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A part of Grid Technologies Collaborative within NETL-RUA Regional University Alliance

Intergrid:
A Future Electronic Energy Network?

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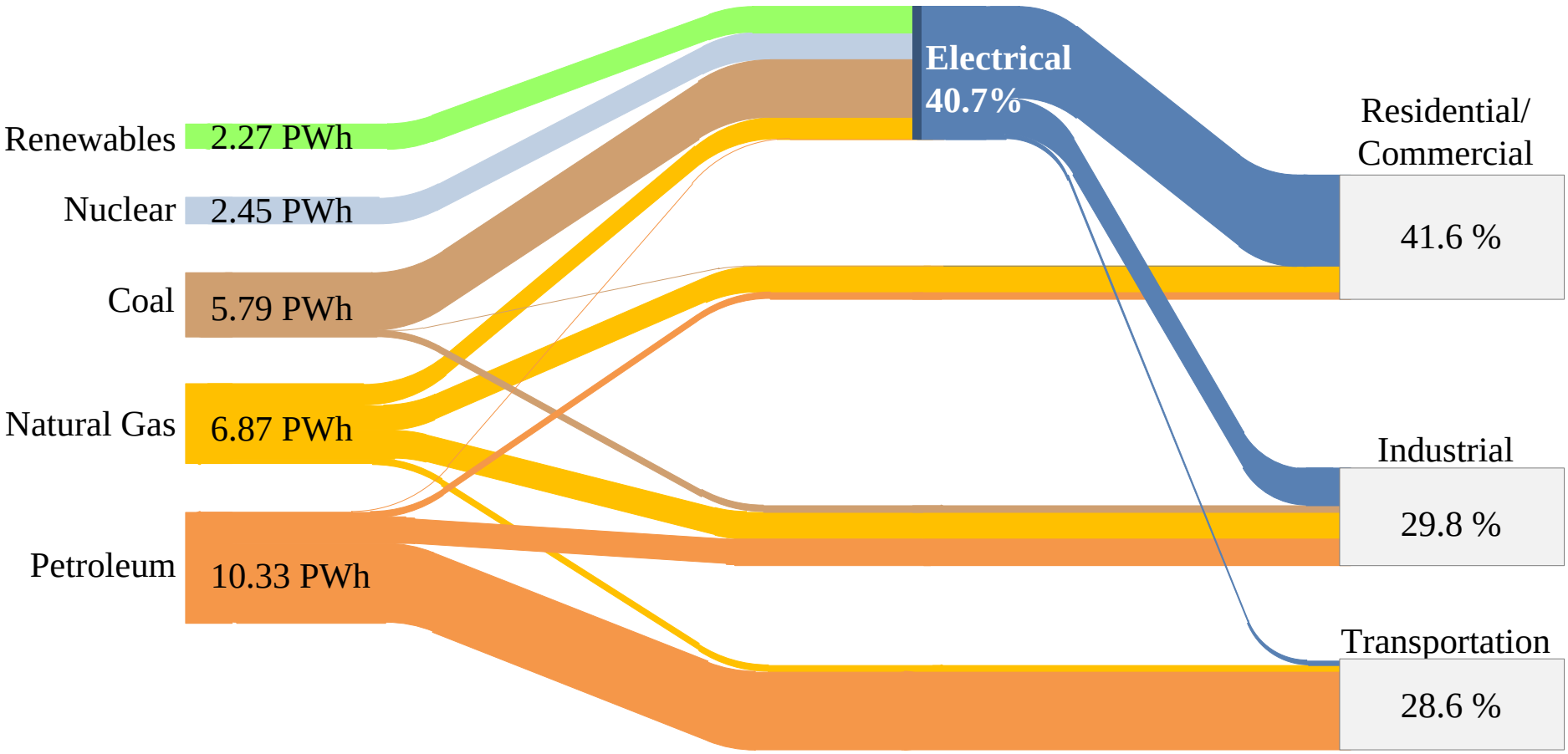
Presentation at Panel Session on
The Impact of Microgrid Developments on Power T&D Planning and Operations

8TH ANNUAL PITT ELECTRIC POWER INDUSTRY CONFERENCE
Presented by the Swanson School of Engineering & the Center for Energy

University of Pittsburgh, Pittsburgh, PA
2013.11.12

US Total Energy Flow



Adapted from U.S. Energy Information Administration / Annual Energy Review 2009

US Energy Flow in Sustainable Future?

Renewables

Nuclear

Biofuels

Natural Gas

Petroleum

Electrical ~ 80%

Storage

Assumption 2: If total energy consumption stays the same, electrical grid has to double!

Residential/ Commercial

40 %

Industrial

30 %

Transportation

30 %

Assumption 1: Up to 80% of total energy consumption will be supplied by electricity in a sustainable future!

Assumption 3: With the lifetime of electrical equipment 30~50 years, we have to rebuild the grid with double capacity in the next 20-30 years!

How should we do it

Renewable Electricity Futures Study by NREL

- DOE Office of Energy Efficiency and Renewable Energy
- Collaboration with more than 110 contributors from 35 orgs.
- Released in June 2012
- Renewables to Supply 80% of US Electricity in 2050

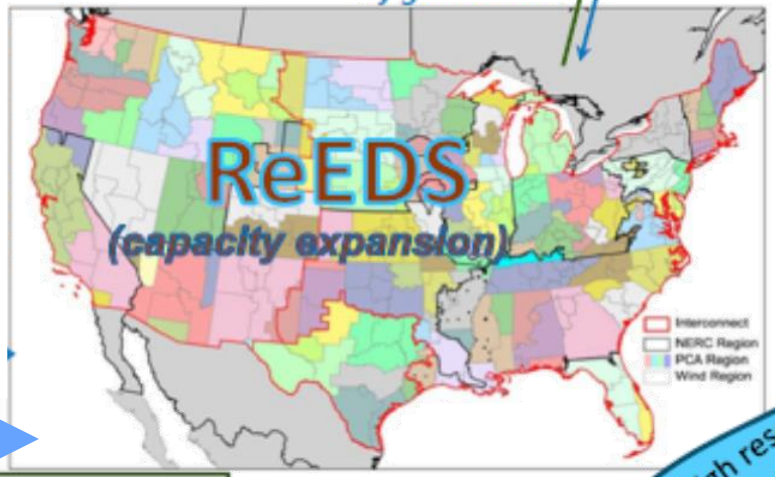
rooftop PV penetration

2050 mix of generators

does it balance hourly?

ITI Projection (by Black & Veatch)
ETI Projections (by Tech Teams)
Flexible Resources
End-Use Electricity
System Operations
Transmission

Technology cost & performance
Resource availability
Demand projection
Demand-side technologies
Grid operations
Transmission cost



U.S. DEPARTMENT OF ENERGY

High resolution modeling using **134 nodes & hourly time steps**

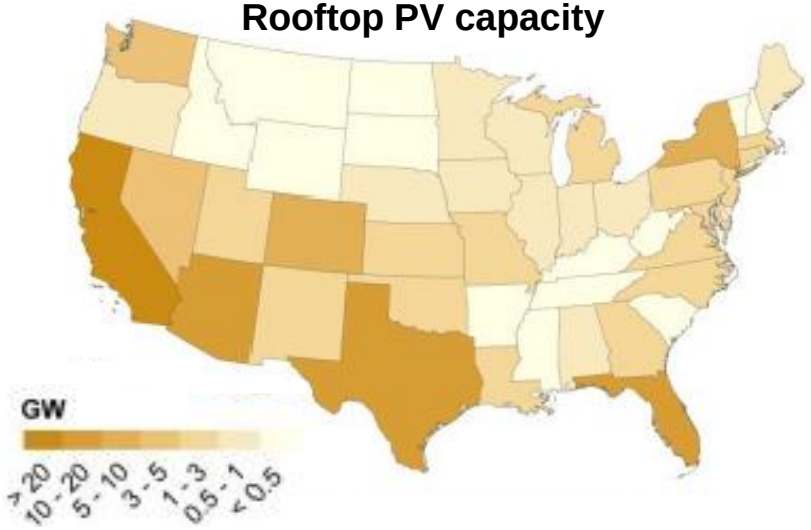
Implications
GHG Emissions
Water Use
Land Use
Direct Costs

Capacity & Generation 2010-2050

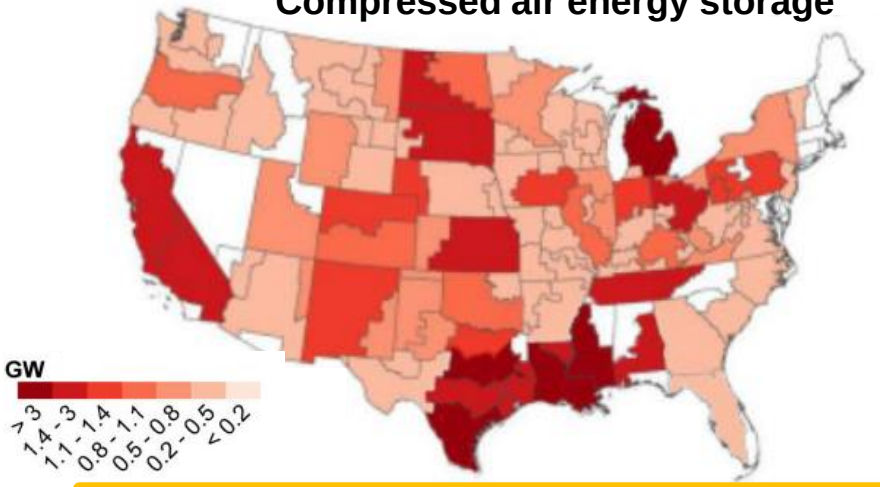
Only currently commercial technologies were modeled, with incremental and evolutionary improvements.

Regional Energy Deployment Systems Model (ReEDS)
Inputs and Outputs

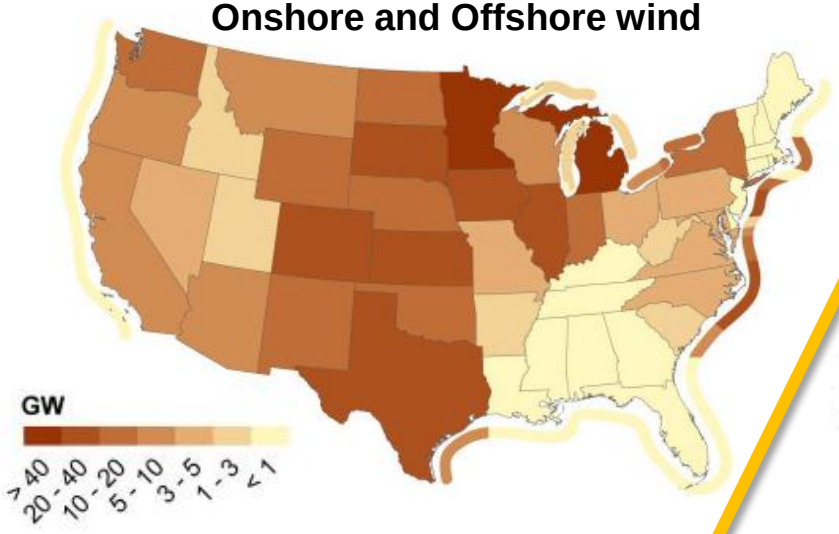
Rooftop PV capacity



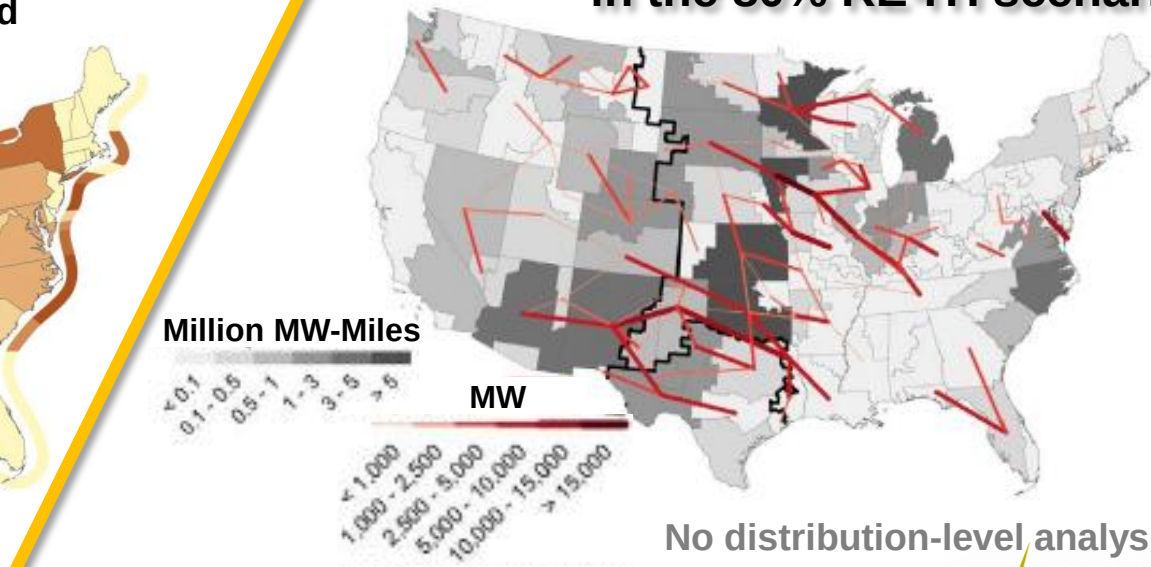
Compressed air energy storage



Onshore and Offshore wind

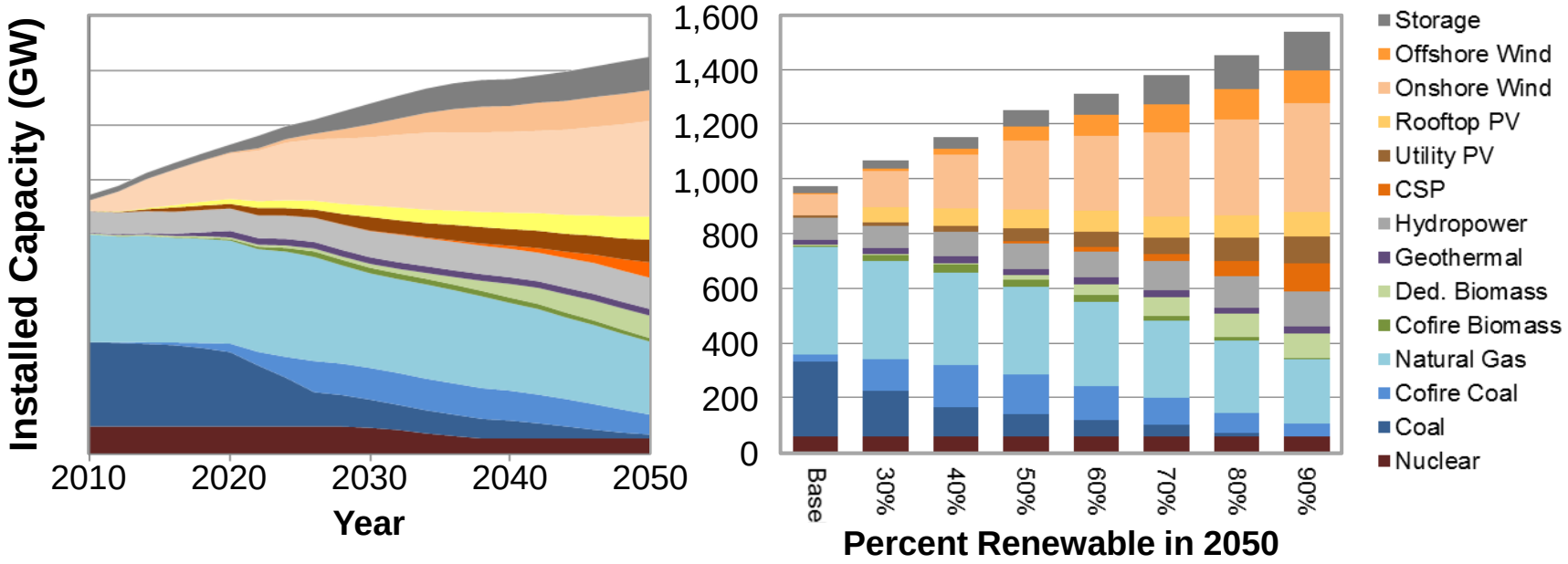


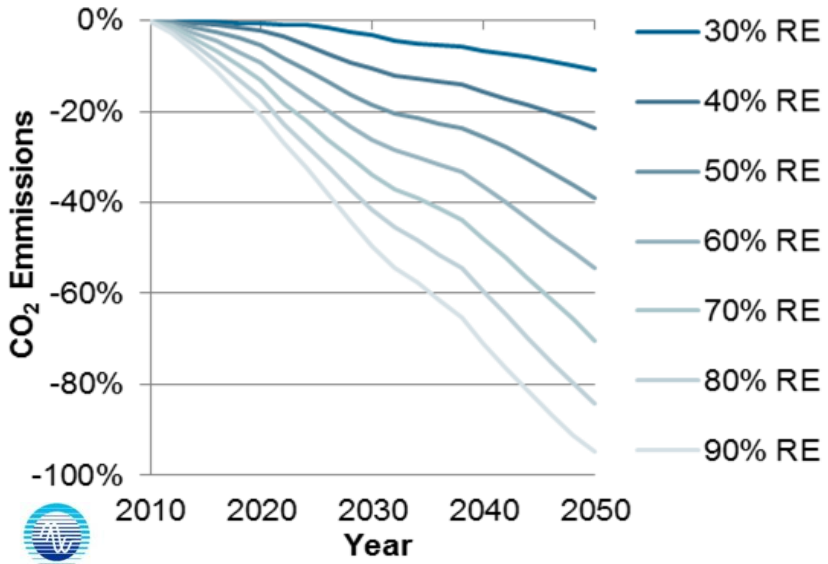
New transmission required by 2050 in the 80% RE-ITI scenario



No distribution-level analysis.

Renewable Electricity Futures Study Conclusions





Renewable electric energy generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 — while meeting electricity demand on an hourly basis in every region of the country!

Patching-up the 20th Century Technology

Integration of grid, renewables, and storage saves money!

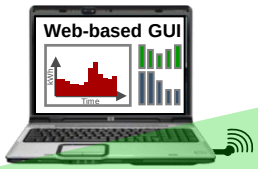
"Smart" appliances save energy!

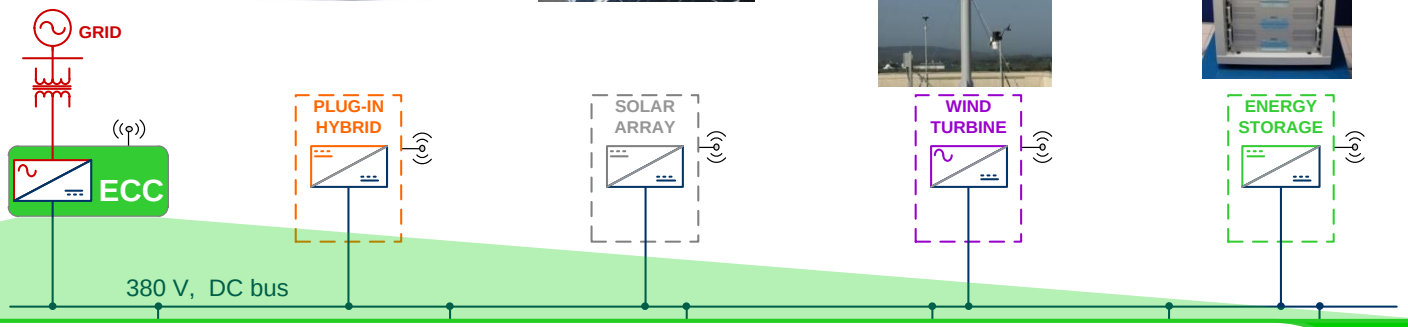
21st Century Electronic Power Distribution

efficient, programmable, safe, … affordable

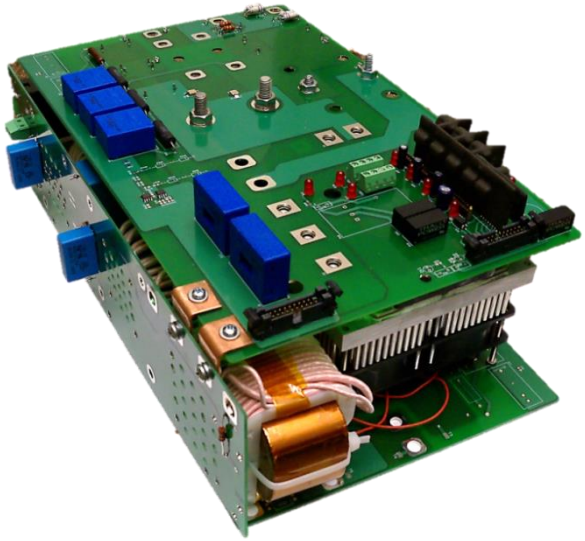
Nanogrid * with the bus architecture

- **Two voltages**
- **Wireless communication**





10 kW Energy Control Center (ECC)



Features:

- **Bi-directional topology**
- **Bi-directional control system**
- **Bi-directional current limit**
- **Bi-directional decoupling due to dc-link**
- **Bi-directional EMI compatibility**
- **Low dc leakage current**
- **Low cost, high density**

* J. Bryan, R. Duke, S. Round, 2003

Control of Wind Turbine (Farm)
for Satisfying Active Power Demand

Wind Turbine

Rectifier stage

DC Link

Bus Regulator stage

Filter

DC or AC Bus

60 Hz

Power Grid

Grid Power

G(s)

G(s)

Local Power

Diode Rectifier

DC Load

D. Rectifier

Motor Drive

G(s)

Active Rectifier

DC Bus

G(s)

A. Rectifier

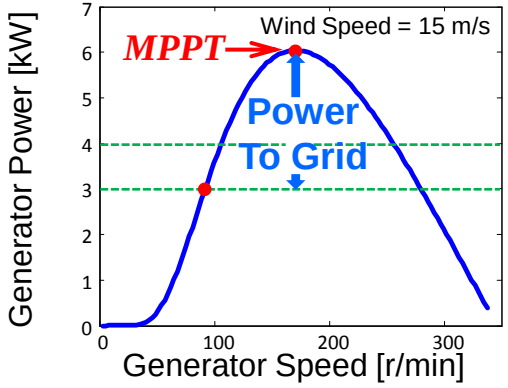
Inverter

AC Bus

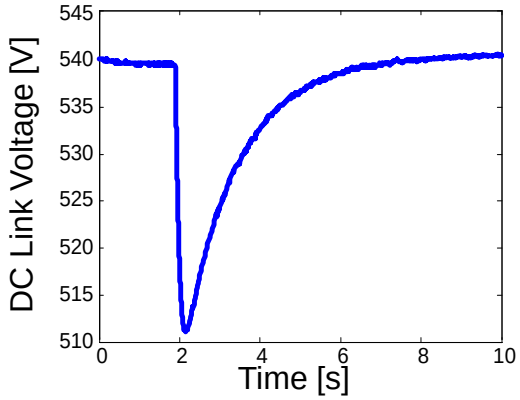
G(s)

G(s)

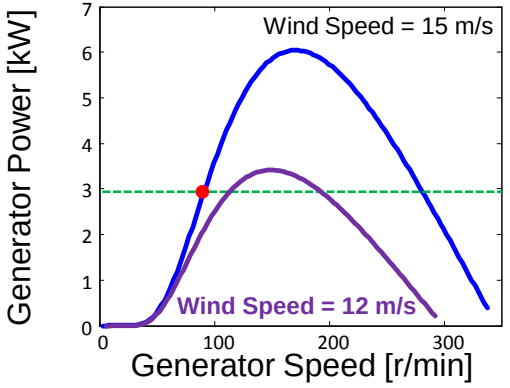
Regulation with Demand Change

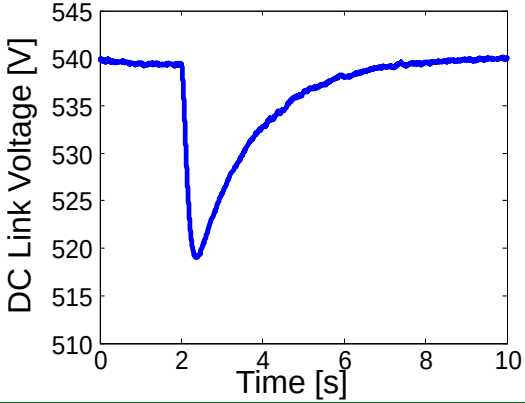


Local Power Demand



Regulation with Wind Change



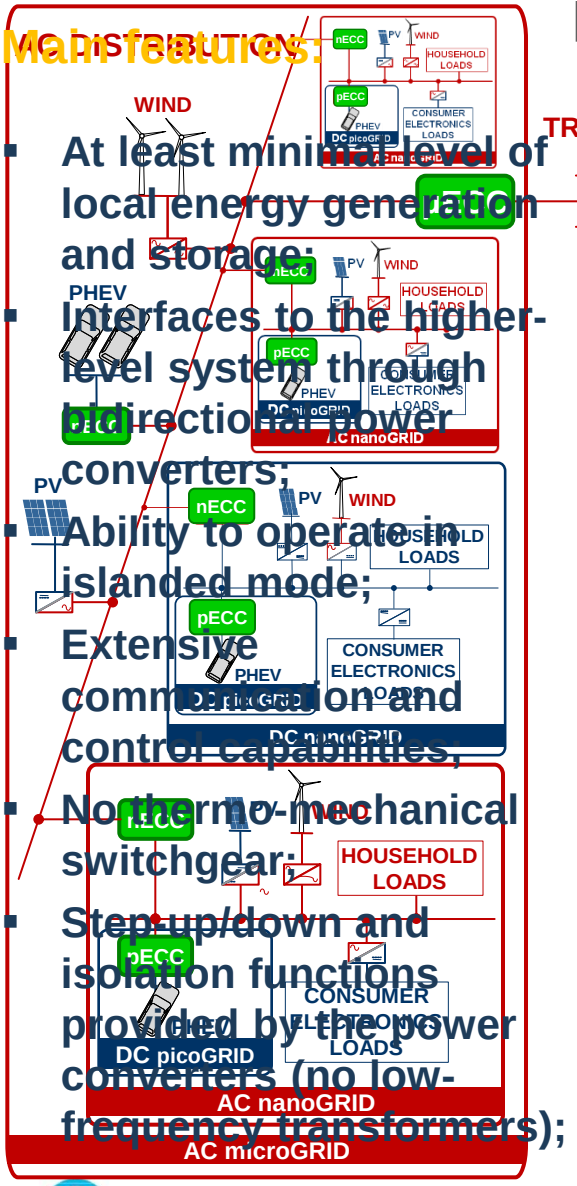


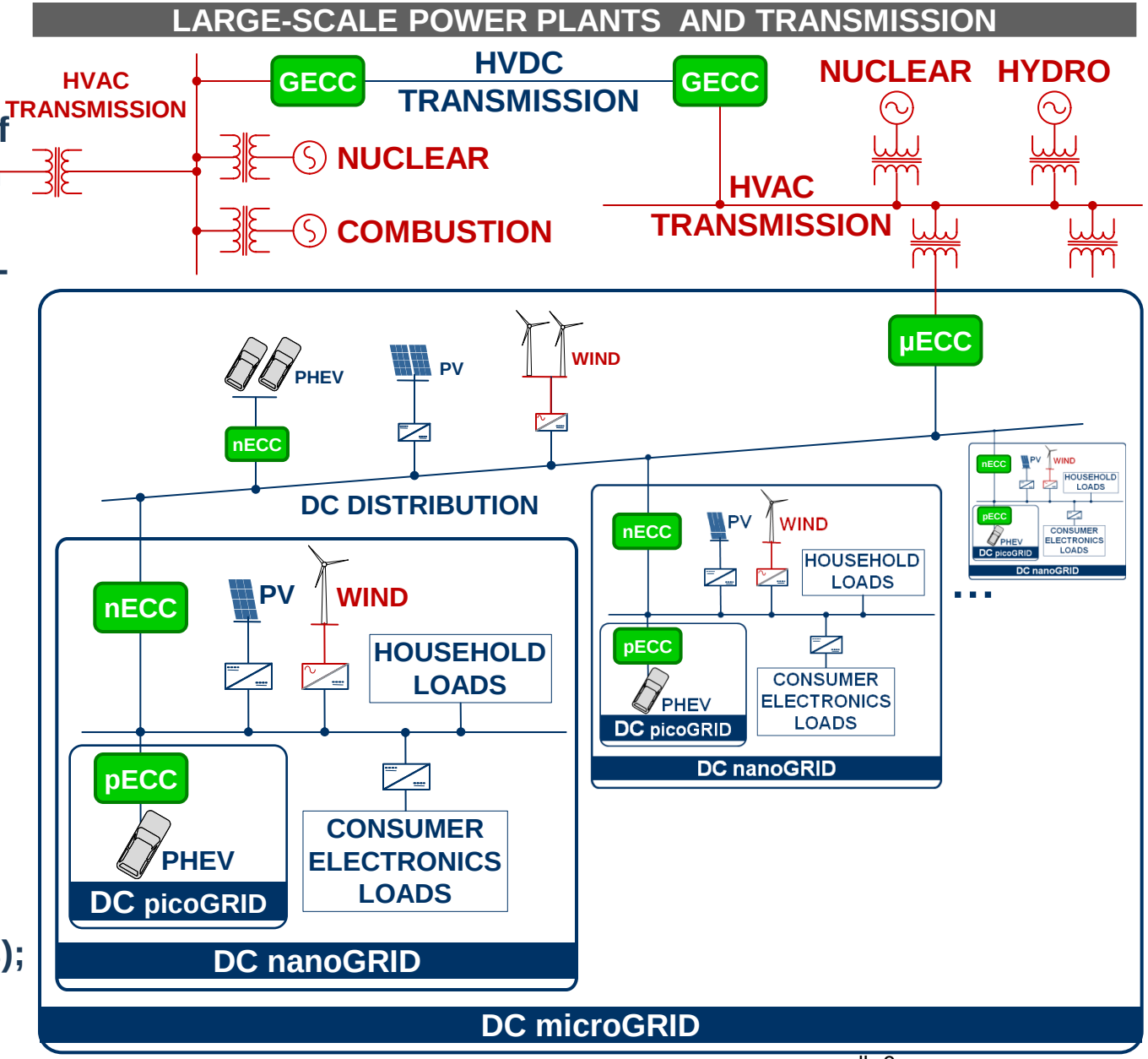
Wind generation can regulate bus voltage (and frequency)!

¿ Intergrid ?

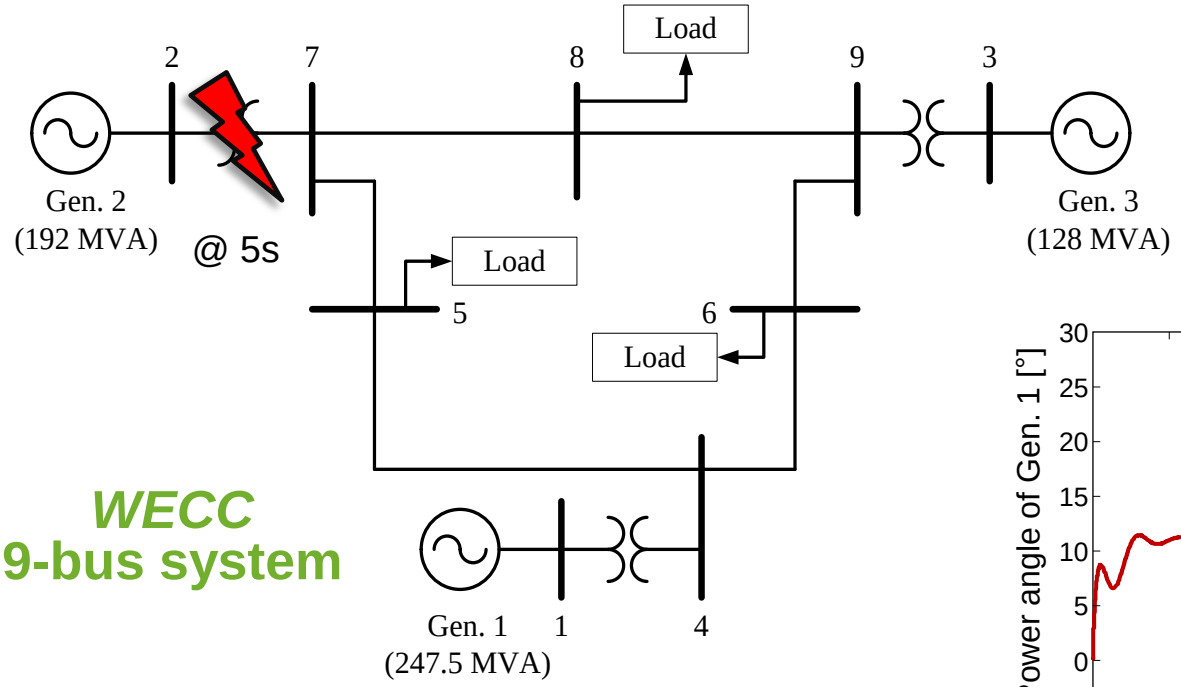
Main features:

- At least minimal level of local energy generation and storage;
- Interfaces to the higher-level system through bidirectional power converters;
- Ability to operate in islanded mode;
- Extensive communication and control capabilities;
- No thermo-mechanical switchgear;
- Step-up/down and isolation functions provided by the power converters (no low-frequency transformers);





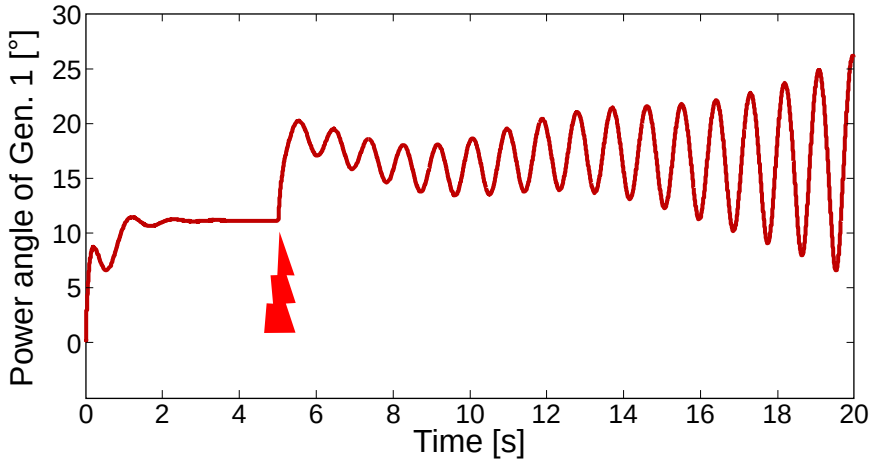
Instability in Traditional System Caused by Partial Loss of Generation



WECC 9-bus system

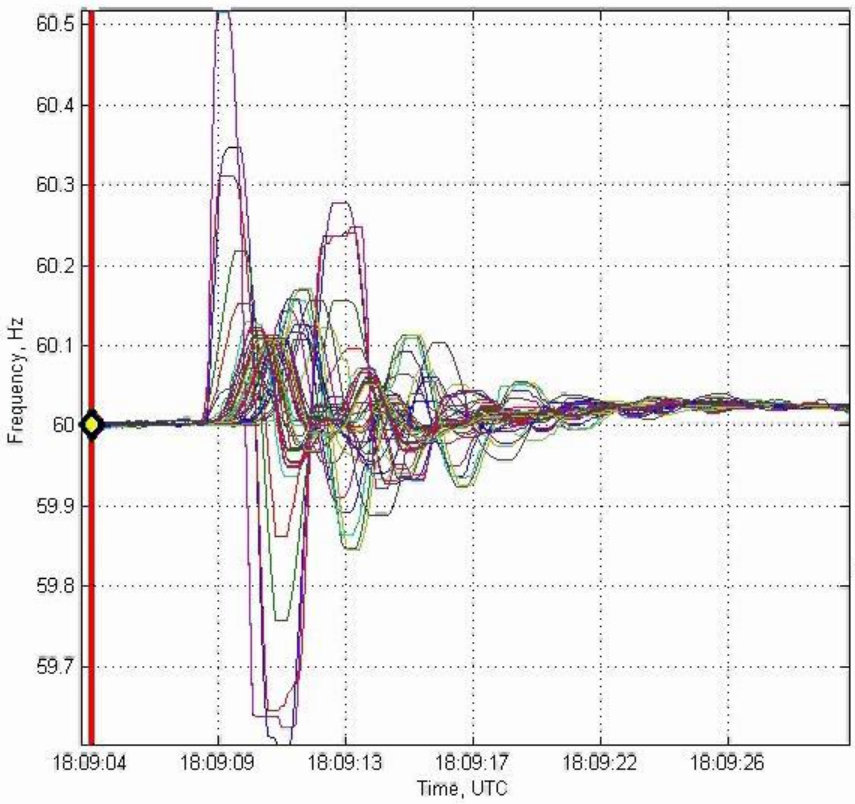
Total generating capacity > 550 MVA

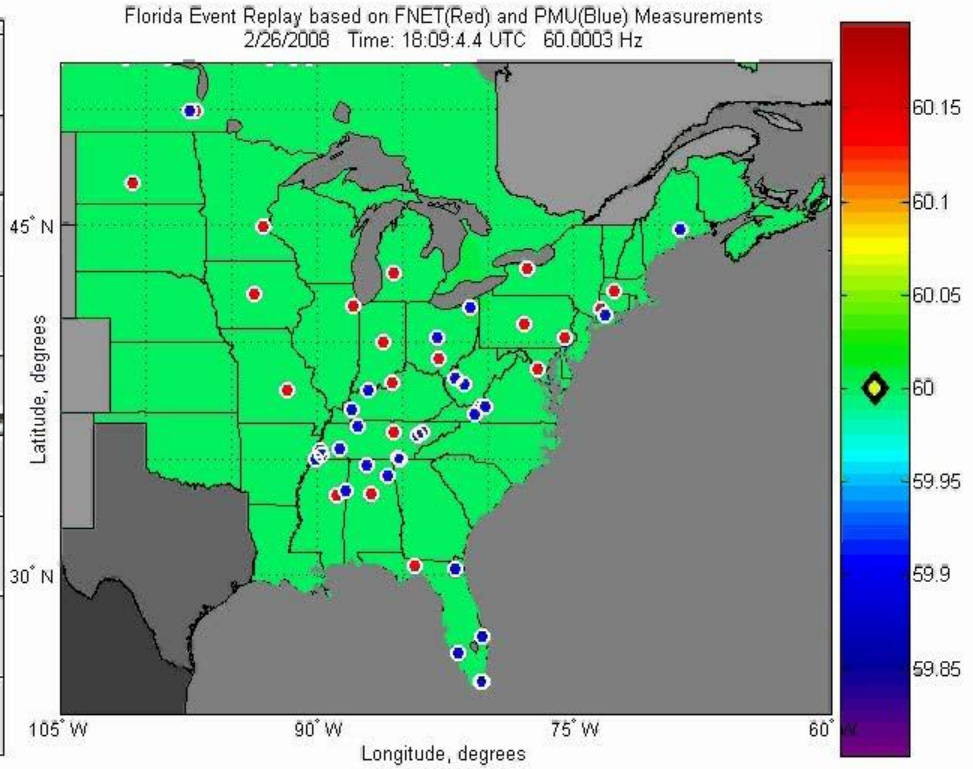
$$P_{\text{Total Load}} \approx 180 \text{ MVA} < P_{\text{Gen. 1}} + P_{\text{Gen. 3}}$$



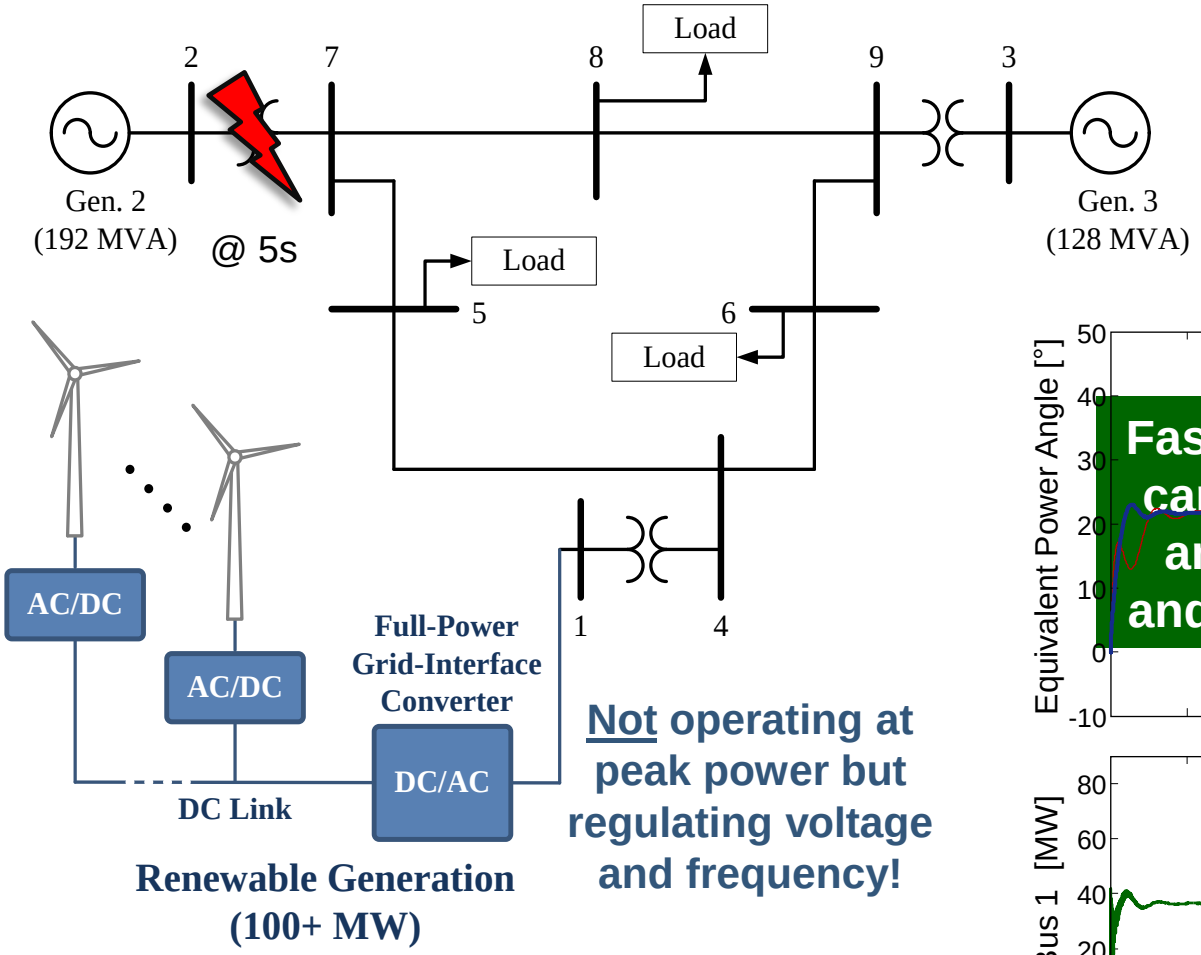
Large transient causes overall system instability due to undamped power oscillations between Generators 1 and 3.

Frequency Variations during 2008 Florida Blackout





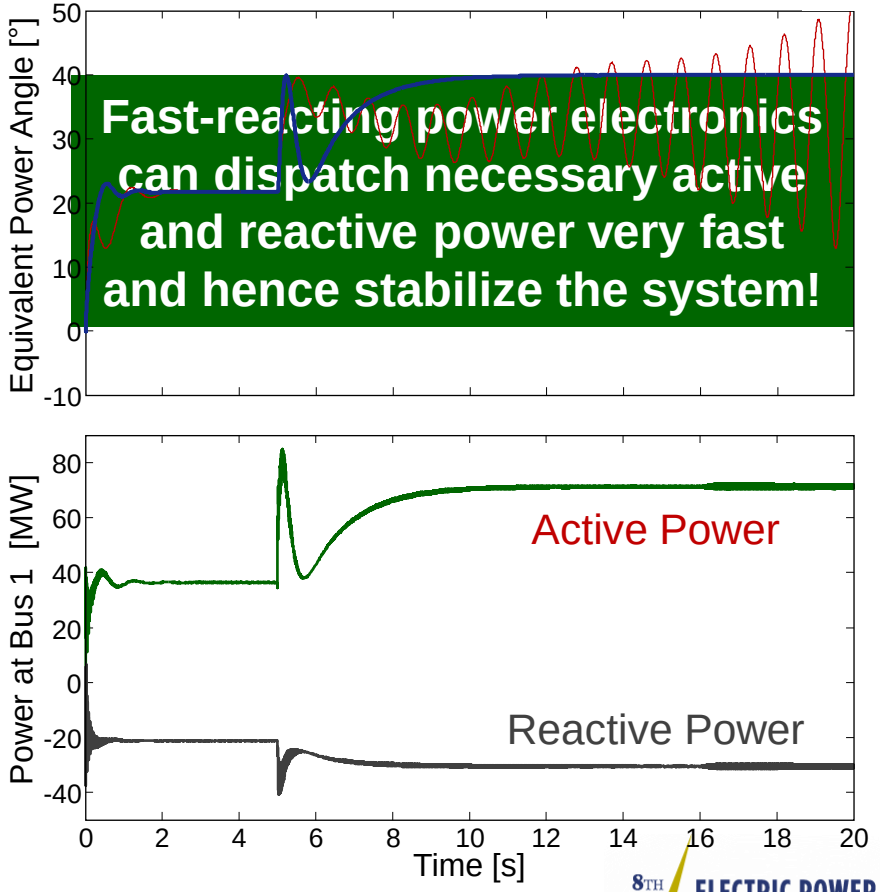
Mitigating Instability with Power Electronics-Interfaced Renewable Generation



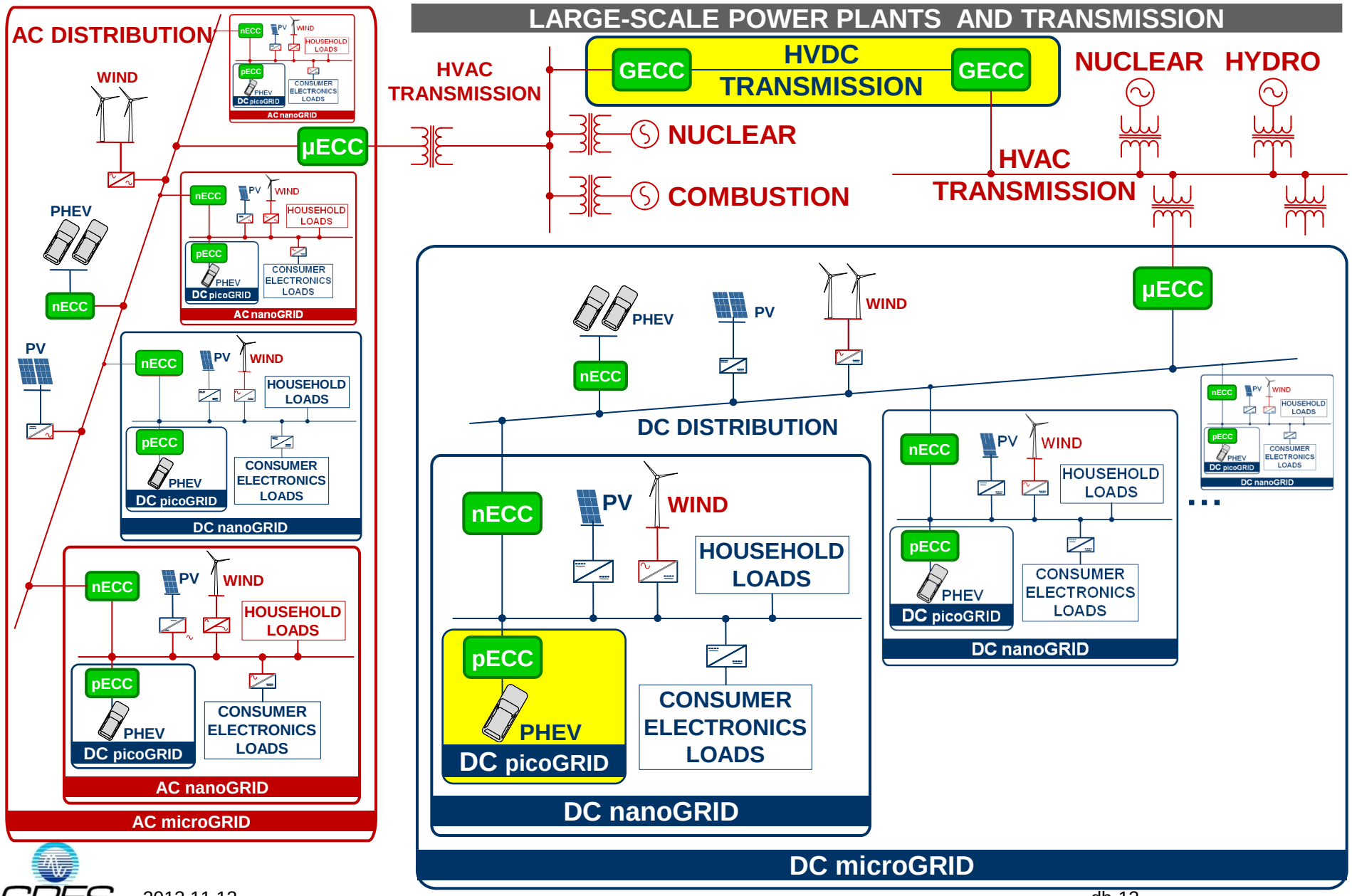
$$P_{\text{Total Load}} \approx 180 \text{ MVA} < P_{\text{Ren.}} + P_{\text{Gen. 3}}$$

Not operating at peak power but regulating voltage and frequency!

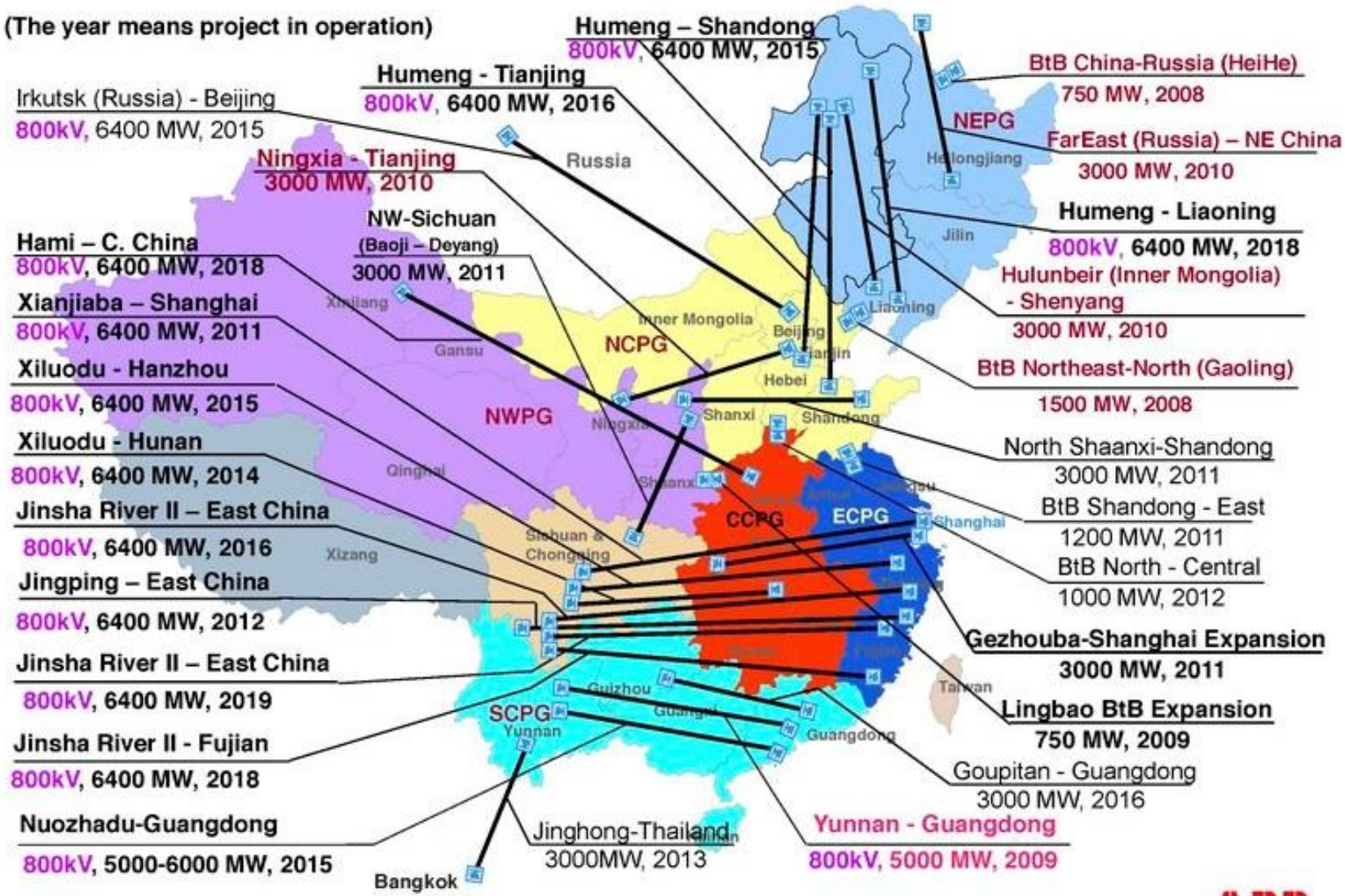
Total generating capacity < 450 MVA



Intergrid: Hierarchical network of dynamically-decoupled, electronically-interconnected, sub-networks



Planned Future HVDC Projects by 2020 in China



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Research Needed to
Replace Electric Energy "Railways" with "Highways"

1. **Network Architectures and Control**
   - Hierarchical network of dynamically-decoupled, electronically-interconnected, sub-networks
   - Distributed generation, storage, loads, and intelligence
   - Continuous control of all energy flows
   - Enabling of efficient market mechanisms
2. **High-Power and High Power-Density Converters**
   - New materials, active and passive devices, thermal management
   - High-density integration and packaging, especially HIGH-VOLTAGE technologies and UNDERGROUND transmission / distribution
3. **Safety and Reliability**
   - Security and availability (need to prove that decoupled networks are inherently more robust and resilient)
   - Safety & protection (need to prove that DC with VSC & bi-cables could be safer than AC)
   - Reliability & lifetime (need to prove that electronics is inherently more reliable than electro-mechanics)