What role do power electronics play in making the grid smarter?

- Workshop -

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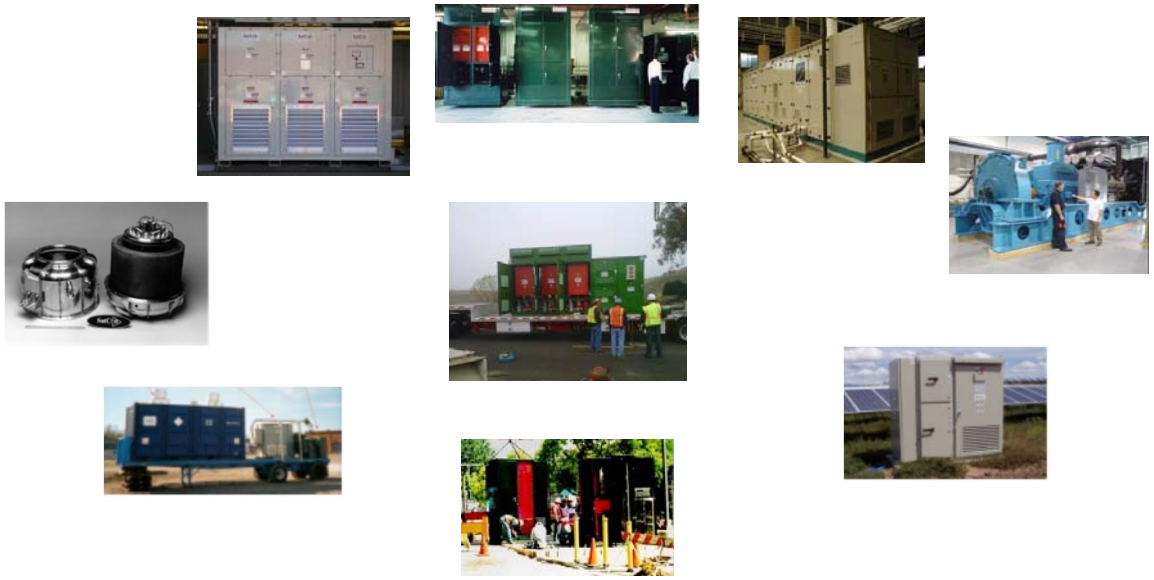
How smart is the grid? Sensing vs Control,
Lots of data, lots of learning, but on the physical side?
(lots for transactive, O&M)

DG, Storage, Grids & Power Electronics, Silicon has been limiting in efficiency and speed (and voltage), so mainly deployed at the edge



decentralization, deregulation, and decarbonization.

What role could power electronics play? What is the future grid?

What grid? Cost effective, reliable, efficient power electronics WILL transform the grid, not just interconnection of DER, but all of the actuation and transformation in the grid will be up for grabs, case in point, MV decoupling of distribution system through B2B (back-to-back) inverters, storage integration at the B2B dc buses, shared storage, asynchronous feeders and sub-transmission ..

- Smart Grid 2.0, embedded intelligence, with real time, high bandwidth actuation …
- Power Electronics IN the grid not just at the edges (electronics pevasive
- It was the last frontier of mechanical and electro-mechanical, but now, through the combination of advances in Power Electronics and Power Systems (cheap PV, Wind, WBG devices, …)
- Uniquely positioned with smarts, sensing, actuation

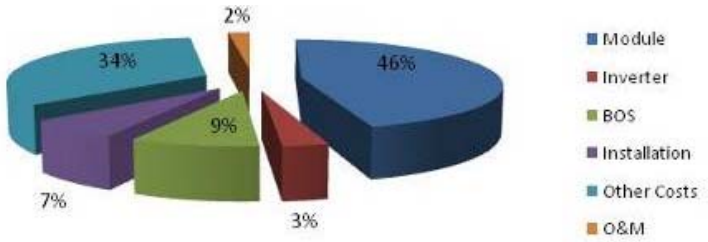
The Narrative we present -- Overview

- Grid(s), are changing, it was metamorphosis, now transformation? Physical layer? Grid Modernization? Instability on many fronts.
- Costs, standards, prices, complexity
- Role for Grid Electronics, power electronics can be transformative, examples
- Limitations, Devices, thermals, developments/trends
- Tipping point? Killer applications?
- Grid electronics typically at the edge (interfaces/parallel, vs series devices … challenging)
- Grid Connected PE vs Grid Controlling PE (a variation on Grid Following and Grid Forming)
- Inverters for Renewables, μGrid switches, Solid State Transformers, voltage controllers
- 3 things in addition to real and reactive power
  - Sensing
  - Actuation (PQ)
  - Controls (PQ and P & Q)

Barriers to High Penetration of Renewables

~2004 DOE/NREL

1. **Cost**
   - Panels
   - Inverters, BOS
   - O&M



2. Controllability
3. **Intermittency** (Variability/Capacity Factor/Capacity Value)
4. Utility Industry Acceptance/Adoption
   - Scale
   - Performance
   - Standards
   - Familiarity (interconnection, protection)

That was $5/W PV

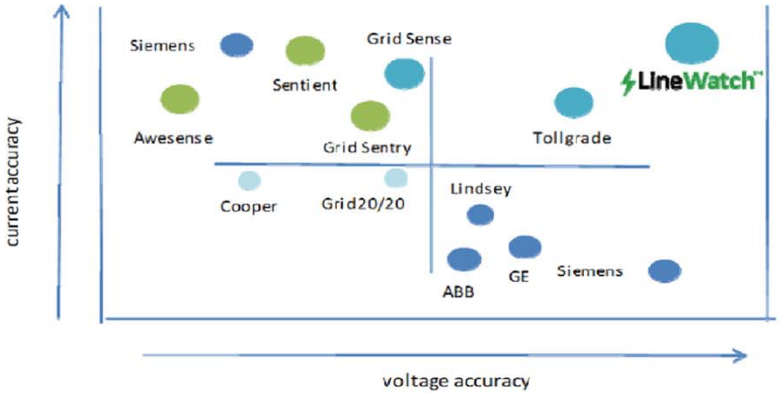
-P metering
-fault notification
-secondary phase identification
-fault location

-V, I metering
-fault (LOS) notification
-fault location
-Ground Fault

SENSE

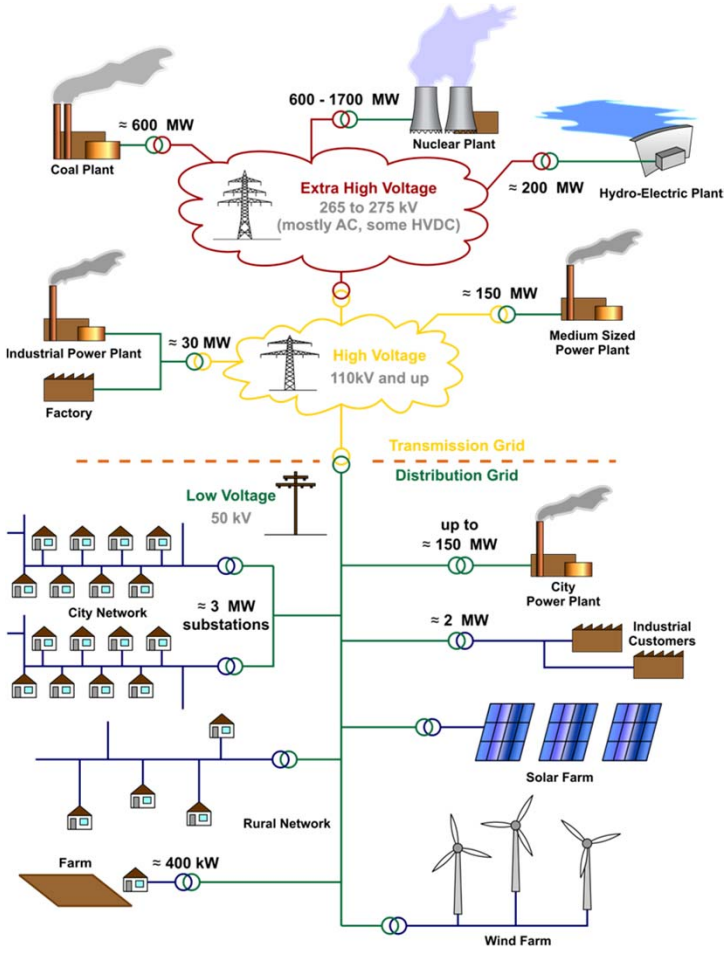
CONTROL/ACTUATE

MODEL/SIMULATE



What is Smart? To observe and **respond.**
-self protecting?
-harmonic cancelling?

Visions, Perceptions and Reality *(LFC, 2007)*



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

WHY?

Major successes have been in dc TX lines and renewables

Electromechanical	Electronic
Clumsy	Smart
Simple	Complex
Large	Compact
Rugged	Less so?
Reliable	Less so?
Slow	Fast
Cheap (1-2c/VA)	Expensive (20+c/VA)
Overload	Limited Overload
99+% efficiency	~97% efficiency?

Hybrids?

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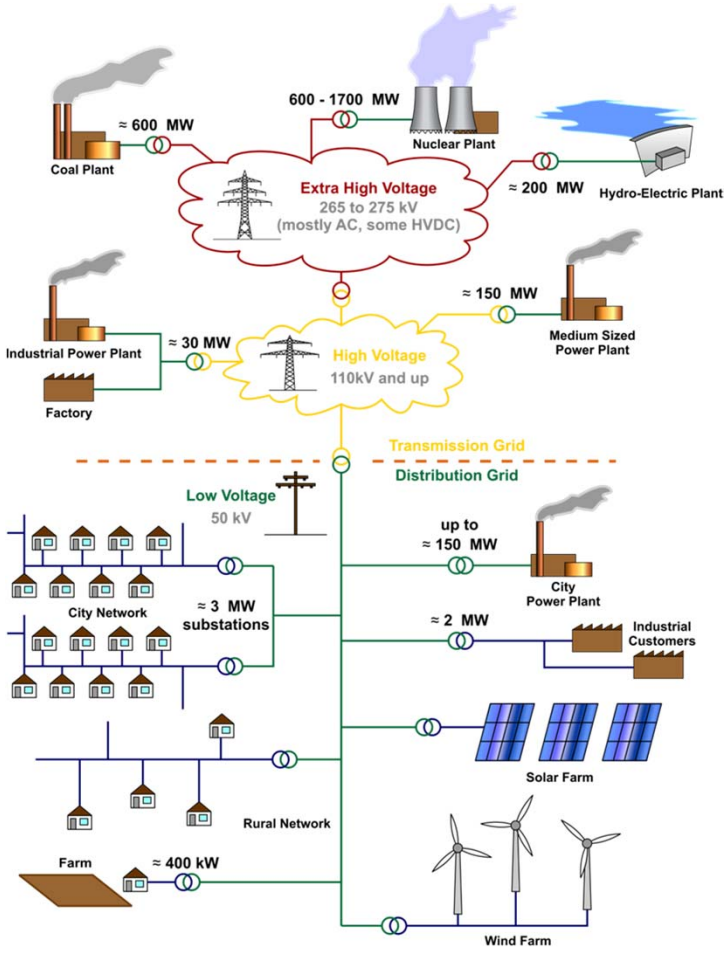

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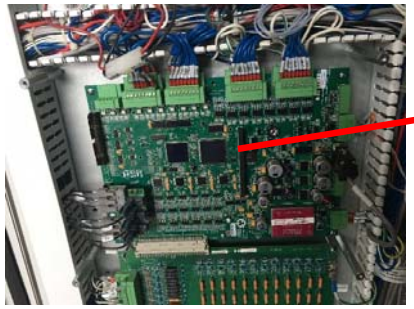
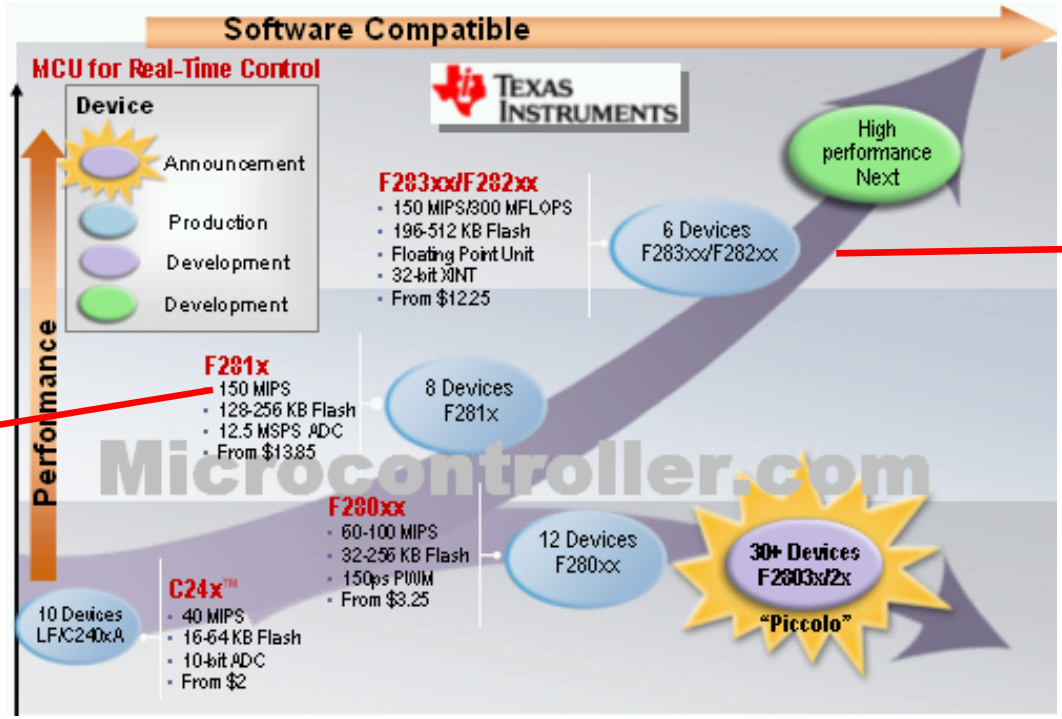
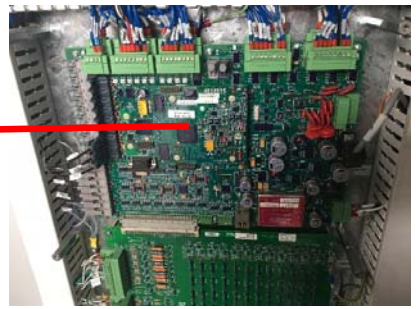
Capabilities limited by the Power Actuation and the Processing







Controls capability and cost over time

Smart and Getting Smarter

- Storage Scope (superb field tool)
- Impedance measurement
- Harmonic analyzer
- Asymetric fault ride through, passive and active
- X/R based Volt-Var control (use impedance measurement)
- Droop
- Inertia
- Prognostics (eutectic solder model → predicted Wind Turbine failures)

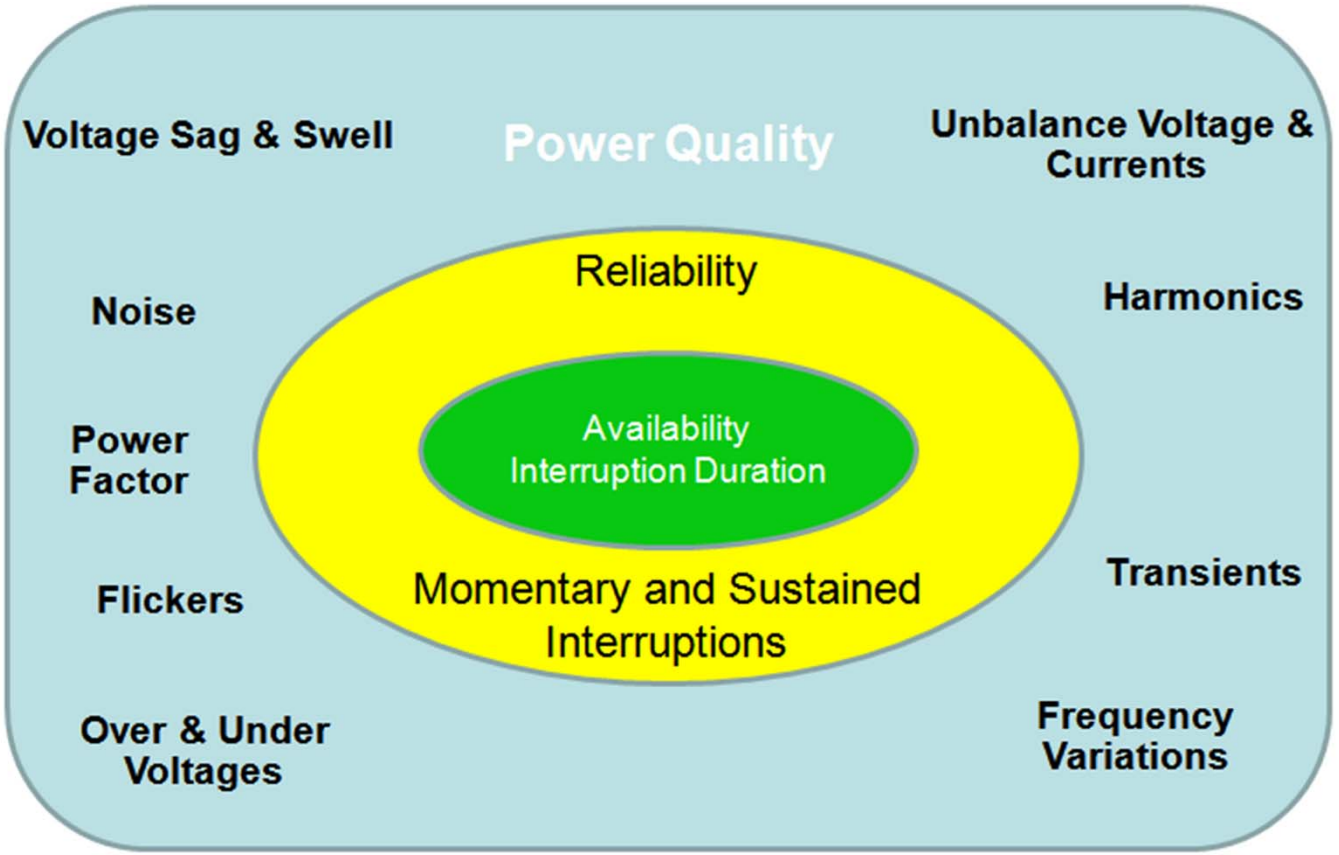
- Not just inverters
- Comms? (rule 21 phase 2 RPP, cert this week)

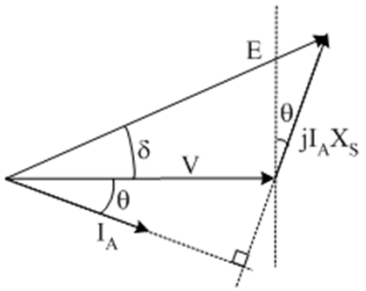
Grid -- What could be measured? Why? Direct/Indirect? Contact/Remote? Why?

- V (direct (contact) or → E field, reveals grounding and faults
- I (B field)
- Φ With phase history, time, and dynamics we can achieve PMU functionality
- Thermal (IR, possibly high speed), diagnostic also Power measurement
- Acoustic (2.f, diagnostic, possibly load measurement, tx and cap)
- Arcing (rf, diagnostic)
- Light (from loads, possibly streetlights though often separate circuit)
- Moisture, charge, solid, liquid, gas ….
- Specific Materials? Leaking coolant in tx or C …
- Also, time synchronization enhances value of these techniques

Why Remote? Portable, immediate, diagnostic, overlapping jurisdictions, ...

What can be Actuated/Corrected





Controls Capabilities

- Seamless (CS to VS transitions, stds permitting (GF, GF)
- Intelligent node, but transformer parasitics
- What has changed?
- costs, performance, reliability → penetration
- Direct connect inverters → change in grid operations and ds planning
- General principal of controls is fast, local, autonomous defaulting to slow, global, coordinated
- Smarts are in the right place, with the actuator

Summary

- The time is now for Grid Power Electronics, not just on the edges of the grid. Power Electronics will be in the grid and it will be a different paradigm.
- Lower and lower impedance, faster and faster “actuators”.
- To date CS on grid (fast with small X impedance)
- Seamless transition to off grid, droop
- Gf-Gf is important, but inherent capability is there
- Ubiquitous data, real time systems need accurate and low latency. Autonomous modes.
- 30khz can cancel 50th harmonic.
- It is our time. 96-98 % carbon free