Advanced Inverters for the Transmission System for the Grid of the Future

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Power Electronics & Energy Conversion Workshop

Tuesday, July 30, 2024
Sandia National Laboratories

video about our collaboration here

Grid Electronics

For DG and Storage, Silicon has been somewhat limiting in terms of efficiency, speed, voltage, ruggedness and cost and so Grid Power Electronics have mainly been deployed at the Grid's edge.

STS, SDS, FCL, Solid State, Statcoms, Breakers, … Inverters

LV and MV Power Electronics, Inverters vs Grid Devices

HV connected Renewables

Larger Power Plants (20MW 150MW and 500MW)
-single plants, T & D

-distributed, D

-Perceived barriers at penetrations >15 - 20%

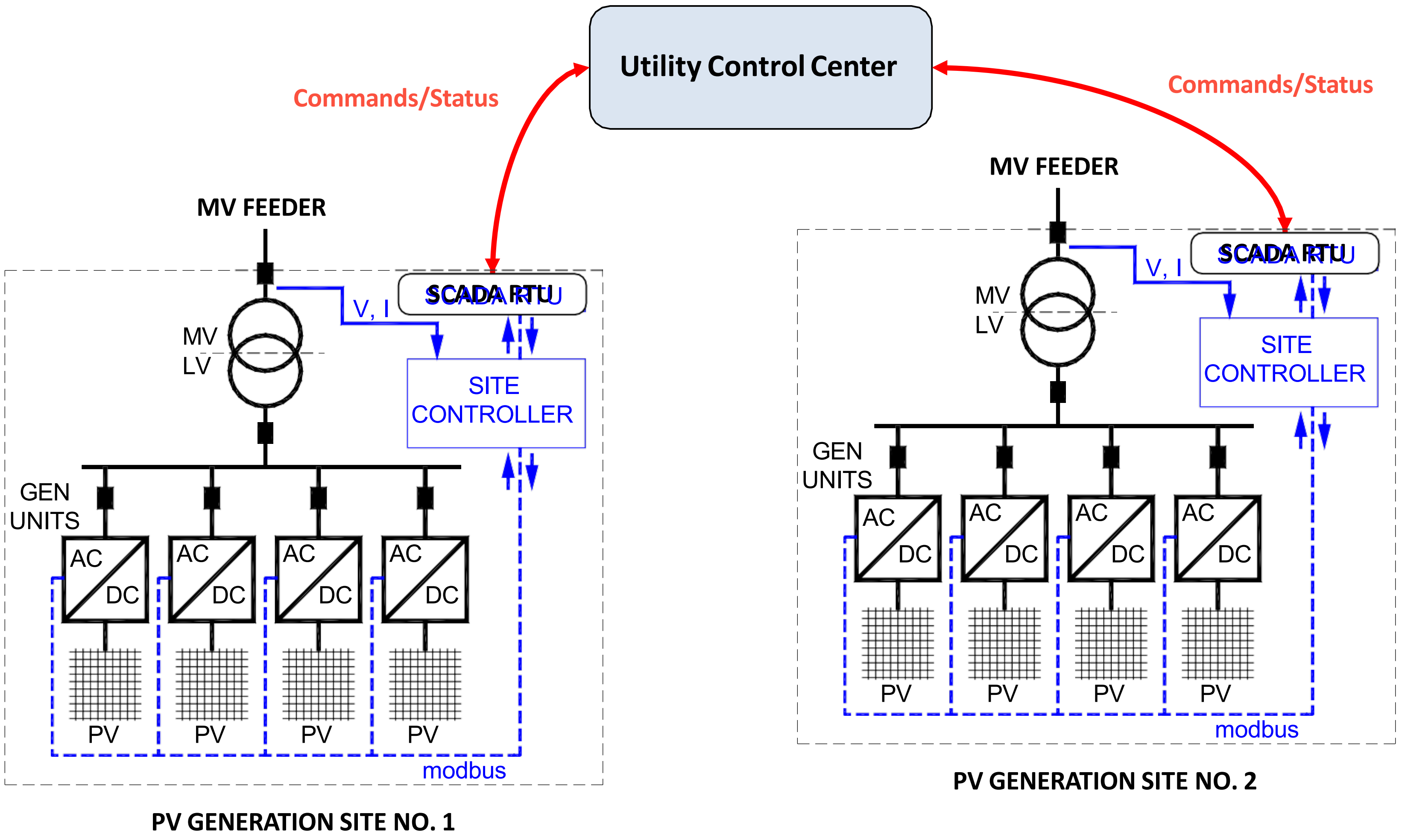
-voltage regulation, protection coordination, cloud and load variability

-Circuit ratings

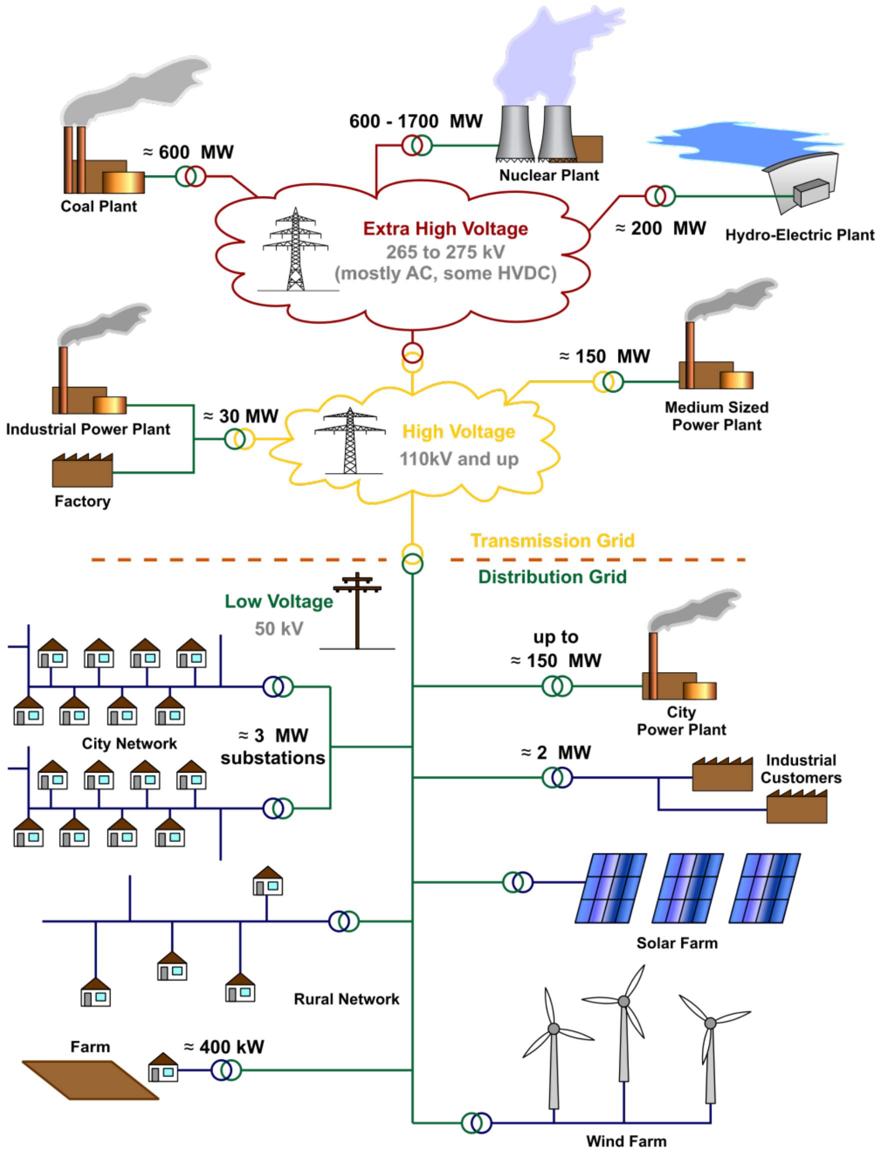
-Trip, transfer trip, islanding

-Utility Assets, efficient, available, long life

Site Controller Provides Real And Reactive Power Management At the Point Of Common Coupling



Visions, Perceptions and Reality



Power Electronics have repeatedly struggled to penetrate the Grid in the past
-FACTs machines? (~90s)
-StatComs? (~2000s)

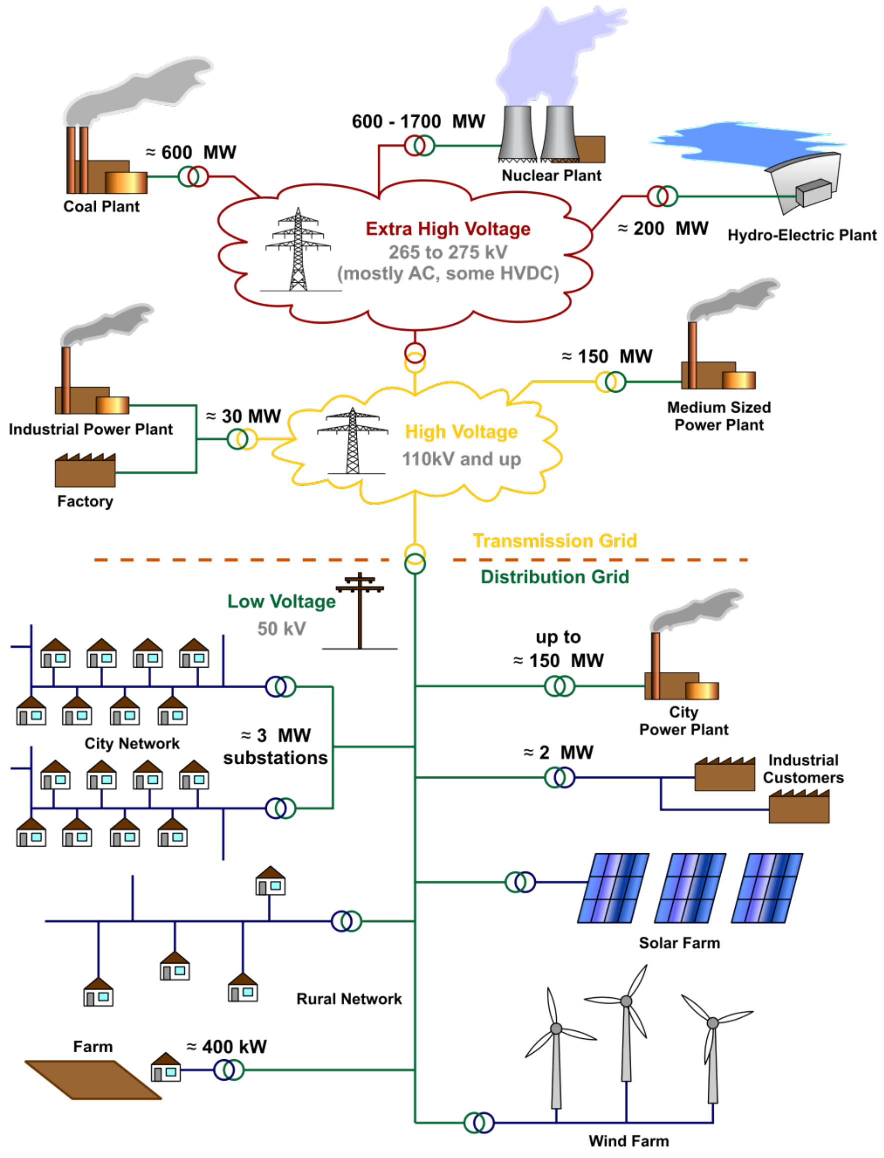
WHY?

Major successes have been in dc TX lines and renewables

2016 DOE Workshop NREL

Electromechanical	Electronic
Clumsy	Smart
Simple	Complex
Large	Compact
Rugged	Less so?
Reliable	Less so?
Slow	Fast
Cheap (1-2c/VA)	Expensive (5-10+c/VA)
Overload (fault clearing)	Limited Overload
99+% efficiency	~97% efficiency?

Visions, Perceptions and Reality



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WHY?

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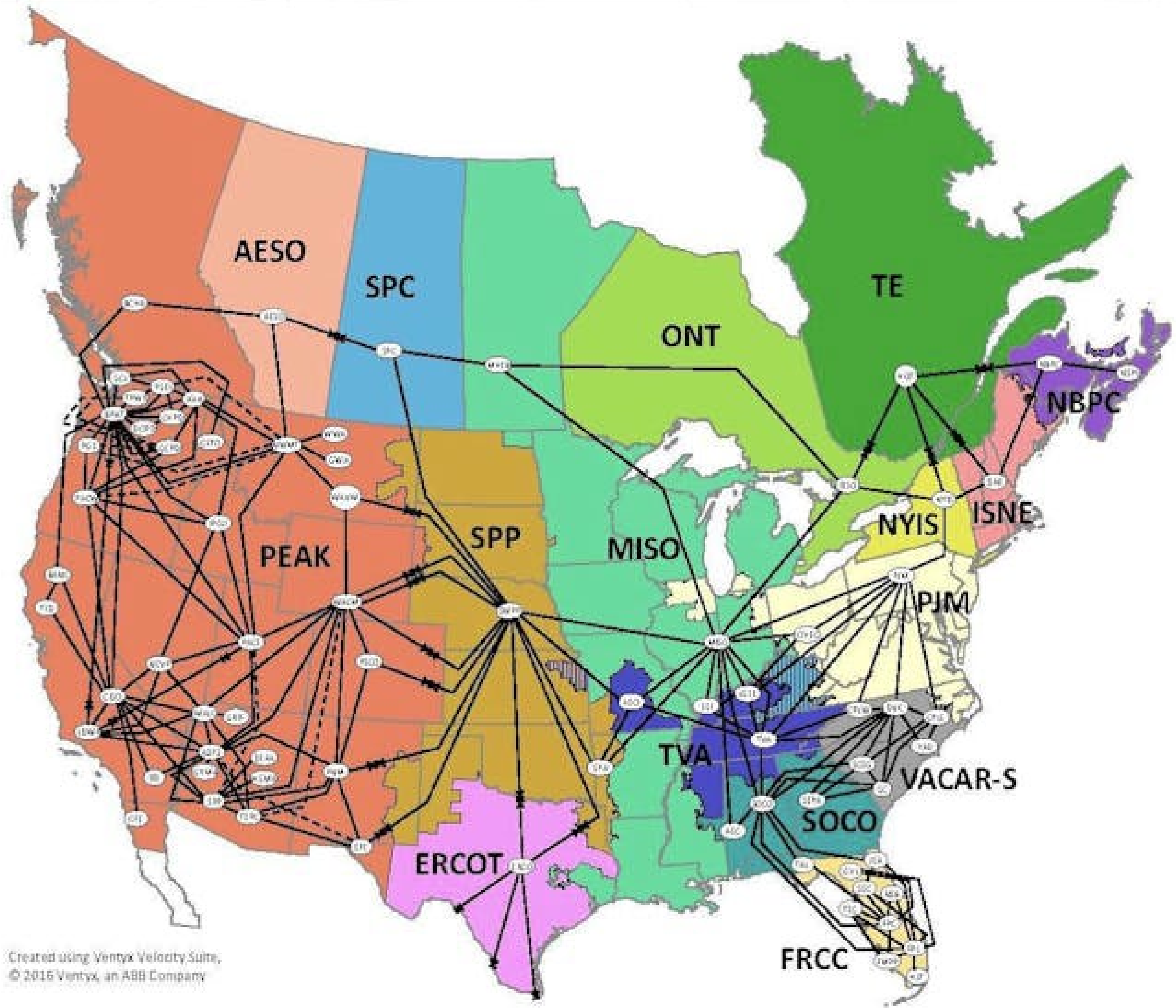
2023 Workshop SANDIA

Electromechanical	Electronic
Clumsy	Smart
Simple	Complex
Large	Compact
Rugged	Less so?
Reliable	Less so?
Slow	Fast
Cheap (1-2c/VA)	Inexpensive (1-2+c/VA)
Overload (fault clearing)	Moderate Overload
99+% efficiency	~99% efficiency?

based on Automotive VSD - CSIRO – X –grid development from VSD

NERC Balancing Authorities

As of October 1, 2015



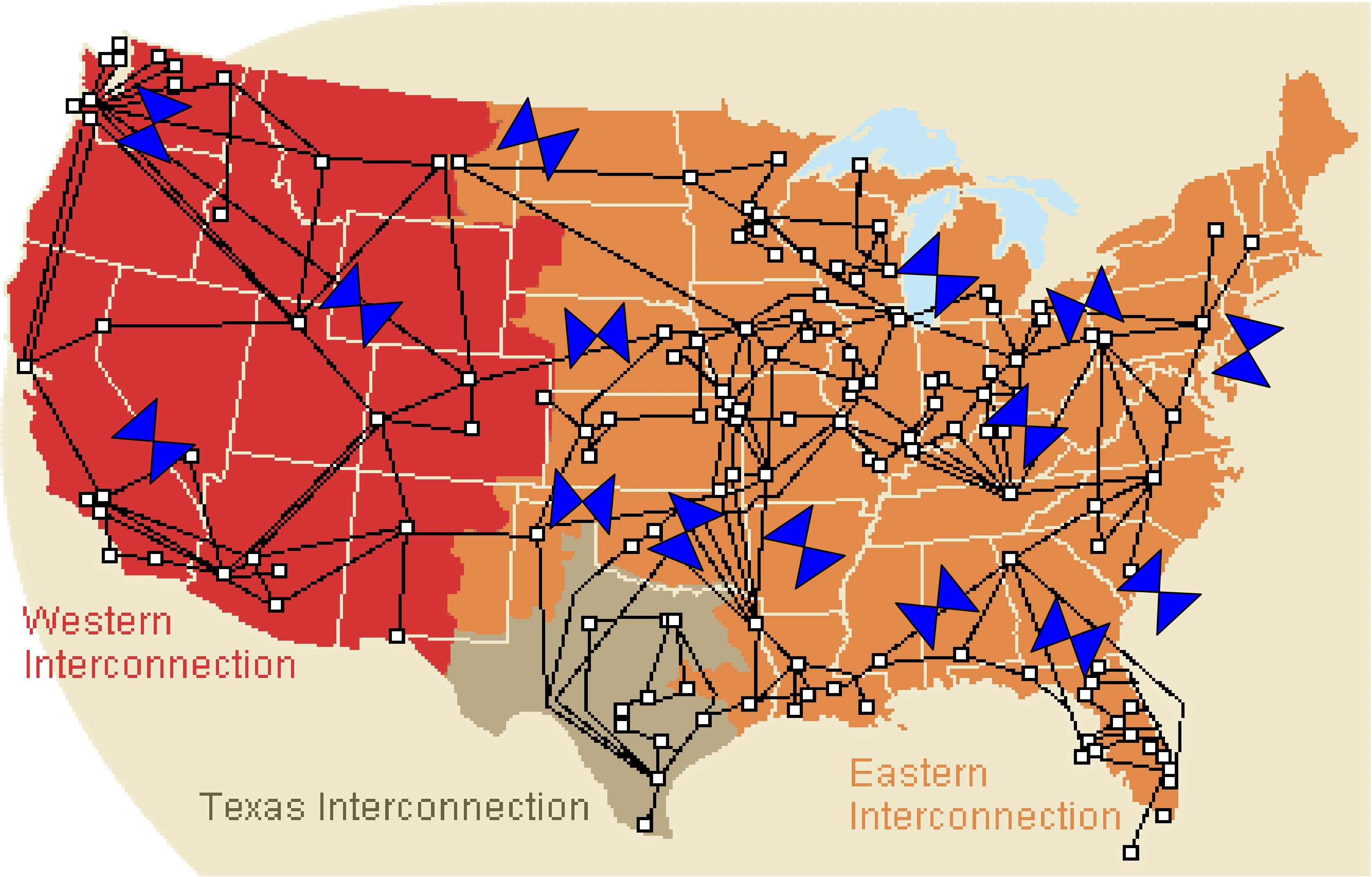
Dynamically controlled generation

Back-to-Back DC Converter

Submit changes to balancing@nerc.com

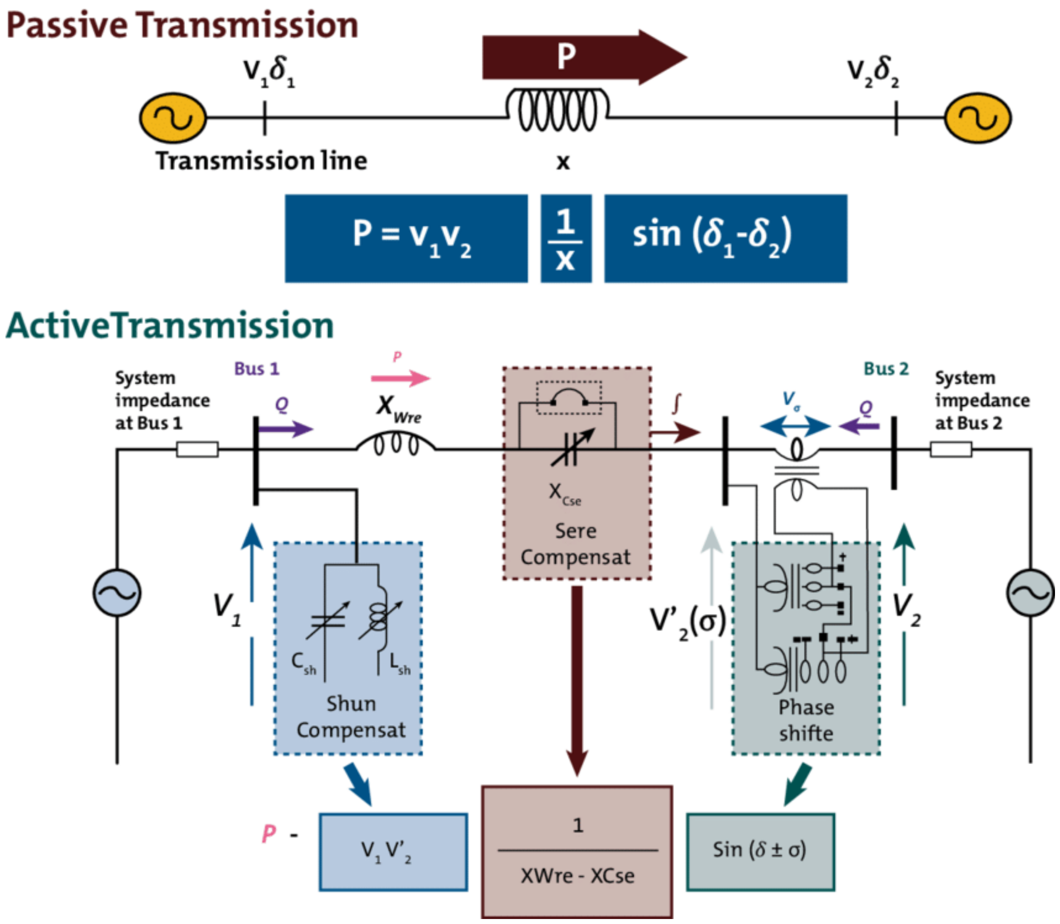
1hr balancing for frequency control/stability, minimal asynchronous links, is frequency as important?

2003 – Reedy and Casey --Back to Back DC links with Mandatory Sub-second Area Balance



How do we add dc to the Bulk Power System?

Grid Enhancing Technologies (GETs) Fundamentals



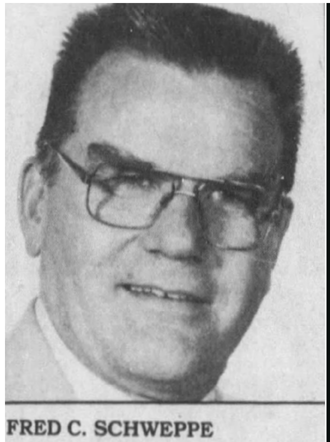
Need:
-Reliable
-Efficient
-Cost effective
-Fast

Transmission System Heroes - Motivation

- Load Growth
  - Natural (e.g. AI/ML)
  - Electrification for decarbonization
  - Growth could/should be largely in D system
- T hard ?
- D easy ?

- Australia leading in renewables
  - 33% of total
  - Peak days at 89% +

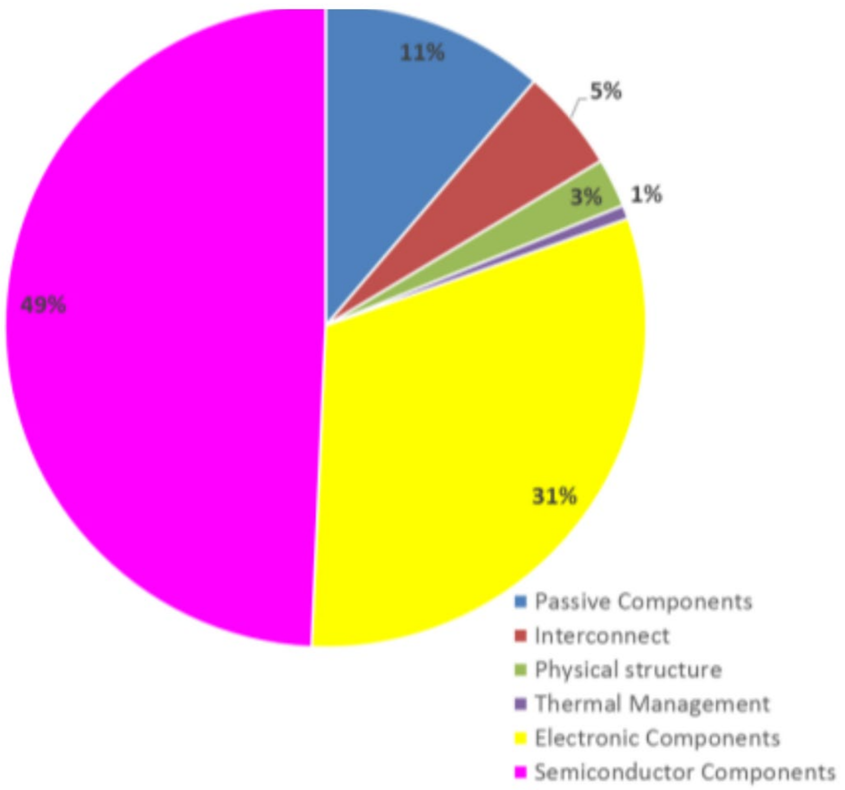
LMP, SEED, PJM



State Estimation, Spot Pricing, Marginal Pricing

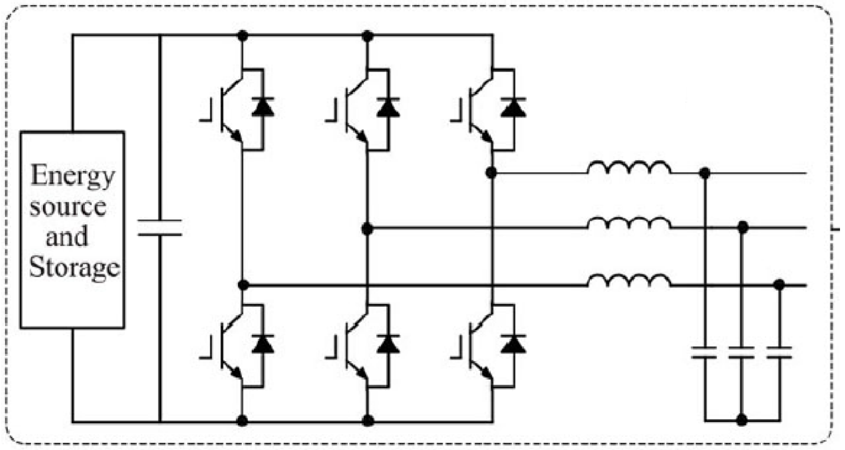
Advanced Inverter Development – T&D

- CSIRO and X
- CSIRO – Newcastle
  - Rich history in Controls
  - Also rich history in renewables (Solar PV)
- X – power electronics
  - Modeling, simulation



Inverter topology & Control

- Semiconductor-based device (SiC)
- Generates AC waveform from a DC source
- RLC interface (harmonics filter) with the grid
- Control components:
  - Output measurement
  - Semiconductor-bridge modulation
  - Current controller (in all cases of inverters)
  - Voltage controller (most typically for grid forming inverters)
  - Active/reactive power controller
  - Grid forming or Phase Locked Loop (PLL) control
- Grid Forming – Grid Following – uGrid – Black Start

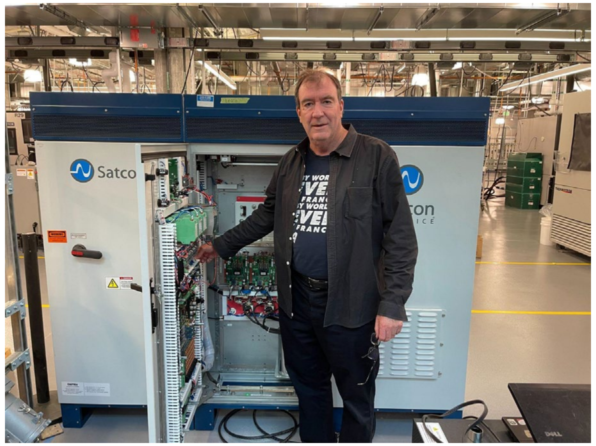


Starting Point

Dr. Ty McNutt – formerly Northrop, now Wolfspeed, VP, Project Leader
-very interested in cooling, coating, packaging, additional hardware

-Team has extensive experience with Wolfspeed/Cree from Satcon, 10+ GW of grid connected inverters, 26 certified designs, inverters also used by Makani/Horizon/Malta/Tapestry

-First 100kW motor drive and first 100kW inverter in SiC, Casey and Borowy, 2003

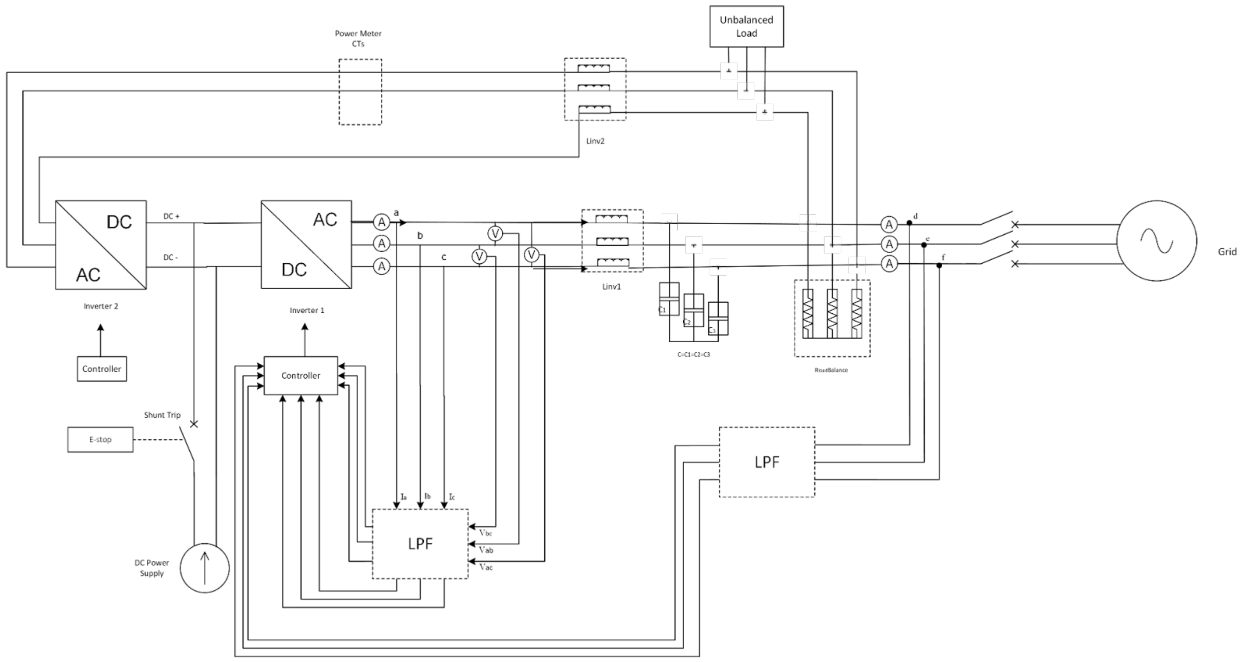


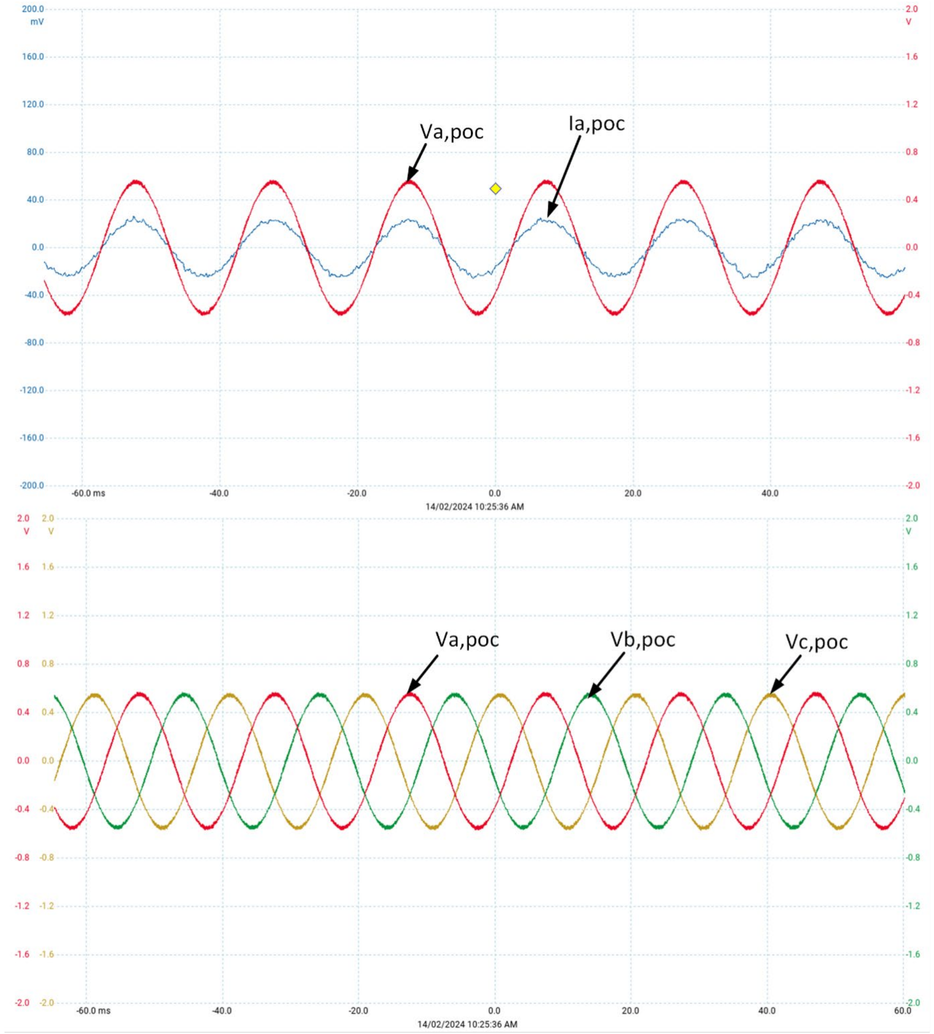
- Control for Wolfspeed evaluation inverter CRD300DA12E-XM3
- by Mathias Schnarrenberger - Karlsruhe Institute of Technology
- We developed a software including the PMSM machine control for the Wolfspeed evaluation inverter CRD300DA12E-XM3.
- Mohawk Valley Fab, 200mm, 20% utilization

300kW Automotive Motor Drive 2c/W in singles

- Need filter (L-C)
- CAN → MODBUS
- Packaging

Prototype – GFL and GFM – back to back – losses from ac or dc

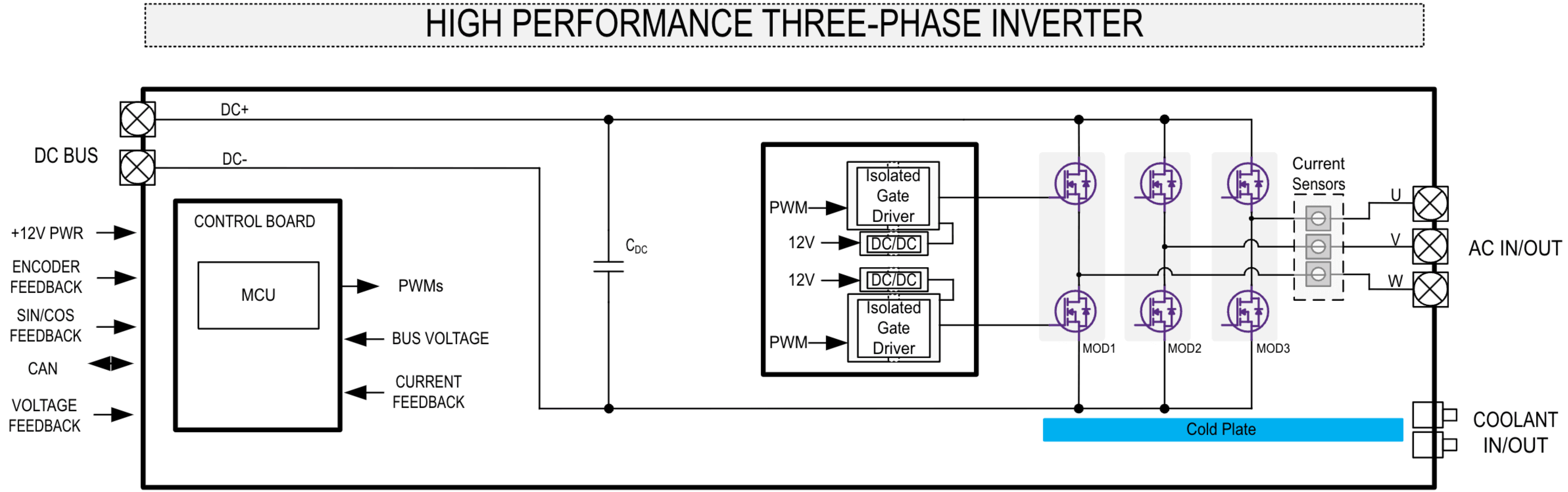




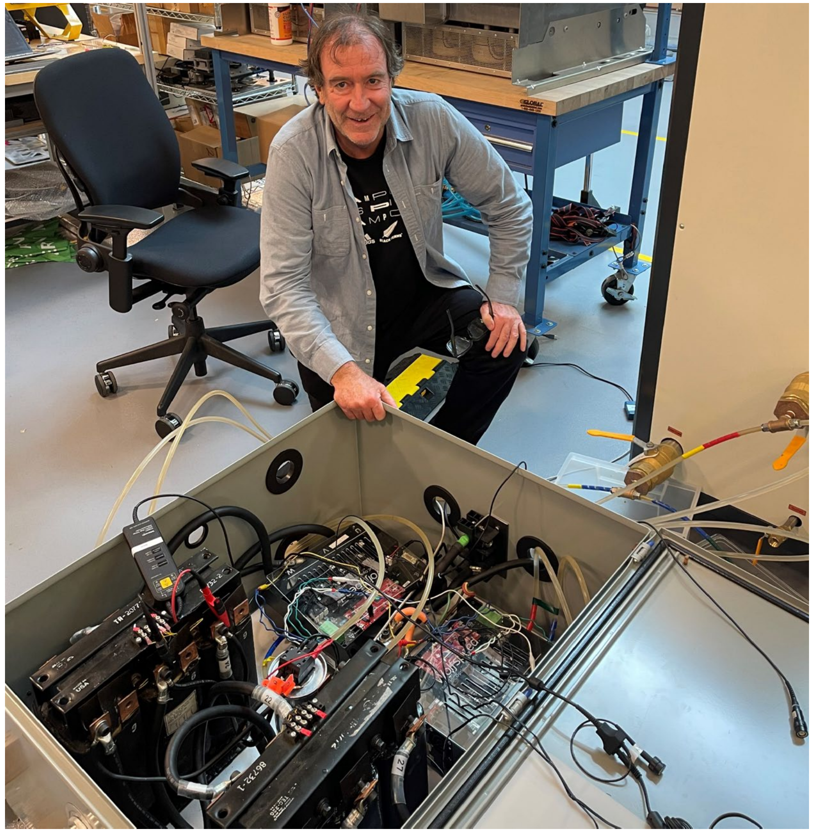
Matlab/Simulink Code → DSP Code
20-80 kHz

Remote Upgrade
Transient Model/Simulate (beyond EMP)

Basic Controls



300kW (at 480V, 250kW at 400V) back to back, GFL and GFM, high power setup

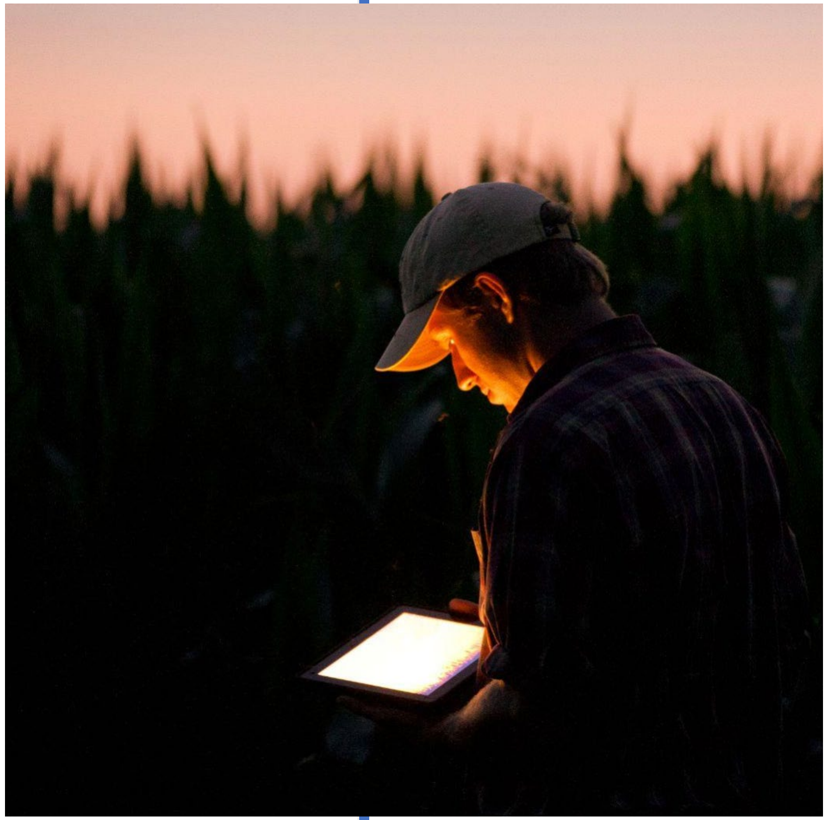


Phase 2a: Advanced Grid Hardware

Issue:
The grid requires advanced interface hardware designed for renewables and storage systems, which is a dramatic step forward in delivering robust, reliable, and cost-effective performance.

Goal:
The table stakes is a transformerless (conventionally this can include high frequency isolation) grid interface. This interface is fully characterized and ALL grid scenarios based on these devices are well understood.

Objective:
This project aims to create a/the world class grid interface that can and should and will be used by all to interface renewable energy and storage electricity power to the grid. The ubiquitous, egalitarian, electric grid of the future is based on this power electronic grid interface.



Phase 2b: Grid Stability

Issue:
High bandwidth devices that interface to a grid with diminishing short term storage (inertia) has proven to be real challenge for stability and control. Southern CA, ERCOT, Great Britain and Australia have all experienced grid wide instabilities. The grid of the future needs to be BETTER than todays grid in all practical ways.

Goal:
A standardized, open sourced, operating system for grid inverters (single and three phase) that is thoroughly modeled and simulated with all known scenarios for expansion studied is the goal of the project.

Objective:
Prototype invertes with candidate grid stability software for universal use and application.

To Do

CAN → MODBUS

True Neutral (4th leg) for Tx-less

Thermals → HS plus fan

Box plus solar shields

Remote upgrade capability

Autonomous Controls Selection

Orchestration of Voltage Control

Field demo → Partners

Summary

- The time is now for Grid Power Electronics, not just on the edges of the grid.
- Seamless transition to off grid, droop, GFL – GFM, uGrid
- GFL-GFM is important, inherent capability is there and demonstrated
- Ubiquitous data, real time systems need accurate and low latency data. Autonomous modes.
- 30khz can cancel 50th harmonic.
- It is our time. Need 90% + carbon free energy supply
- In many cases (faults a good example) Inverters and other high speed devices are the solution not the problem
- These high speed grid devices can truly enable a Faster, Smarter, Controllable, Greener, Distributed Grid
- High speed grid devices? STS, SDS, FCL, Solid State, Statcoms, Breakers, … Inverters
- Inverters as StatComs
- Shock Absorbers (disturbance mitigation), distributed?
- Control, local-autonomous-high speed, slower regional/area, PMU for control (not forensics only). Voltage regulation from +10/-12 to +/- 2%?
- More devices → more data

https://www.youtube.com/watch?v=6jWgjAZWMns

video about our collaboration here

Partners?