Pumped storage for balancing wind power fluctuations in an isolated grid

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Pumped storage hydro power plant

- Upper and lower reservoirs
- Pumped storage units are feasible for a wide power range
  - Small unit of a few KW
  - Large units with ratings of several hundreds of MW
- Roundtrip efficiency up to around 85 %
- Reversible Francis turbine
  - Optimal speed depends on turbine head
  - Maximum efficiency for different speeds in generator mode and in pumping mode
  - Efficiency and utilization range can be improved with variable speed operation
  - Variable speed operation allows for controllable power in pumping mode
Types of controllable pumped storage units

Examples of existing units:
- Large variable speed units in operation for load balancing in power systems
  - Mainly doubly-fed asynchronous machines
  - Japan
    - Ohkawachi with 2X395 MVA and 72 MVA rotor circuit cycloconverters
    - Units reaching 475 MVA are under construction with rotor circuit VSC
- Germany
  - Goldisthal with 2x300 MVA and 100 MVA rotor circuit cycloconverters
- Few examples of LCI-drives
- Low power units in small isolated systems
  - Islands in Greece and Spain
  - Stand-alone systems with separate pump and turbine units
  - Standard industrial induction motor drives with speed/power command for smaller pump units
  - Synchronous generator for the turbine unit
Investigated system configuration

- Salient pole synchronous machine
- Full scale voltage source converter
  - Medium voltage (3.3 kV)
  - Three-level topology based on IGCT switches
- Converter can be bypassed and the system operated as a normal hydropower plant
  - Redundancy
  - Keeps familiar technology available for operator
- Diode rectifier as grid side converter if variable speed is not needed in generator mode
- Improved operation can be obtained with Active Front End converter
  - Reversible power flow
  - Control of reactive current and grid voltage
- Relevant for pumped storage units in medium power range
Case study: The Faroe Islands
Case study II

- The Faroe Islands
- Isolated power system
  - Minimum load: 14 MW
  - Maximum load: 70 MW
- Existing electricity supply
  - 60% based on diesel generators
  - 35% traditional hydropower
  - 5% wind power, 4 MW installed
- High CO₂ emission per capita
- Need for energy storage and grid stabilization to integrate higher amount of wind power
Case study III

- Simplified grid model of the Faroe Island power system
- 10 MW wind farm with induction generators directly connected to the grid
  - Assumed worst case with respect to controllability
- Synchronous machine for pumped storage
  - Rating of 10 MW
  - Full scale converter
- Aggregated model for diesel generator sets
- 5 MW hydropower plant
General challenges of the system

- System operation with high share of wind power
  - Minimum load and maximum wind power production corresponds to 10 MW wind and 14 MW load without pumped storage
  - Pumped storage can be introduced as a controllable load
  - Maximum share of wind power in the system is more than 40% even with pumped storage running as load
  - Wind generators and pumped storage will dominate the system under minimum load conditions
- Momentary power balance
  - Controllability of available conventional production units
  - Power control of pumped storage synchronous machine and turbine
  - Power control of wind turbines
Grid simulation model

- Simulation model in PSCAD/EMTDC of simplified power system with pumped storage drive
- Investigation of the pumped storage unit for balancing fluctuations from the wind power production
Simulation model based on vector control principles
- Three controllable variables under variable speed operation
  - Torque or power
  - Flux
  - Power factor
- Fast and accurate response in torque or power
Pumped storage power control

Investigation of two main ways of controlling pumped storage unit

- **Balance power fluctuations directly**
  - Minimize the influence from the wind power on the rest of the system
  - Frequency bias of the power system is indirectly increased since more production is kept online during low load condition

- **Closed loop frequency control**
  - Pumped storage is participating in the primary frequency control like normal synchronous generators
  - Pumped storage unit will contribute directly to the frequency bias of the systems and will improve the response to all changes in load or production
Power flow in the system

- Simulated cases:
  - Minimum load in the system
  - Pumped storage in pumping mode
  - Two or more pump units for controllability in the range of 3 to 12 MW
  - Medium average wind speed with severe fluctuations
  - 18 MVA diesel online with 0.7 pu power set-point
  - 5 MVA hydropower with 0.8 pu power set-point
  - Investigation of control strategies

- The diesel generators must cover most of the fluctuations when the pumped storage is run with constant power

- Droop control of the pumped storage is reducing the power fluctuations from the diesel generators

- Only small fluctuations are remaining with compensation of variation in measured power from the wind turbines
  - The remaining influence is mainly because of oscillations in the output power of the small hydropower plant
  - These fluctuations can be reduced by improving the excitation system of the 5 MVA generator
Influence on system frequency

- The system would be difficult to control without the pumped storage as additional load
  - The amount of diesel generators corresponding to the wind power production could not be turned off
- The system is able to operate with constant power input to the pumped storage unit but the frequency fluctuations of the system is large
- The frequency bias of the system is significantly improved with pumped storage taking part in the primary frequency control
- Influence on frequency can be further reduced by compensating measured fluctuations in output from the wind turbines but this will not increase the frequency bias of the system
Main results

- Variable speed pumped storage units can improve the dynamic power balance of isolated system and balance power fluctuations from wind turbines both in generation and pumping mode.
- The power system can be kept stable with a high share of wind power as long as there is enough capacity for fast power control.
- Synchronous machine drive system allows for quick control response without electrical limitations of the operating range.
- Variable speed operation in pumping mode allows for control strategies that can increase the frequency bias of the system and improve system response to disturbances.
  - The pumped storage unit can be controlled to perform additional auxiliary services to improve power system operation.
  - Different power control strategies can be combined to obtain suitable characteristics.