Large Grid-Supportive Inverters for Solar, Storage, and V2G

NIST Workshop on Power Conditioning System Architectures for Plug In-Vehicle Fleets as Grid Storage

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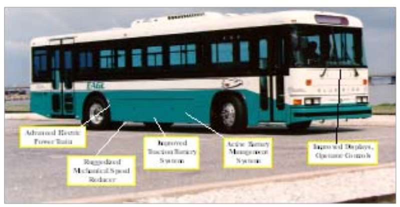
Our Alternative Energy Journey



BEACON
1997

1985 MIT-DRAPER

Patriot - 1992

Magmotor
1997

FMI & HiComp
1998

WEC/NG 1999

InverPower
2001

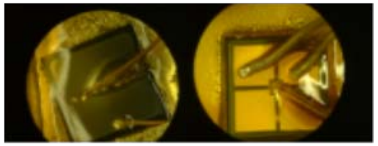
2003 Subsidiary Corporations

Divested 2007

RCT Systems
2009

Today

- Grid Products
- #1 Utility Scale PV
- 400+ employees
- 2GW inverters

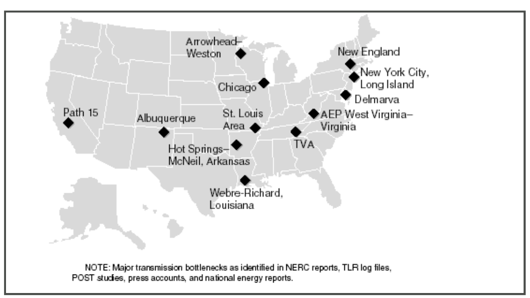


Energy Storage | *Renewable Energy* | *Distributed Energy* | *Grid Support*

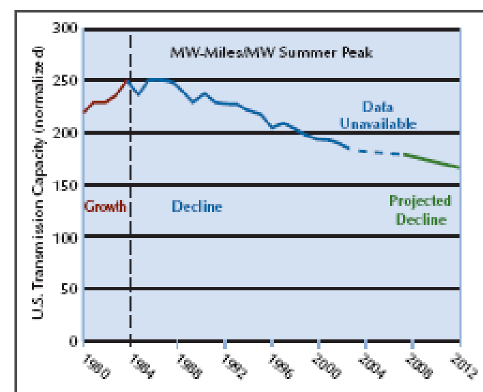
Technology Development

Electric Power – More Electric Future

- Dominant secondary source of energy
- Grid is a BEAUTIFUL thing
  – Instantaneous energy
  – ac
  – Rugged generators
  – Spinning “reserve”
  – Excess capacity (>15% is critical) **SIZED FOR 20%+**
  – Low Impedance
  – Fault clearance
  – Overload
- Beautiful, but
  – no significant energy storage
  – Supply must equal demand
  – generator power angle
  – minimal local control
  – Time constraints of protective devices
- Importance of storage (some storage)
  – Distribution (remoteness of generation and utilization)
  – Load leveling (excess capacity), energy arbitrage
  – Power Quality (4-5 9’s vs 5-6+ in EU)
  – Intermittent Renewables (**WIND**)



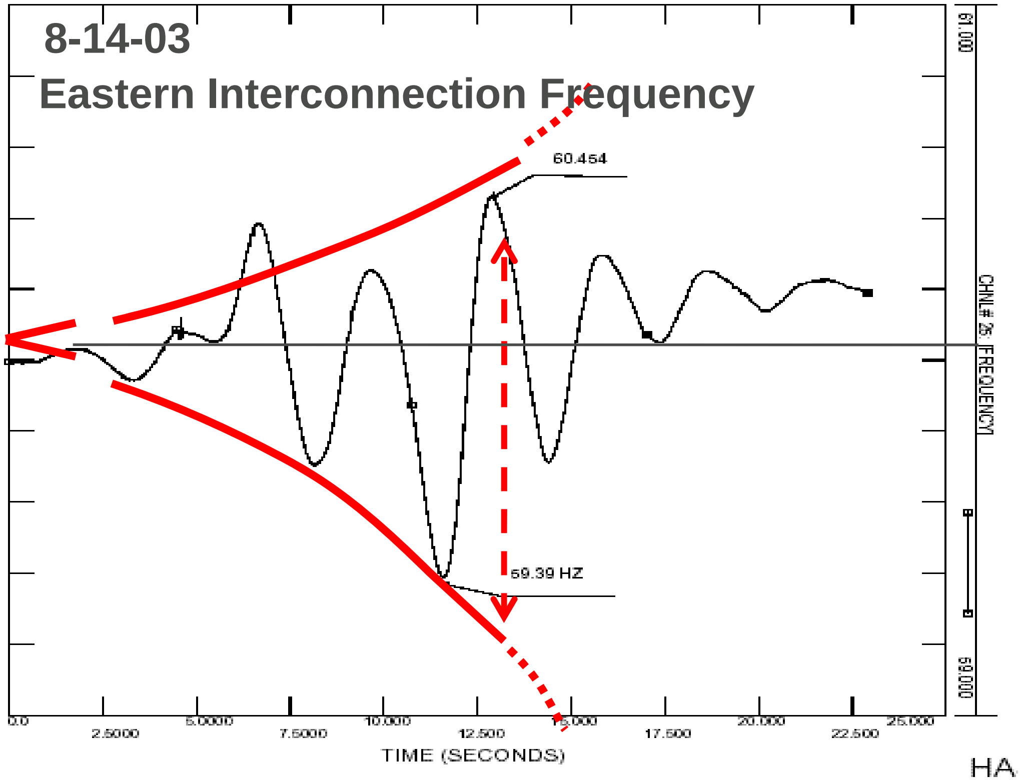
Electricity Infrastructure	
Transmission SCADA control points	
FERC grid monitor/control	12
Network Reliability Coordinating Centers	20
Regional Transmission Control Centers	130
Utility control centers	>300
Power plants	10,500
Large (>500 MW)	500
Small (<500 MW)	10,000
Transmission Lines	680,000 miles
Transmission substations	7,000
Local distribution lines	2.5 million
miles	
Local distribution substations	100,000



U.S. Transmission Capacity Normalized by Summer Peak Demand.

Modern Grid Issues

- An age of Increasing Electrification (~1TW capacity in EI),
  - BUT
    - Energy sources problematic (climate, security!)
    - Grid Power Quality is inadequate to electronic age (many aspects to this)
    - Slow and Archaic Electromechanical Hardware & Controls
    - Congestion in T&D infrastructure
    - NIMBY etc
  - SOME ANSWERS
    - Demand Response (time scale?)
    - Efficiencies
    - Renewables
    - Hi-Speed Controls
    - Hi-Speed Devices
    - Reconfiguration
    - DC transmission
  - TO SOME PROBLEMS



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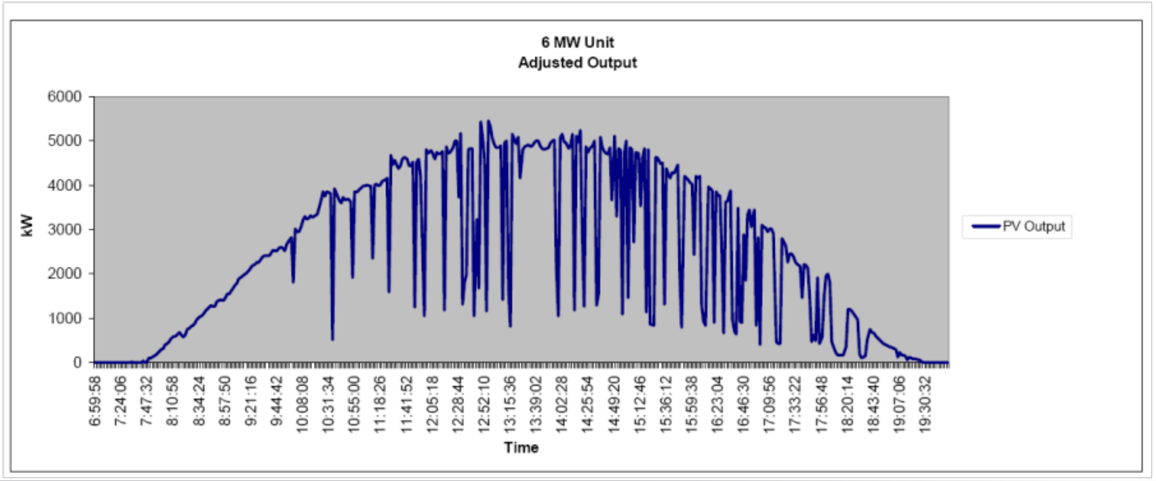
Renewable Energy and EV Challenges

- Renewables Intermittency
  - Large, sudden changes in plant output power can result in power quality degradation (e.g., flicker)
  - Existing grid infrastructure has much slower reaction times than renewable intermittencies
- Electric Vehicle Charging
  - EV charging, especially during peak periods, stresses utility infrastructure
  - New charging infrastructure is required for ubiquitous charging capability

PV Plant Power Output Fluctuations Due to Passing Cloud Cover



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Background: Capabilities of Existing Inverters (Converters)

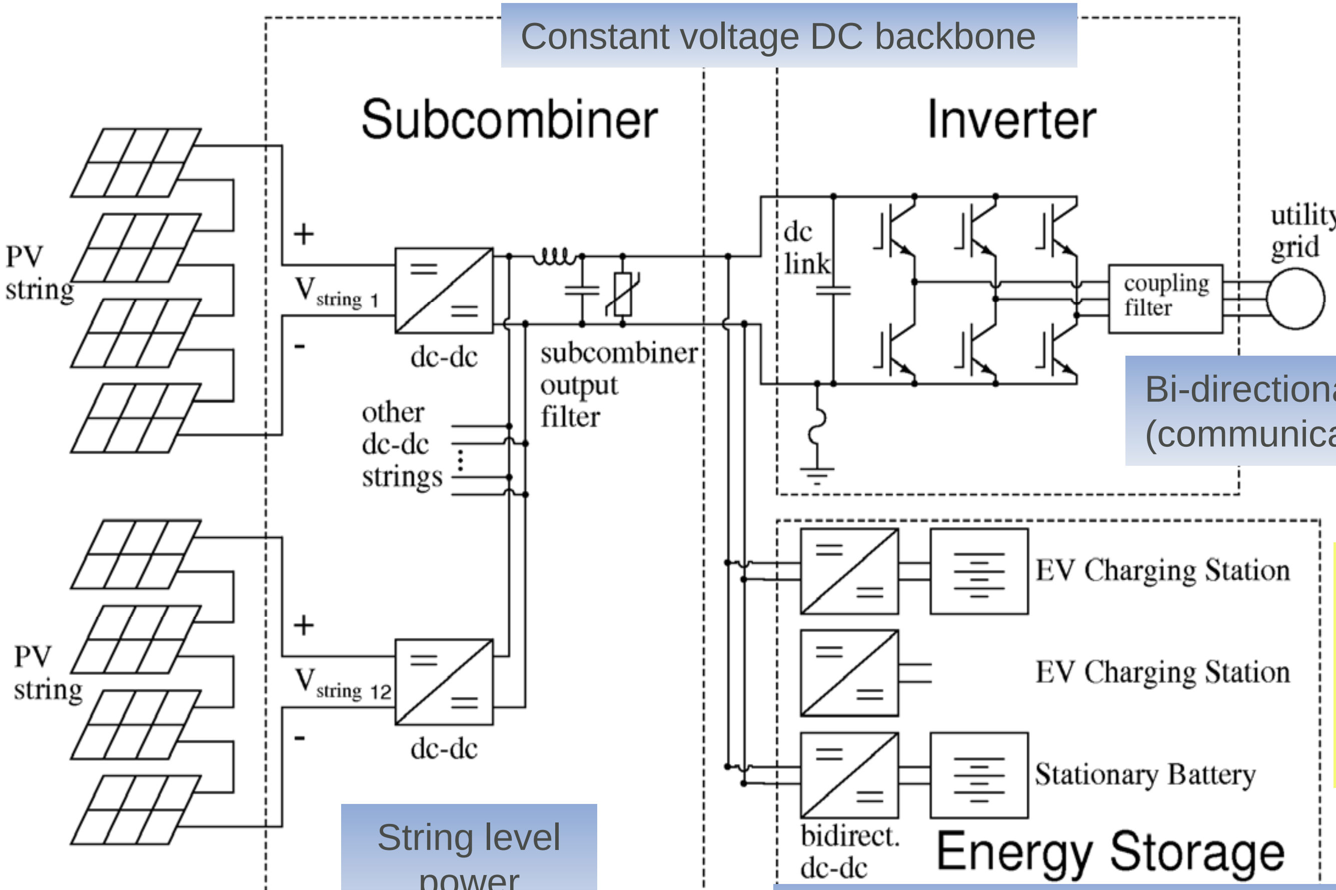
- **Bi-Directional Real and Reactive Power Flow:** Capable of absorbing or delivering real and reactive power
  - Voltage regulation, fully adjustable power factor – potential to provide autonomous or utility-directed control
  - Curtailment commands used to control ramp rates
- **Site-level control:** Provides aggregated power management functions at PCC with the utility
  - Can manage multiple inverters and/or energy storage
- **Communications with the utility (SCADA, PLCC):** has been used to demonstrate utility-directed real power limits, ramp rate, and reactive power control
- **Ride through capability for specified disturbances**
- **Two stage architectures facilitating energy storage**
- **Ac/dc microgrids**

Vehicle Charging Energy Storage Design Tradeoffs

- **Concentrated/Centralized vs. Distributed Architectures**
- **Energy storage:** Mobile storage only vs. stationary + mobile storage
  - Maintaining localized power quality, aggregating/managing energy storage, and meeting demand using only mobile resources presents a formidable challenge at high penetration. Limited by existing infrastructure.
  - Stationary storage could act a buffer to mitigate these issues, and provide rapid charge capability
  - Real world experience is needed to assess appropriate blend of stationary and mobile energy storage resources.
- **Integration with PV:** Significant advantages compared to standalone energy storage architectures
  - Leverages existing grid connection hardware (*low cost*)
  - Enables tightly-coupled synergistic interaction between PV and energy storage (*enhances functionality of PV and energy storage*)
- **Microgrid:** PV + battery can provide the basis for a high reliability microgrid

Two-Stage Architecture Integrated with Energy Storage

Constant voltage DC backbone



Bi-directional grid-smart inverter (communications and power flow)

Stationary energy storage can support vehicle charging, enable PV integration, and provide grid services

String level power conversion

Bi-directional DC battery chargers

Simultaneously enhances the value proposition for E.V.s and PV

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Enhanced Inverter Capabilities Enabled by Energy Storage

- **Improved capacity factor**: Small amounts of stored energy can mitigate intermittency of renewables
  - Rapid changes in the real power output of renewables affect power quality (voltage and frequency), frequently necessitating curtailed operation
  - Stationary batteries act as a buffer to absorb rapid variations in plant output power enabling controlled ramping and reducing or eliminating the need for curtailment
  - Simulations by Satcon indicate that a narrow (+/-5%) state of charge window eliminates the need for curtailment (20 kW PV, 10 kWh battery)
- **Grid Stabilization:** Sub-cycle real and reactive power control
- **Reliability:** Enables extended ride through and provides voltage and frequency support for both plant AND grid induced disturbances
- **Flexible Load Management (i.e., peak shaving):** EV charging loads can be shed by the Utility or PV plant so the full PV power output can be used to meet peak demand spikes
- **Simplified Integration:** Capacity factor and reliability enhancements can be implemented on a *fully localized basis*, without the need for utility communications or control; inverter's PCC and site controller provide a natural gateway for managing V2G services

Enhanced EV/Stationary Battery Value Proposition

- **Efficient recharge:** Charging directly from DC bus eliminates round trip AC to DC energy losses, and chargers are upwards of 98% efficient
- **Level 3 DC Charging:** Charge rate is limited primarily by battery C-rate, not charging infrastructure
- **Low-cost:** Modular bi-directional DC-DC converters can be manufactured and installed at low incremental cost compared to dedicated Level 3 EV charging stations
- **Simplified control/aggregation:** Tight integration of stationary batteries with PV enables fully localized control of charging and provides a single site controller for communications with the utility
- **Renewable:** All PV charging is 100% renewable solar power (not just "certified green power", but actual "renewable electrons")

Satcon's Integrated Energy Storage Demonstration Activities

- PICHTR[1] funded demonstration of Grid-Interactive DC Link PV Charging Station
  - Project Partners: CU-Boulder, Host site at Castle & Cooke resorts on Lanai
  - 15 kW PV, bi-directional Solstice Inverter, bi-directional DC-DC converter, and Plug-In Prius (10 kWh battery)
  - Demonstrates rapid recharge, ramp rate control, load balancing of PV, and power factor control
  - Expected completion in October 2011
- CEC[2] funded demonstration of Grid-interactive PV System with a DC-link Stationary Battery
  - Project Partners: SMUD, A123, RES, host site at planned SolarHighways site
  - 500 kW PV, bi-directional 500 kW Solstice inverter, 500 kW bi-directional DC-DC converter, 500 kWh stationary battery
  - Demonstrate load management, ramp rate control, voltage and frequency support, and bi-directional communications with the utility grid
  - Project expected to start August 2011
- DOE Santa Rita Jail Microgrid
  - Medium Voltage Static Transfer Switch
  - PV and Fuel Cell Inverters and Controls with CERTs

[1]Pacific International Center for High Technology Research
[2]California Energy Commission

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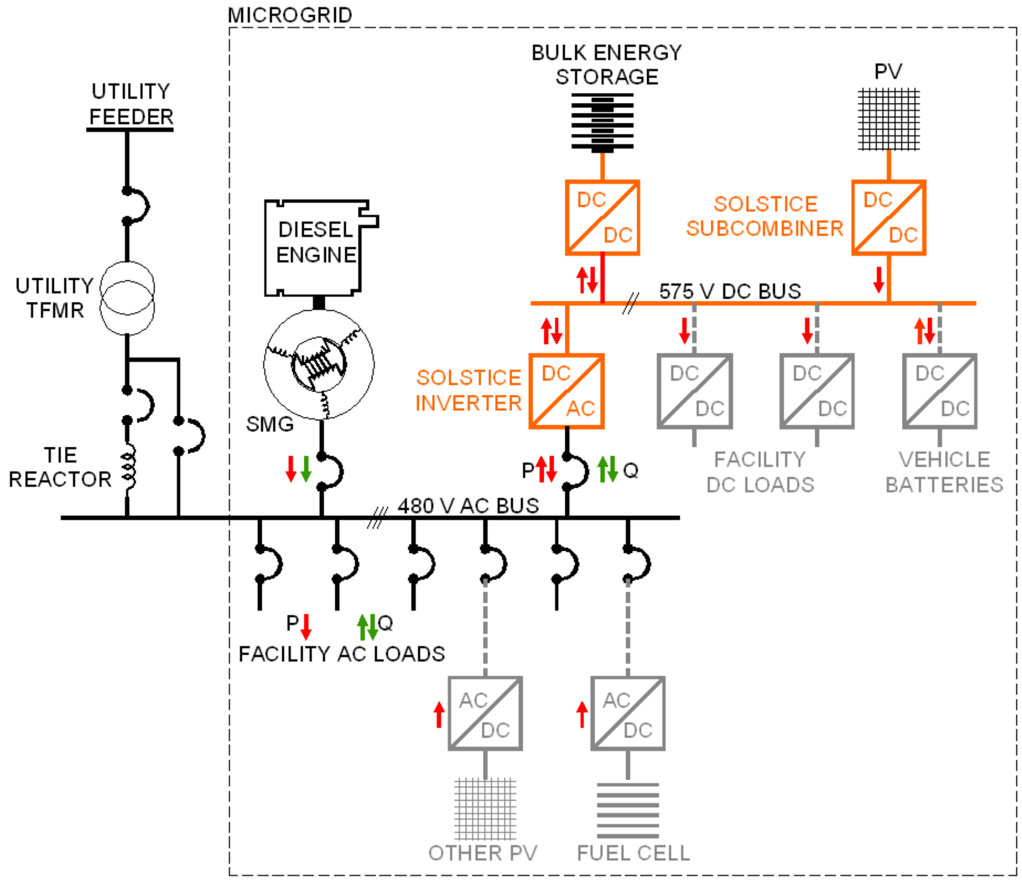
Hybrid Microgrid Utilizing Energy Storage

- Inverter maintains the instantaneous balance between generated real and reactive power and load ("swing generator") in a hybrid microgrid
- Solstice DC bus w/energy storage can power DC loads: e.g., EVs, DC data center, DC lighting
- High quality, nearly uninterruptible AC power during island conditions
- True uninterruptible DC power source during island condition



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Conclusion

- **Concentrated Inverters enjoy large cost advantages**
- Two-stage inverter architecture coupled with existing grid-smart inverter capabilities provide a natural platform for integration with stationary or mobile energy storage, mitigate problems and provide synergies
- **Benefits:**
  - **Improves PV capacity factor:** Narrow SOC excursions enables ramp rate control and effectively eliminate the need for curtailment
  - **Grid-side services:** enhanced reliability through real and reactive power delivery, extended ride through and voltage/frequency support; peak shaving
  - **Enhances the EV value proposition:** Low-cost, fully renewable level 3 recharge capability, low round trip losses,
  - **Simplified integration:** PV/EV synergies may be realized with localized, autonomous control (no utility involvement); inverter's point of common coupling and site controller provide a natural gateway for managing V2G services
  - **Microgrid:** Potential to realize a robust, high reliability AC/DC microgrid
- **Maturity:** Capabilities are currently being demonstrated