Grid Forming and Grid Firming Inverters

- Grid following versus grid forming inverters
- Comparison to synchronous machines
- Some basic terms
- Early applications
- Other control applications

Grid Following Inverter

- Fast current control—current source
  » Current references from outer control
  » Vector current control (VCC)
  » Often related to P and Q related outer controls
- Synchronization to the power system
  » Fast tracking of changes in angle or frequency
  » Maintain current setpoint—fault current limiting
  » Looks like nearly zero inertia
Grid Forming Inverter

- Inverter controlled to maintain:
  - Voltage magnitude
  - Frequency
  - Angle reference
  - Back to early VSC control concepts
- Effectively a voltage behind a reactance
  - Needs current limiting control
  - Faults or other disturbances
- Not just for isolated systems…

Grid Firming Inverter

- PLL or similar variant
- Slow voltage source controller
- Energy storage or controllable energy source
  - Treat as dispatchable
- Some able to transition to grid forming
- VSC HVDC links
  - Grid forming or firming on one end
- Able to improve ESCR for LCC HVDC
Weak Grid: In the Past

- Historical: Large impedances between sources or sources and load centers
  » Long lines
  » Low-capacity lines
  » Decommissioning of synchronous generators
    – Local “city center” machines

Weak Grid: Emerging

- Modern:
  » Large percentage of generation made of up VCC converters
  » Possibly located far from synchronous generators
  » Fewer synchronous generators
    – Economics
    – Policy
Issues with Weak Grid

• Poor voltage magnitude regulator
  » Similar to problem with low SCR in LCC HVDC
  » Voltage is sensitive to load/generation changes or control actions
  » Leads to fault ride through
  » Grid following inverters need stiff voltage and frequency

• Frequency
  » Faster excursions (swing rates)
  » Bigger swing amplitudes
Some Equations

- SCR for renewable generation (simple definition)
  \[ SCR = \frac{MVA_{\text{effective, grid}}}{Total MVA_{\text{Grid, Following}}} \]

- Hosting Capacity
  » SCR in 2.5-5 desired

\[ Max_{\text{Grid Following MW}} = \frac{MVA_{\text{effective, grid, forming}}}{SRC_{\text{Required}}} \]

Some other terms

- Isochronous operation: frequency (and voltage) is independently held constant, zero generator droop

- Droop Control: applied to generators for frequency control (sometimes voltage) allowing parallel generator operation
Grid-Forming with Multiple Sources

- One generator is designated to run in isochronous mode
  - Larger and higher inertia prime movers normally reference
  - Problem with one machine/inverter as absolute reference
- All others follow in droop mode
- PV inverters may operate in a droop mode
  - Voltage droop
  - In addition to frequency droop

Consider Synchronous Machines

- Spinning masses
  - Rotor
  - Prime mover stages
  - Inherent droop
- Delay in response to a disturbance—inertia
- Controls
  - Exciter
  - Governor, engineered droop, AGC
- Can connect to weak grid
Compare to Grid Forming Inverter

- Synthesized voltage waveform
- Stiff frequency
- Response time is programmed
- As noted earlier, droop can be programmed for f, |V|, P, Q, etc.
- Inertia?
  - Still very little
  - Unless add significant energy storage or
  - Don’t operate renewable resource at max power point

Other Control Functions/Challenges

- Power oscillation damping
- Virtual Synchronous Machines
  - Synthetic inertia
  - Requires energy storage or energy source that can be varied
  - Impact on converter ratings?
- Slow PLL or some form of programmed droop
- What sort of control interactions/modes introduced?
- Current limiting