Coordinated control of DFIG-based offshore wind power plant connected to a single VSC-HVDC operated at variable frequency

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Objectives
This work proposes an OWPP design based on variable speed wind turbines driven by doubly fed induction generators (DFIGs) with reduced size power electronic converters connected to a single VSC-HVDC converter which operates at variable frequency within the AC collection grid. OWPP may have several VSC-HVDC converters forming clusters of wind turbines, such that each cluster operates at its own optimal frequency. The aim of this study is to evaluate the influence of the power converter size and wind speed variability within the OWPP on energy yield efficiency, as well as to develop a coordinated control for the VSC-HVDC converter and the individual back-to-back reduced power converters of each DFIG-based wind turbine in order to provide control capability for the OWPP at a reduced cost.

Description of the concept
This wind power plant proposal combines DFIG wind turbines with reduced size power converters (approximately 5-10% instead of 25-35% of the rated power) and a single VSC-HVDC converter which dynamically changes the collection grid frequency (f) as a function of the wind speeds of each turbine.

- The common VSC-HVDC provides variable speed control to the whole wind power plant (or the wind turbine clusters).
- Reduced size power converters inside each DFIG wind turbine are in charge of attenuating the mechanical loads and of partially or totally compensating the wind speed difference among turbines due to the wake effect.
- Improved reliability, increased efficiency due to the lower losses and a cost reduction are expected to be achieved.
- Wind energy captured may be reduced owing to the narrower speed range that can be regulated by a smaller power converter.
- HVDC transmission link is required to decouple the VPP collection grid from the electrical network.
- Especially worthwhile for offshore wind power plants where the wind speed variability among turbines is assumed to be lower than in onshore.

Individual power converters optimum size depends on various criteria such as:
- Capital cost
- Increased energy capture [3]
- Mechanical load reduction [2-4]
- Fault ride through (FRT) capability [5-7]

Influence of power converter size and wind speed variability on power generation efficiency

Steps:
1. Grid layout definition.
2. Wind conditions definition.
3. Wind speeds calculation on each WT by considering wake effects.
4. Applications of the optimum electrical frequency search algorithm to maximize OWPP power generation.
5. Computational energy generated by the OWPP during its lifetime.
6. Calculation of energy capture efficiency as a function of different wind speed variability and power converter sizes.

Control design
The power converter is modelled using an average-value model (AVM) based on switching functions which approximates the system dynamics by neglecting switching events, i.e. itled gate-biased transistors (IGBTs) are not explicitly represented. The AVM assumes that all internal variables of the MMC are perfectly controlled, all sub-modules capacitors balanced and harmonic currents circulating in each leg are suppressed.

Results

Static analysis

Case of study

Power converter rated slip = 5%
Power converter rated slip = 16.8%

Wind speed input profile

Before 10 seconds
After 10 seconds

Dynamic analysis

Measured wind speed data [6]

Frequency

Power generated

WT speed

Rotational speed (rad/s)

Power generated by WT3 (actual vs available)

Clipped

Slip

Pitch angle

References


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