ECE 529
Utility Applications of Power Electronics

Session 32
Adding energy storage: case 1

1. DC Bus Reg
2. Grid current function
3. Grid voltage function
4. VSC regulates Vdc

Diagram:
- PV
- DC/DC
- DC Bus Reg
- Storage
- VSC
- AC system

Notes:
- VSC controls grid support
- DC/DC regulates voltage
Energy Storage Case 2

Grid Follow

Storage

VSC

VSC

(maybe had converters)
Capacitors

↑ most capacitors don't scale well with bulk storage

\[ E = \frac{1}{2} CV^2 \]

↓ even though density is poor, can handle fast charge/discharge

\[ \text{Disk} \]
ultracapacitors, also known as supercapacitors

→ much much greater "plate" area

hundreds or thousands of Farads in "small" package

- low voltage
- connect in series
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

Effective Short Circuit Ratio
**MVA short circuit**

- **Isc**
- **V_th**
- **Z_{TH}**
- **mVA_{SC}**

**Point of interconnection**

\[ I_{SC}^{pu} = \frac{V_{TH}}{Z_{TH}} \rightarrow 1pu = \frac{1}{Z_{TH}} \]

**Scalar**

\[ MVA_{SC} = I_{SC} \cdot V_{TH} = \frac{V_{TH}^2}{Z_{TH}} = \left( \frac{1}{Z_{TH}} \right)^2 \rightarrow \text{multi times } Z_{BASE} \]