster the transmission capacity will diminish as a function of the length.



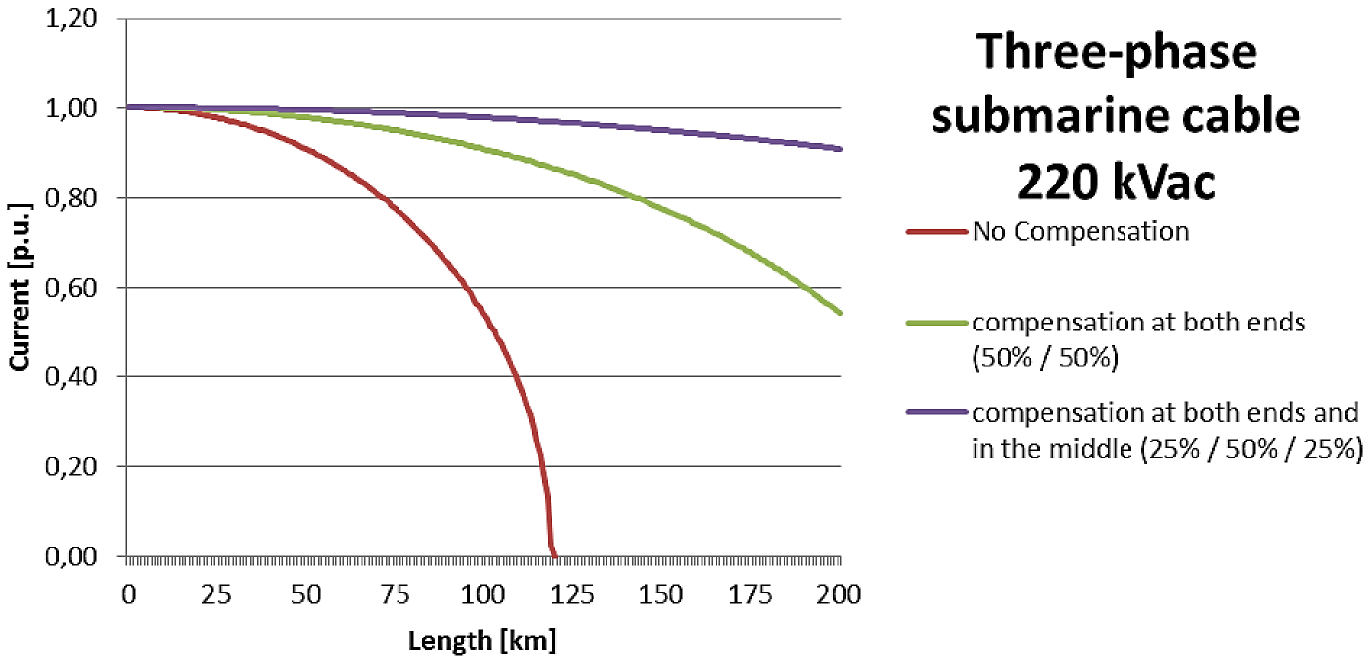
Loading of an open-ended cable line and schemes for reactive power compensation

Source: W. Wiechowski and P. B. Eriksen, “Selected studies on offshore wind farm cable connections - challenges and experience of the Danish TSO,” *IEEE PES General Meeting*, Pittsburg, PA, July 20-24, 2008

Influence of Reactive Compensation on AC Cable

Offshore AC – solutions

- One or more parallel 3-core export cables
- Reactive compensation on land and if necessary offshore - by cable reactors and WTGs
- WTGs absorb reactive power during the energization of inter-array cables, offshore substation’s transformers and export AC cables.
- Onshore grids require additional FACTS devices



Influence of compensation on a three-core 220 kVac submarine cable system

Source: CIGRE TB 610-2015

Reactive Power Compensation

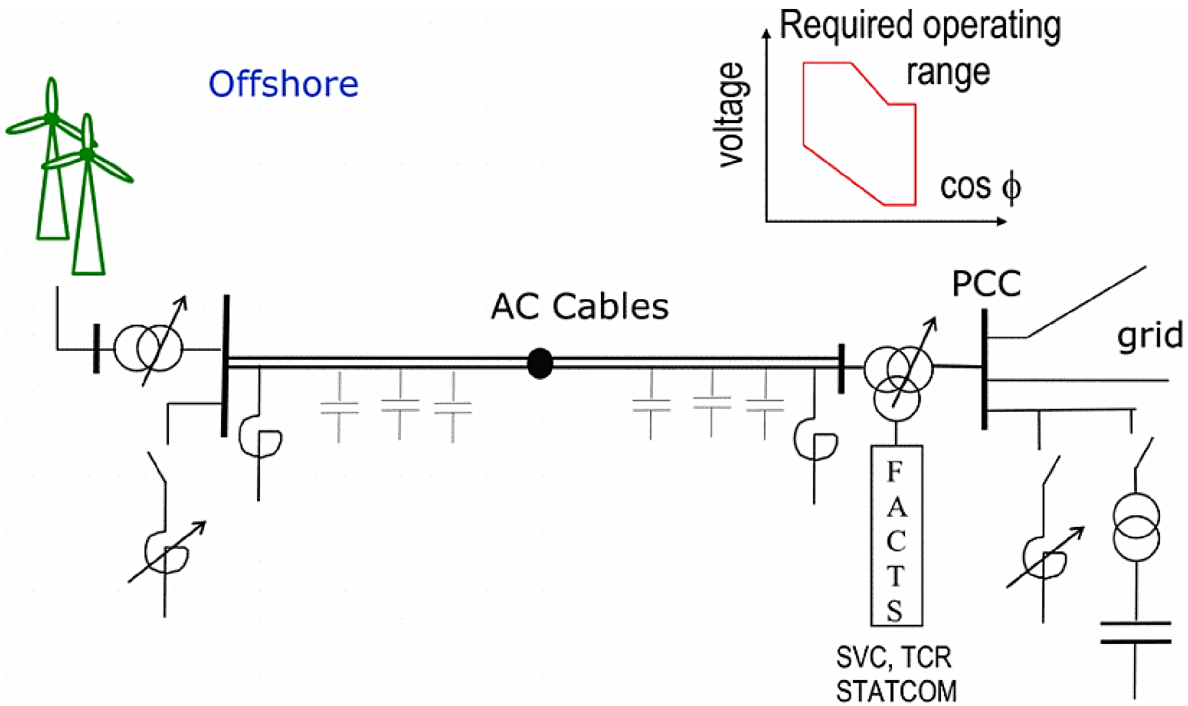
- Reactive Compensation
  - To increase the transmission capacity of the AC cables
  - To reduce losses
  - To ensure stable system voltage

- Charging current distribution along the cable length can be improved by using FACTS devices enabling an equal current flow at both the generation and load ends.
  - Mechanically switched capacitors (MSC)
  - Mechanically switched shunt reactors (MSR)
  - Mechanically switched capacitive damping networks (MSCDN)
  - Variable shunt reactors with tap changers
  - Thyristor based Static Var Compensators (SVC)
  - VSC based SVCs or Synchronous Static Compensators (STATCOM)

Reactive Power Compensation (Cont'd)

- The need and rating of VAr devices depend on the system configuration, wind plant's P&Q generation capacity, type of wind turbines, distance to shore (between the onshore and offshore substation), voltage and power rates, transformers' impedance and other equipment such as harmonic filters.
- The costs for reactive compensation are predominantly voltage dependent; devices at higher voltages are more expensive than compensation devices at lower voltages.

Conclusions



Key Takeaways

- Reactive power (Q) distribution through the AC cable links needs to be balanced wisely to achieve a stable, secure, and economical operation of the power grids.
- Optimization of Q-compensation is an important part of overall system planning - that should include Q-reserve.

Q&A