VSC Control Strategies for Strengthening of AC Systems

A Presentation at:

HVDC and FACTS Sub-Committee

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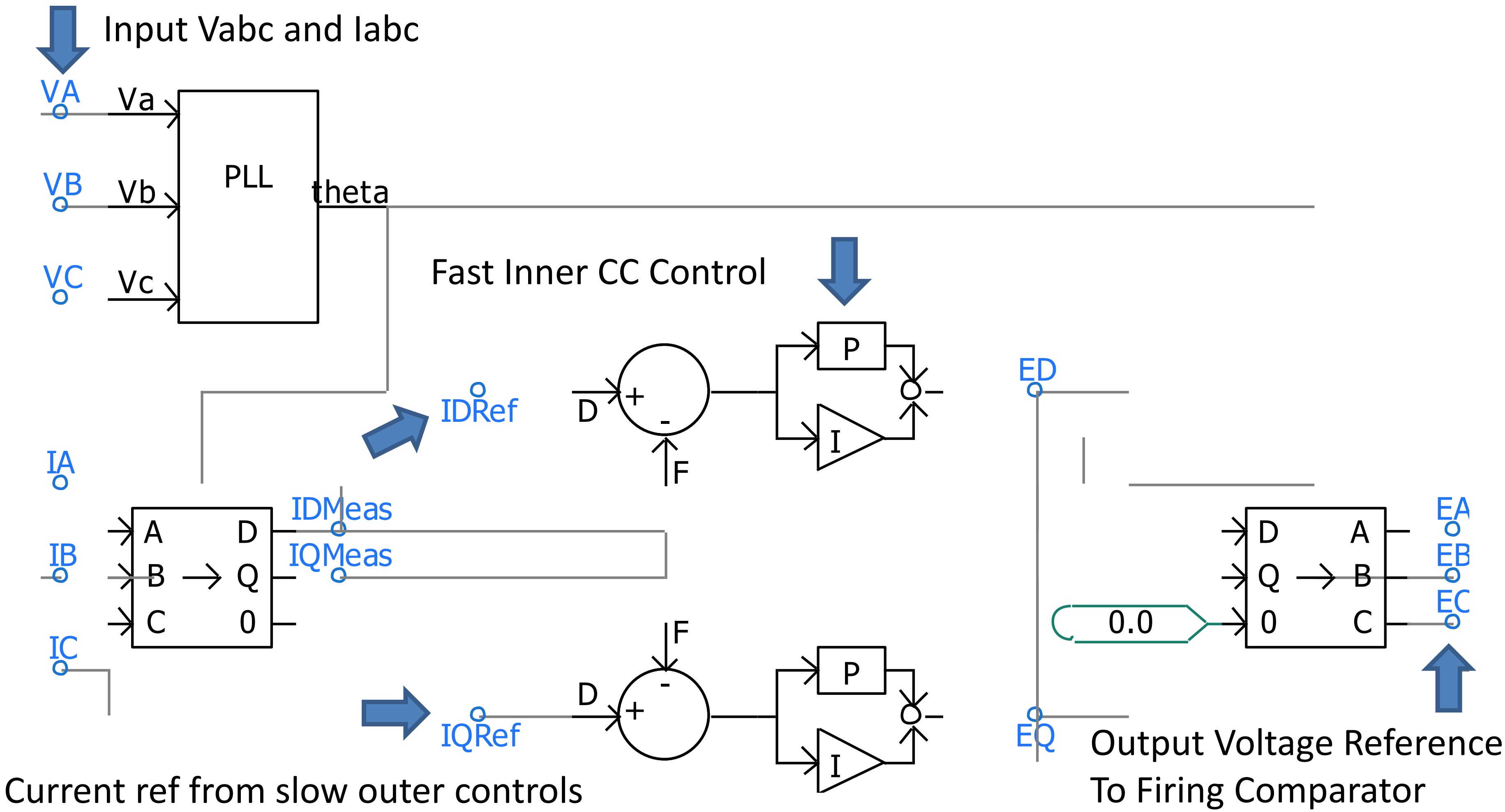
Conventional VSC Control

- "Voltage Source Converter" is a strange name!
- Electrically is like a voltage source, but 99% of VSC Converters use a fast inner current control scheme
- Slow outer controls:
  - Real IDRef: DC voltage, DC current or DC Power
  - Reactive IQRef: Q, Power Factor or AC Voltage Control
- Fast inner controls
  - look like current sources, not voltage sources!

Conventional VSC Control

- PLL tracks voltage (ie get voltage phase angle)
- Converter inner controller output is a voltage behind valve reactance
- Ie quickly follows changes in the voltage phase angle in order to keep the current constant.
- I call this CC = “Constant Current” control.

Conventional VSC CC Control



HVDC VSC Control Scheme

- Outer/slow controls:
  - One side controls DC voltage
  - The other side controls DC current (or power)
  - Both sides control Q or AC voltage.
- Both sides have fast inner CC control!

VSC CC Limitations

- Similar CC principle used in VSC converters in almost all wind, solar, BES, Statcom etc…
- CC is an “Inertia Parasite” or a follower:
  - Requires inertia, SCMVA etc.
- Results in weak system instabilities – ie SCR Limits.
- Little known fact:

  Retiring synchronous generators (coal, gas, nuclear etc.)

  and adding wind/solar has limits (already reached in many places in the world).

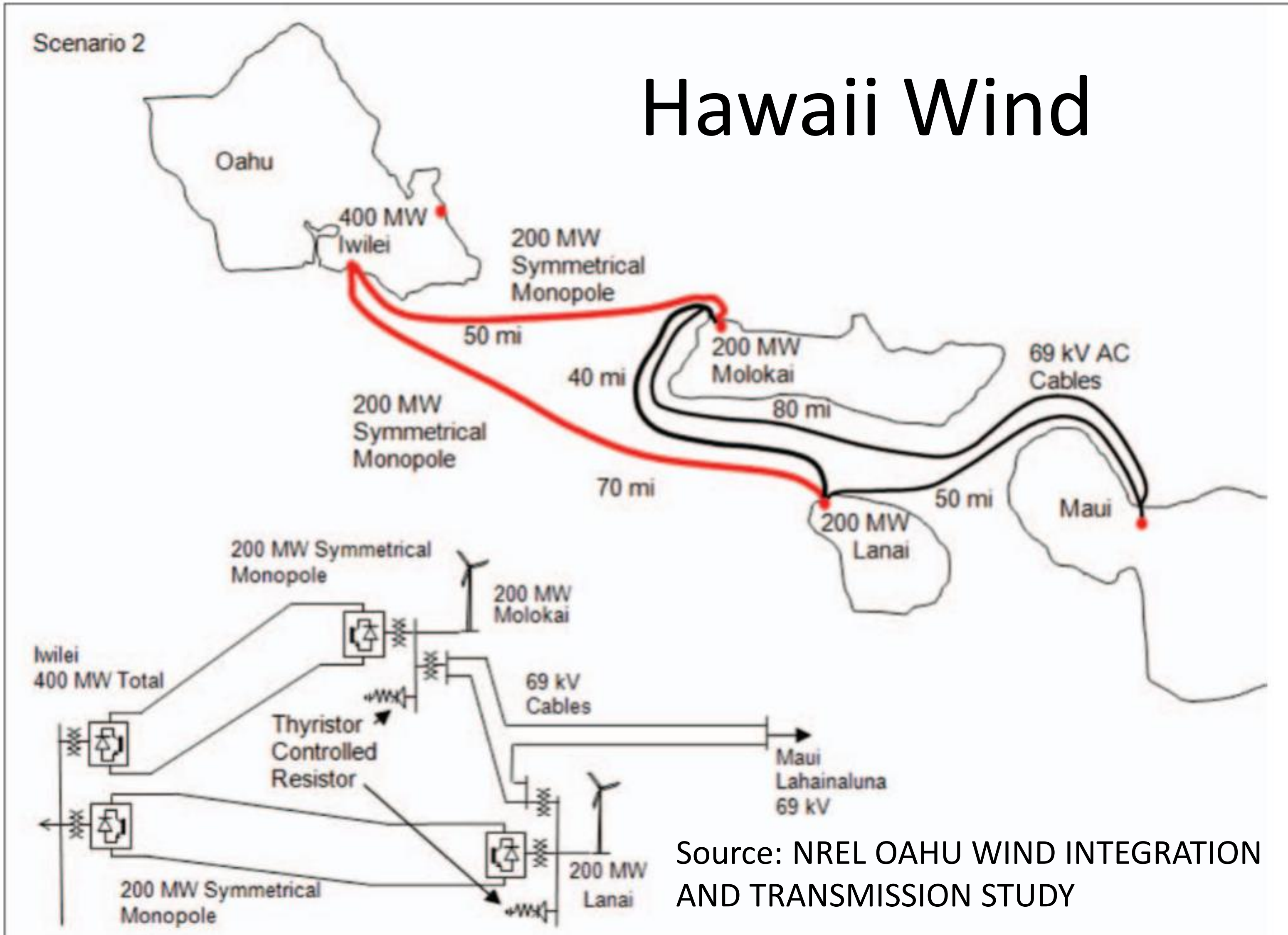
Offshore Wind HVDC VSC Control

- Onshore converter controls DC voltage (CC)
- Offshore converter has PLL gains set to 0.0
  - What? The PLL is the heart and sole of an HVDC link – how can you set its gain to 0.0?
  - Means it is a clock – ie a 1.0 pu 50 Hz sin wave generator
  - Ie CV "Constant Voltage" control
- Offshore wind converters (which use VSCs with CC control) synchronize to the CV HVDC VSC link
- No machine or conventional inertia – SCR = 0.0
- Very stable offshore control (no power control, no PLL dynamics)…

Hawaii Wind
Dennis Woodford ~2010

- 2 x 200 MW HVDC VSC links from Honolulu to Lanai and Malakai
- CV used on the Islands, CC with DC voltage control on mainland
- Slow phase angle changes to control AC power flow between islands (and open loop power-frequency droop to play nice with existing generation)
- Very stable: 200 MW HVDC, 200 MW wind and 20 MW load/existing generation

Hawaii Wind



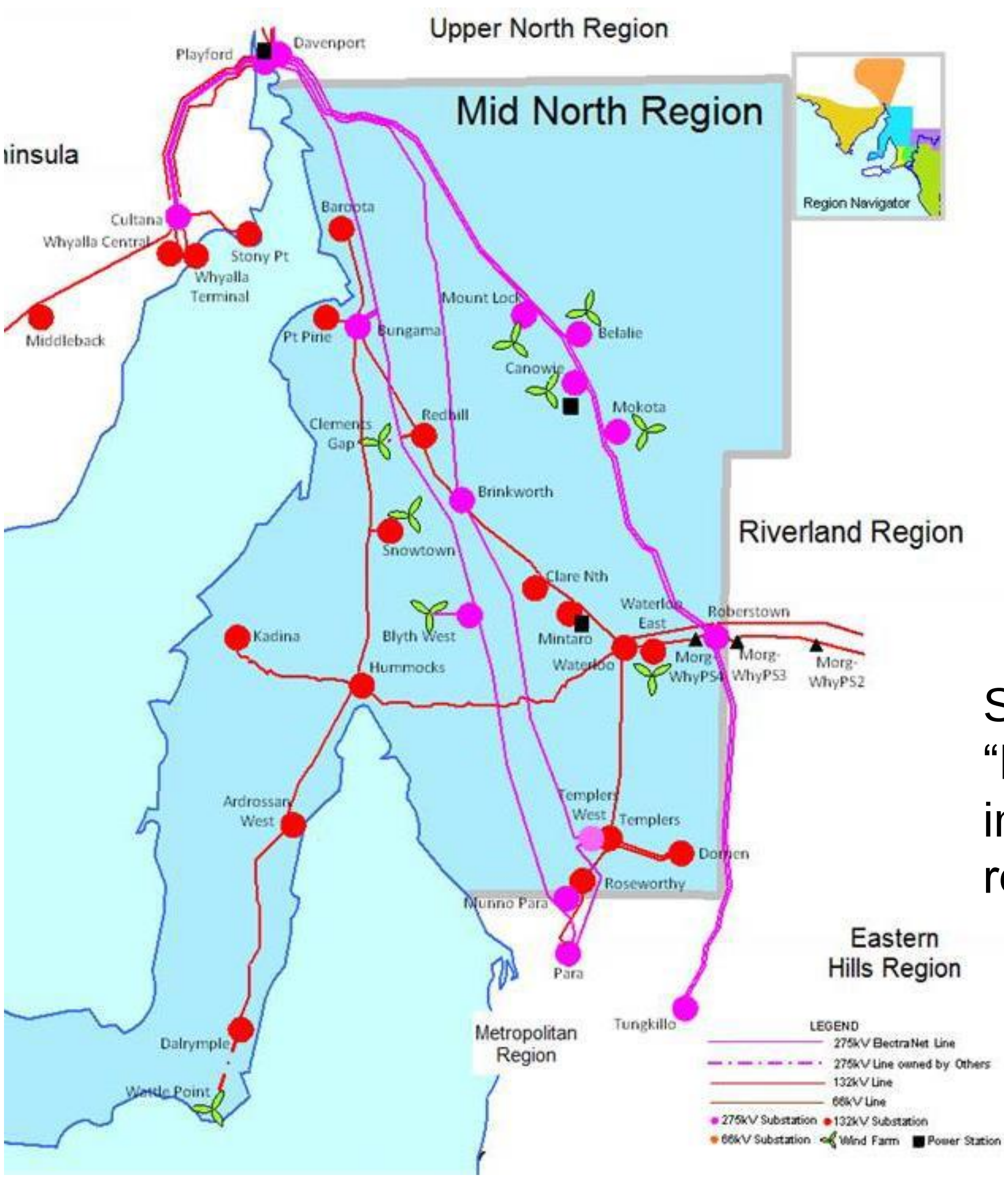
Source: NREL OAHU WIND INTEGRATION AND TRANSMISSION STUDY

Imbedded HVDC VSC Control

- “Strong” converter controls DC voltage (CC)
- “Weak” converter slowly controls the DC current (or DC power) – ie CV but with slow phase angle changes to allow it to control/dispatch power.
- For fast transients, it looks like CV however.
- Very stable control in weak systems.
- Mackinac HVDC VSC Back-Back (ATC) – automatic power order runbacks and islanding.

Dalyrmple ESCRI-SA BES Project (Battery Energy Storage)

- VSC Converter slowly controls the DC current (or DC power) – ie CV but with slow phase angle changes to allow it to control/dispatch power
- For fast transients, it looks like CV however
- Very stable control in weak systems or islands
- **Can survive grid-following to island mode transitions**
- Will automatically change power order to meet the power mis-match in an island – can feed zero inertia passive loads (ie no SCR limits)



Source:
"ESCRI-SA Battery storage to improve transmission network resilience" – May 2018

CV versus VSM “Synthetic Machine”

- Synthetic inertia (1/2Hs) concept:
  - Use a VSC to reproduce a synchronous machine
  - Programmable H, governor etc..
- Results in oscillations (just like a machine)
- Suggest alternative non-oscillatory CV control methods
  - Smooth control scheme without double integrator oscillation effects

System Strength Measurements

- Short Circuit MVA
  - Powerflow fault current – ie an "E behind Z" equivalent
  - Conceptually flawed – ie ESCR vs SCR issues (shunt capacitors etc.)
- Suggest Using ZEFF (Effective Fundamental Frequency impedance)
  - Non linear converter impedance individually determined by perturbation impedance scanning
  - LDU reduction of admittance matrix of grid to single point (or multi-point)
  - Method currently used to form network equivalents
- CV Converters have smaller ZEFF than CC

CV Converters - Challenges

- How to handle over-currents:
  - Steady state over-currents (BES too small for example)
  - Over-currents during faults?
- Transition to CC control?
- Over-rate IGBTs?

R&D - Distributed CV VSC

- Existing CV examples (offshore wind and 1 HVDC VSC back-back) have 1 large VSC converter
- Distributed VSC inverters (wind, solar etc..) now use CC (ie synchronizing to a system voltage)
  - CC is easier (currents add into a strong voltage source)
  - Have SCMVA limits (weak system instabilities)
  - Synchronous condensers may be required
- **CV with distributed VSCs is possible**
  - May require communication/coordination with other nearby converters (avoid loop flows etc.)

Thank you!

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