Electrical Models to Support Grid Deployment of Smart Grid Advanced Batteries

SEVENTH ANNUAL CARNEGIE MELLON CONFERENCE ON THE ELECTRICITY INDUSTRY

March 9, 2011

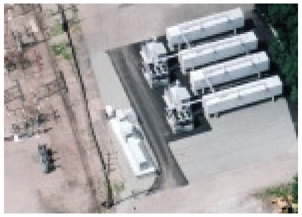
Grid Studies, Mapping Type to Deployment Need

- Load Flow Simulation, Feasibility Study, System Impact Study
- Dynamic Stability Simulation, SIS
- Short Circuit Duty/Fault Study, SIS

- Protection Coordination, is this a study or project engineering task?
- EMTP analysis, a screen for equipment risk? Or, could be included/required as requirement of interconnection where there is subsynchronous resonance risk?

Evolution needed: Extend from the priority of identifying and mitigating any negative impact (preserving status quo) to meeting emerging requirements, and identifying and delivering new benefits

Study Priority #1, Getting Permission to Connect. Is 20 MW a Magic Bullet?



- SGIP Hope
  - No Stability Study?
  - Fast Track?
  - Lower Cost of Interconnection Application
- At The Expense Of
  - Maximizing Project Revenue Potential
  - Minimizing Project Unit Cost, Economies of Scale
- SGIP Reality

A123's Initial Grid Projects

- Frequency Regulation (6 MWh))
  - AES Huntington Beach, CA – 2009 (2MW, 15Min)
  - AES Westover, NY – 2010 (20MW, 15 Min)
  - A123 Medway, MA – 2011 (2MW, 15 Min)

- Renewable Firming & Ramp Management (40.75 MWh)
  - Europe – 2010 (400 KW, 15 Min)
  - DTE, Michigan (1MW, 30 Min)
  - SCE Tehachapi, CA - 2011 (8 MW, 4 Hours)
  - West Virginia – 2011 (32MW, 15 Min)

- T&D and Substation Support (9 MWh)
  - SCE, So. Calif., CA – 2009 (4MW, 15 Min)
  - Chile – 2009 (12 MW, 15 Min)
  - Chile – 2011 (20 MW, 15 Min)

PRE-CONNECTION STUDIES INCLUDE STABILITY SIMULATION

IEEE 1547 (≤10MW) -> SGIP(≤20MW) -> LGIP(>20MW)

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F.3.1.4 Outline of a system stability study

The Federal Energy Regulatory Commission's small generator interconnection procedures do not require stability studies. However, a stability study may be justified for high-impedence EPSs or intentional island systems.

A system stability study evaluates DR impact on a system's transient and oscillatory response to a disturbance. Most fundamentally, a system and connected synchronized machines must withstand transient events. Transient stability is generally demonstrated by maintaining synchronism (first swing test). The DR generator characteristics (such as internal machine voltage, impedance, and inertia) are key variables that affect transient response. Dynamic stability considers the longer-duration effect of DR exciter and governor action. Dynamic stability is demonstrated if machine and system oscillatory responses are positively damped {i.e., reduced in a reasonable time—6 s per IEEE Std 399™-1997 (*IEEE Brown Book*™) [B25]}. For DR connected to relatively strong systems with high short-circuit duty, DR effects on wider system stability are typically not a concern and are usually not a bounding constraint.

Following are the general steps of a system stability study. These are described in greater detail in IEEE Std 399-1997 8.6.

— Simulate the system.

— Simulate the disturbance.

— Obtain results.

— Interpret results.

Source, IEEE Std 1547.2, Copyright IEEE, Used here for promotion of engineering practice and methods

1547 (≤10MW) -> **SGIP(≤20MW)** -> LGIP(>20MW)

5.0 A system impact study shall consist of a short circuit analysis, a stability analysis, a power flow analysis, voltage drop and flicker studies, protection and set point coordination studies, and grounding reviews, as necessary. A system impact study shall state the assumptions upon which it is based, state the results of the analyses, and provide the requirement or potential impediments to providing the requested interconnection service, including a preliminary indication of the cost and length of time that would be necessary to correct any problems identified in those analyses and implement the interconnection. A system impact study shall provide a list of facilities that are required as a result of the Interconnection Request and non-binding good faith estimates of cost responsibility and time to construct.

6.0 A distribution system impact study shall incorporate a distribution load flow study, an analysis of equipment interrupting ratings, protection coordination study, voltage drop and flicker studies, protection and set point coordination studies, grounding reviews, and the impact on electric system operation, as necessary.

Source, FERC Order 2006 "Standardization of Generator Interconnection Agreements and Procedures", May 12, 2005

1547 (≤10MW) -> SGIP(≤20MW) -> **LGIP(>20MW)**

3.2.1.2 **The Study**. The study consists of short circuit/fault duty, steady state (thermal and voltage) and stability analyses. The short circuit/fault duty analysis would identify direct Interconnection Facilities required and the Network Upgrades necessary to address short circuit issues associated with the Interconnection Facilities. The stability and steady state studies would identify necessary upgrades to allow full output of the proposed Large Generating Facility and would also identify the maximum allowed output, at the time the study is performed, of the interconnecting Large Generating Facility without requiring additional Network Upgrades.

Source, FERC Order 2003-A, "Standardization of Generator Interconnection Agreements and Procedures", March 5, 2004

The Models: Library or Custom?

- PSLF, Modified Library, SMES1, 15 s to 1,800 s

```
/* CV Copy in parameter values from GE file "ES_tw100_d8_s2.dyd", by
A.S. */
/* except A123: battery emax 21600, 12MW X 30 min X 60 sec */
@Tw                 = 100.0
@T1                 = 0.1
@eff                = 0.90
@emax           = 21600
```

- PSSE, Modified Library, CBEST
- DigSilent, Custom

What is a "validated" model?

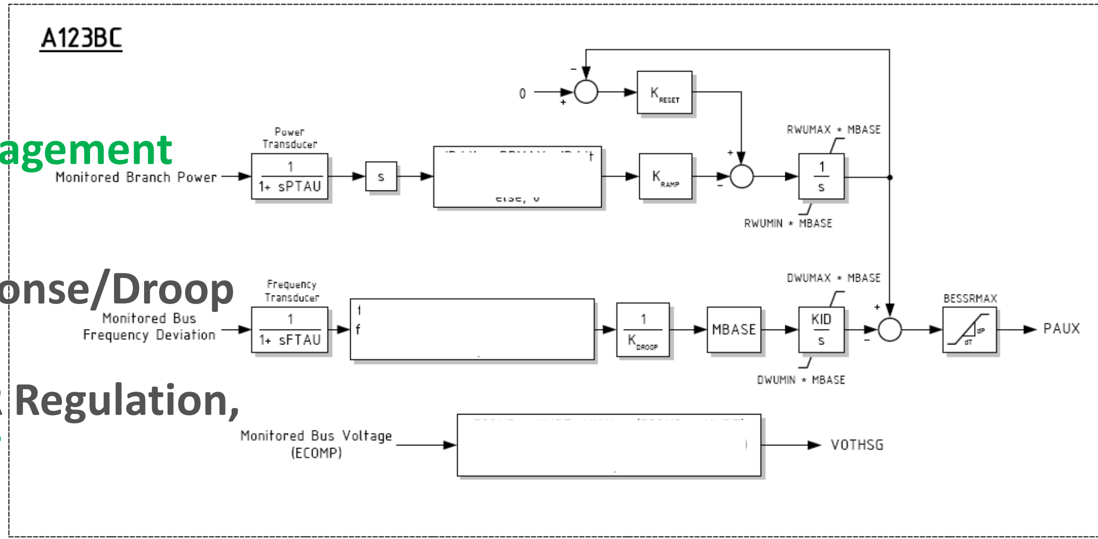
Does inclusion in PSLF or PSSE model library qualify?

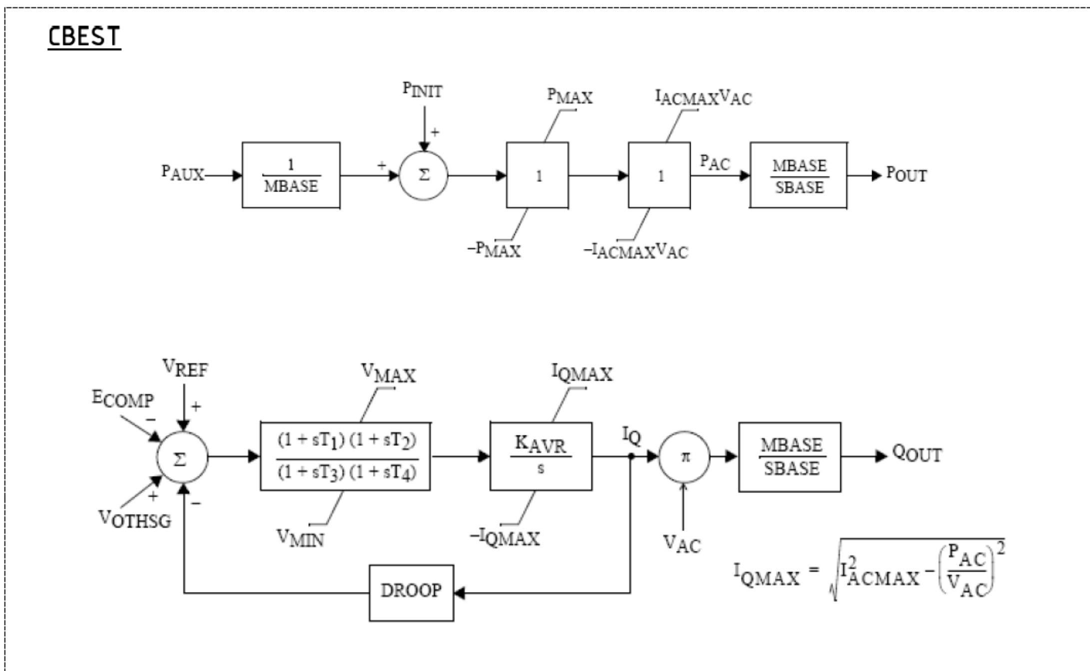
PSSE Example, A123 Battery Storage

Ramp Rate Management

Frequency Response/Droop

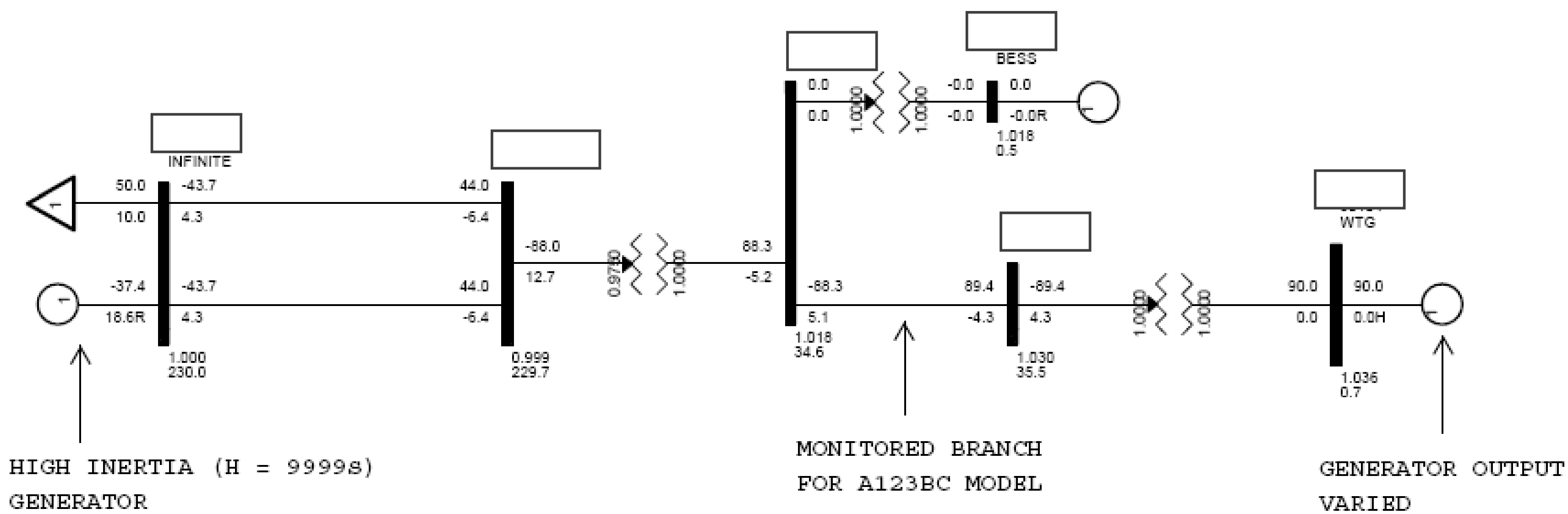
Volt/VAR Regulation, and LVRT





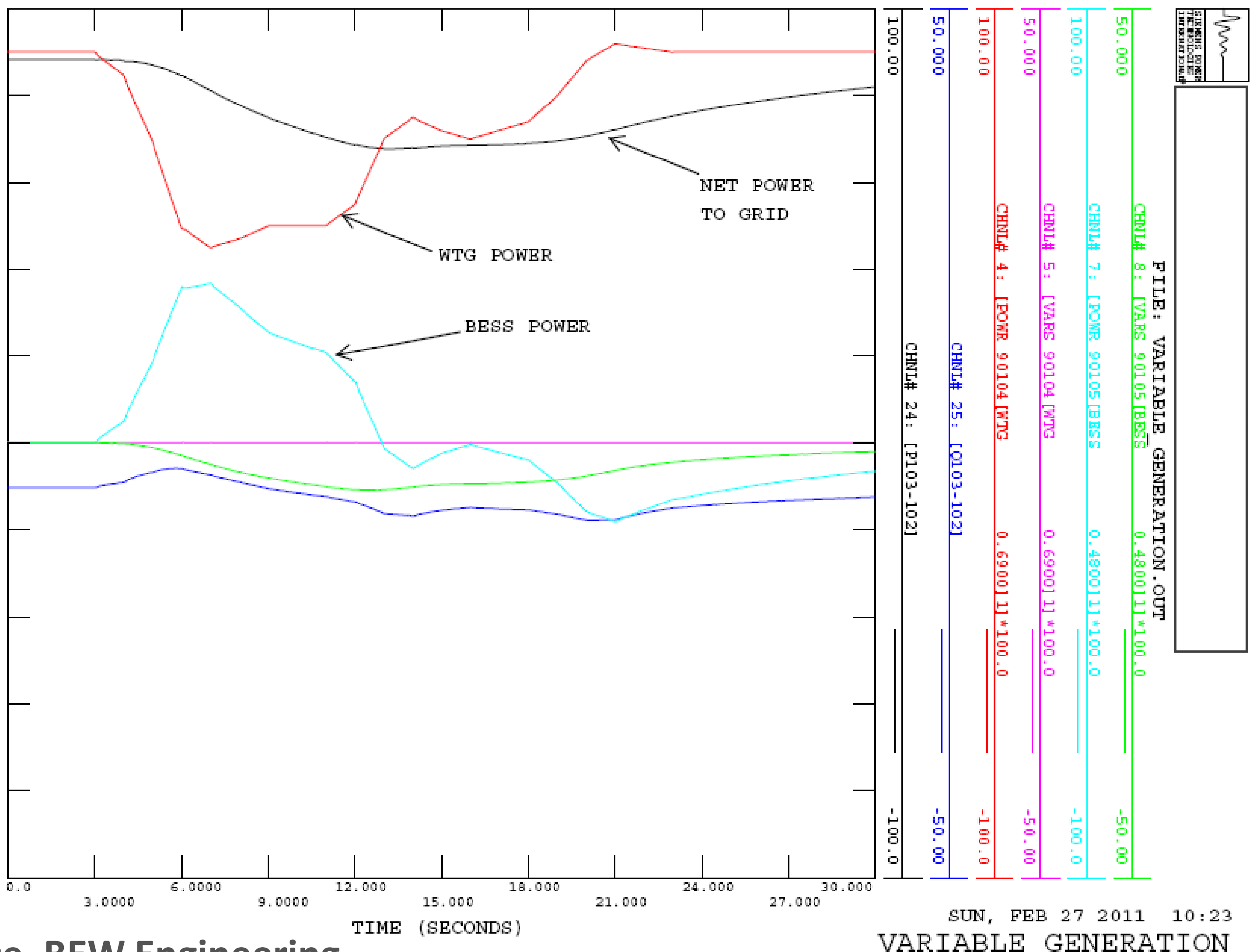
For Wind Project Interconnection Support, Ramp Rate Management

POWER FLOW CASE FOR DEMONSTRATION OF RAMP RATE COMPENSATION



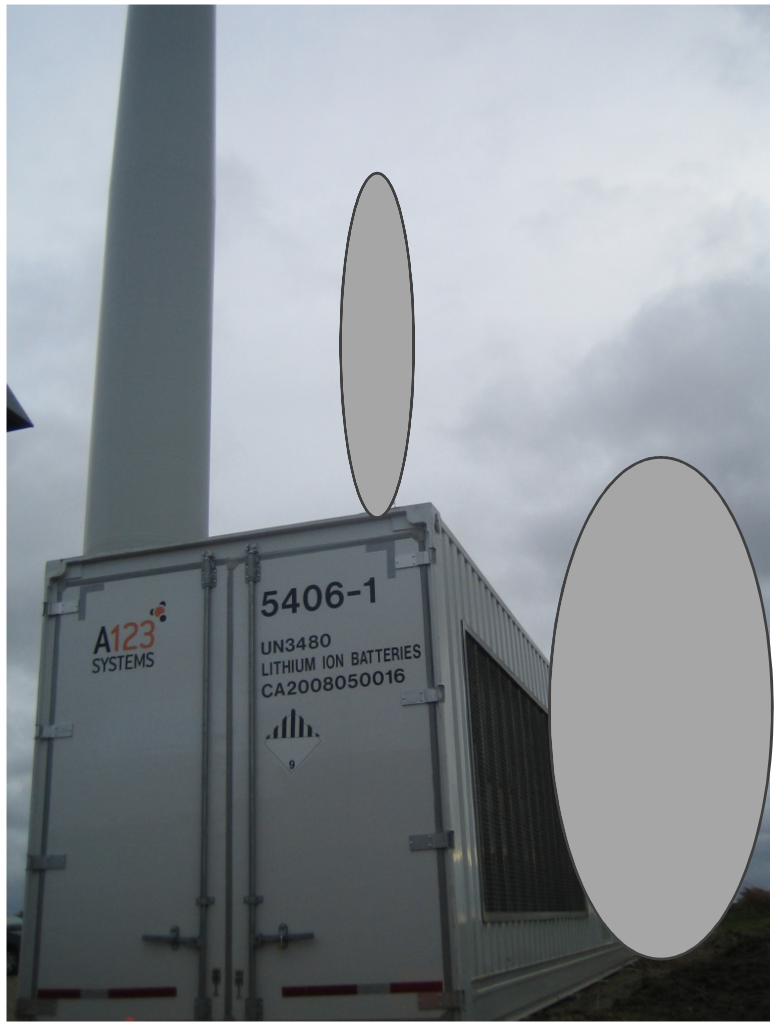
Source, BEW Engineering

For Wind Project Interconnection Support, Ramp Rate Management



Source, BEW Engineering

Energy Storage: One Contributing Solution for A Greener and Cleaner High-Renewable-Penetration Future



Inertial Equivalent, Providing H (MW-S), IS CRITICAL

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Q: Can it be done with a battery interfaced to the grid with an appropriate inverter?

A: Yes.

Timescale/response rate of advanced storage is a major plus. Timeframe is a matter of economics: No technical barrier. (see Cazalet/Vartanian paper, CMU 2008)

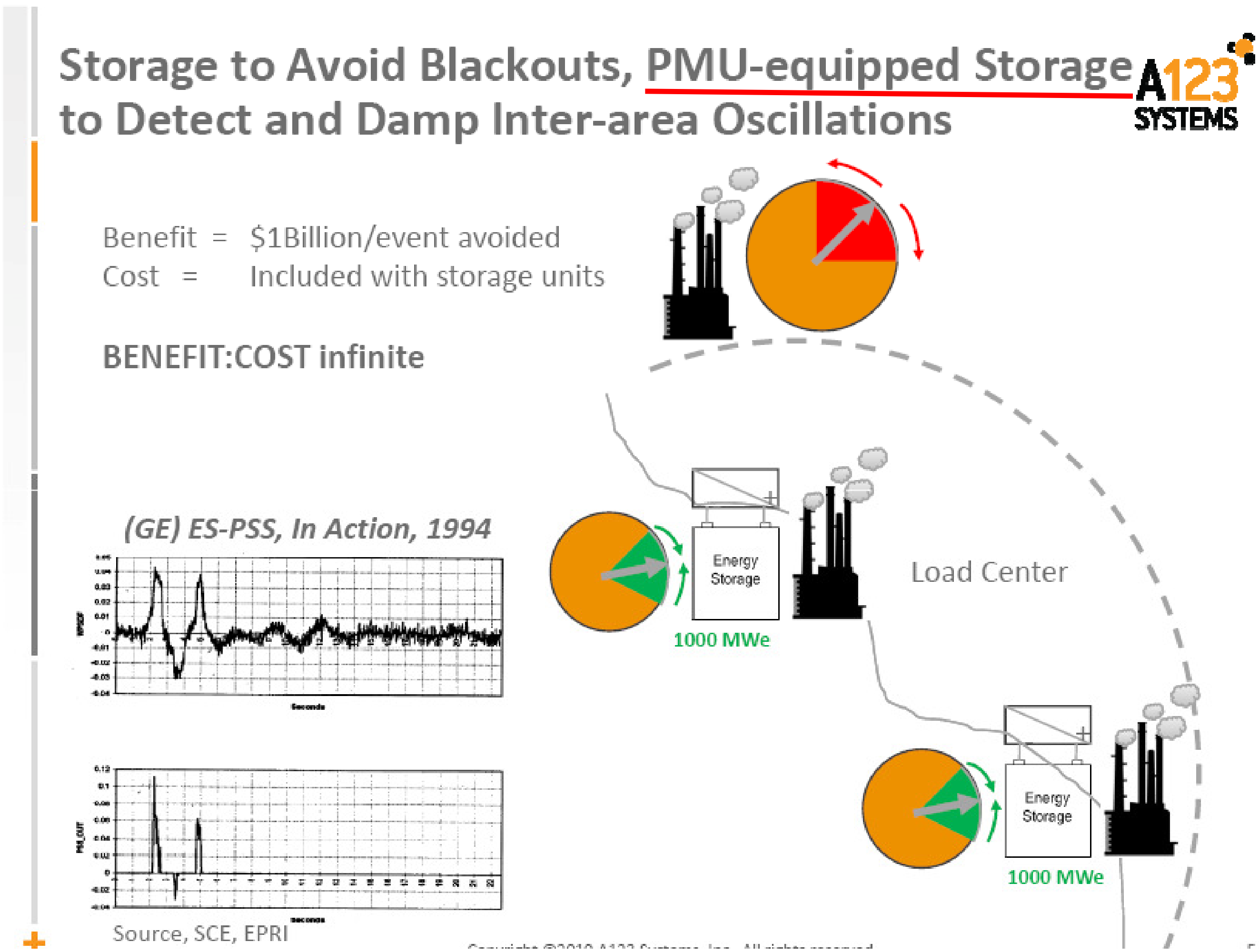
SUBSTANTIAL EMERGING RELEVANCE

1) Complimentary support to variable resources that may have this requirement imposed as condition of interconnection, then

2) Pathway to 50% renewables with coincident 50% improvement in grid reliability

+ ***CMU-ECE AND OTHER POWER SYSTEMS RESEARCHERS, PLEASE LEAD THE WAY***

Inertial Equivalent, Preserve and Enhance Wide Area Stability



A123 presentation to CA PUC, March 17, 2010

A123 Systems, Background

March 2011

A123 Systems Global Locations

Corporate Headquarters and R&D: Watertown, Massachusetts

- 2000+ employees in multiple locations worldwide
- >1,000,000 square feet (total) of manufacturing facilities in United States, China and Korea
- Cell assembly capacity > 760MW hours annually by the end of 2011

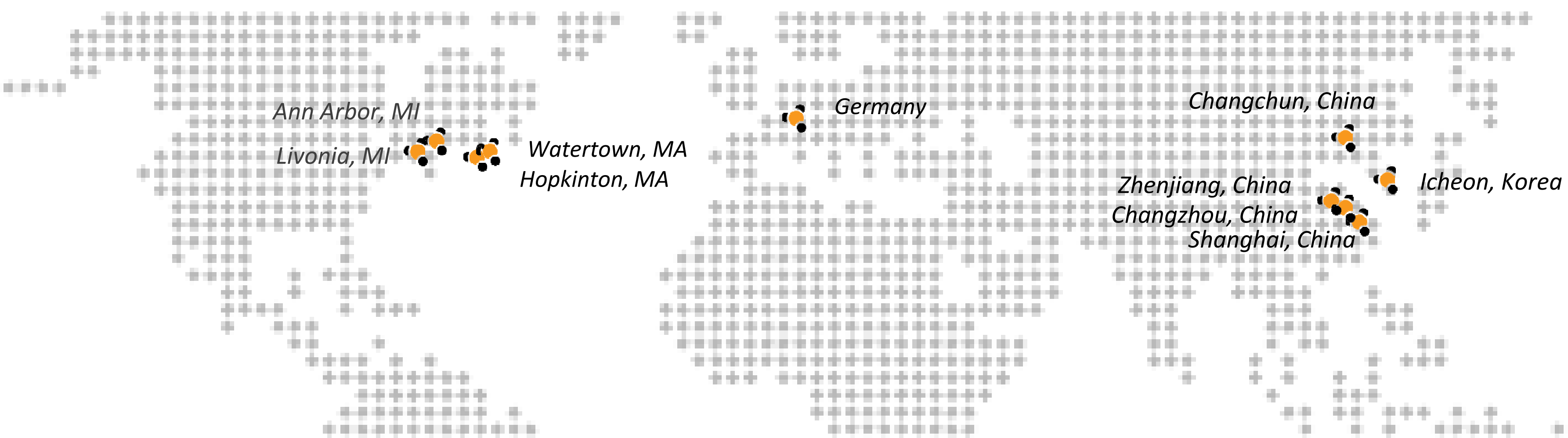
Corporate Headquarters, Research and Development
- Watertown, Massachusetts

Systems Design and Manufacturing
- Hopkinton, Massachusetts
- Livonia, Michigan

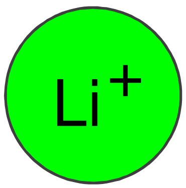
Materials Research
- Ann Arbor, Michigan

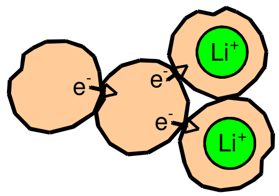
Powder, Coating, and Cell Plants
- Livonia, Michigan
- Icheon, Korea
- Changzhou, China
- Changchun, China
- Zhenjiang, China

Supplier Quality
- Shanghai, China



A123's Core Technology, Nanophosphate for Power, Safety, and Life





The addition of dopant significantly increases rate capability

High Contact Area

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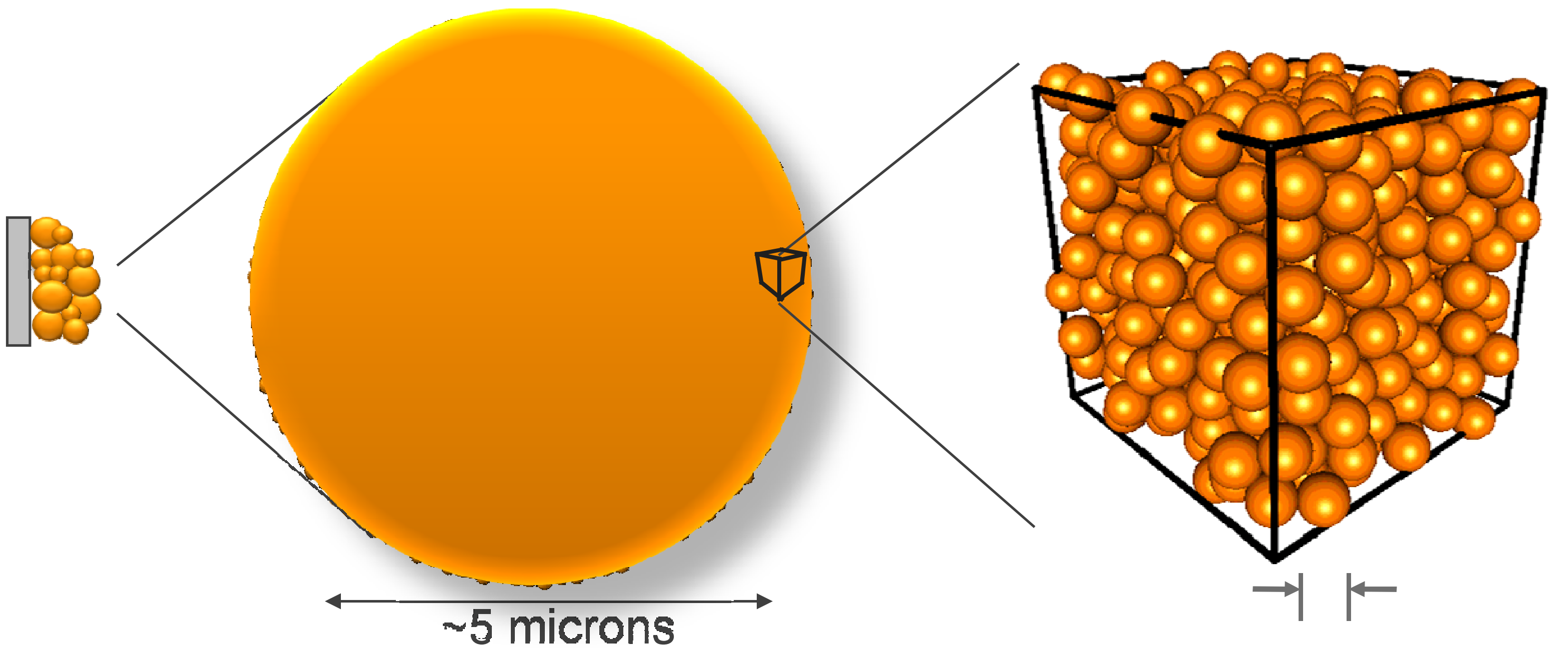
Low Internal Impedance



<0.1 micron

A123 Designs and Manufacturers Advanced Energy Storage Systems

Sharing innovation across three market segments

Transportation

Hybrids, Plug-In Hybrids and Electric Vehicles

Heavy-Duty Hybrids

Electric Grid

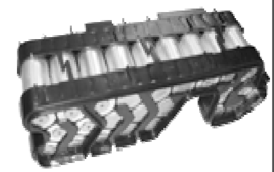
Frequency Regulation & Power Plant Hybridization

Network Energy Storage

Consumer & Industrial

Portable Power

Industrial



Drivers

Transportation:
- Fuel economy
- Reduced emissions
- Energy independence
- Lighter-weight components
- Fuel efficiency

Electric Grid:
- Increase grid reliability
- Enable Wind and Solar
- Increase plant efficiency/utilization

Consumer & Industrial:
- Improve performance
- Reduce emissions
- Reduce toxic battery chemicals

The A123 GBS: Containerized Grid Battery System

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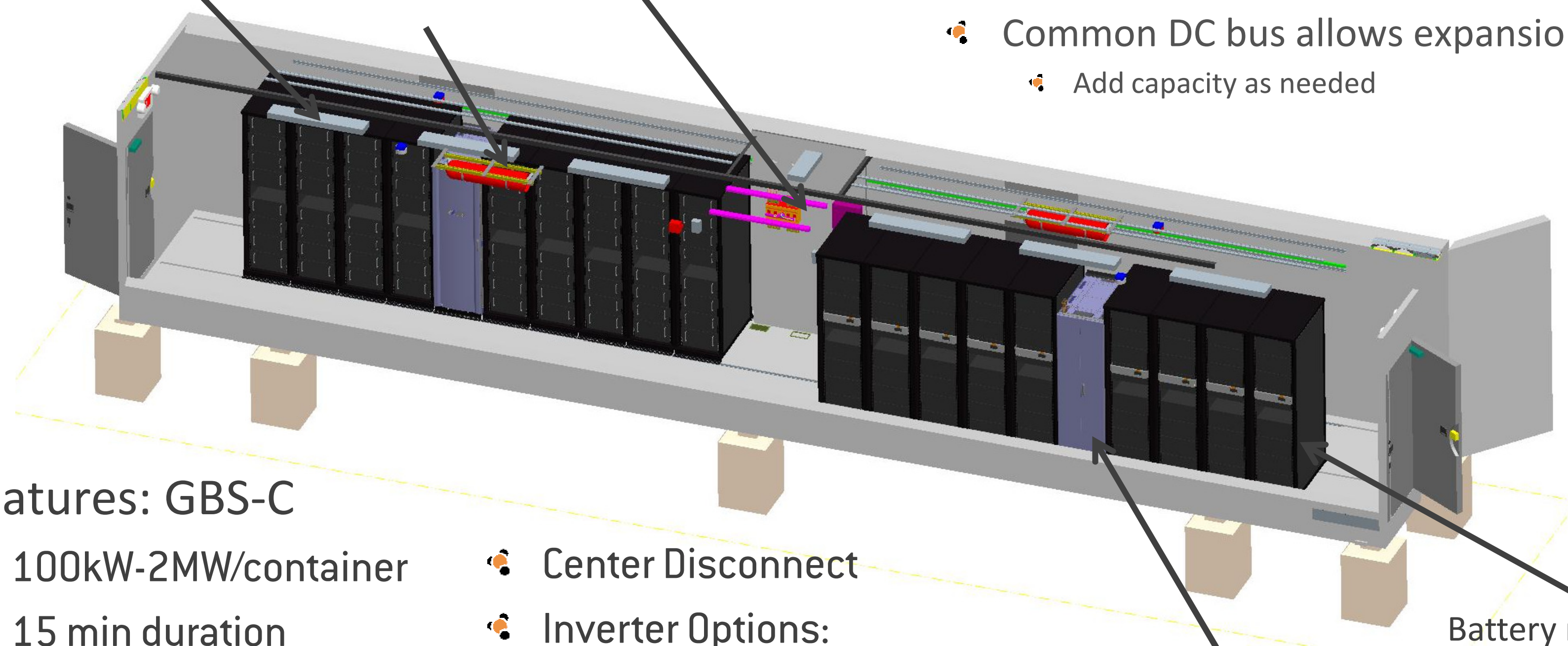
Benefits of GBS Design

- Flexible design supports many applications
- Shorter delivery lead time
- Common DC bus allows expansion
  - Add capacity as needed



Features: GBS-C

- 100kW-2MW/container
- 15 min duration
- 2C rms, 4C max
- Up to 22 racks/container
- 53' container only
- Center Disconnect
- Inverter Options:
  - 100KW/200KW/400KW/600KW
  - 1MW/2MW/4MW

A123 is Leveraging Smart Grid

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Today, A123's modular GBS is used primarily in Frequency Regulation & Spinning Reserve service

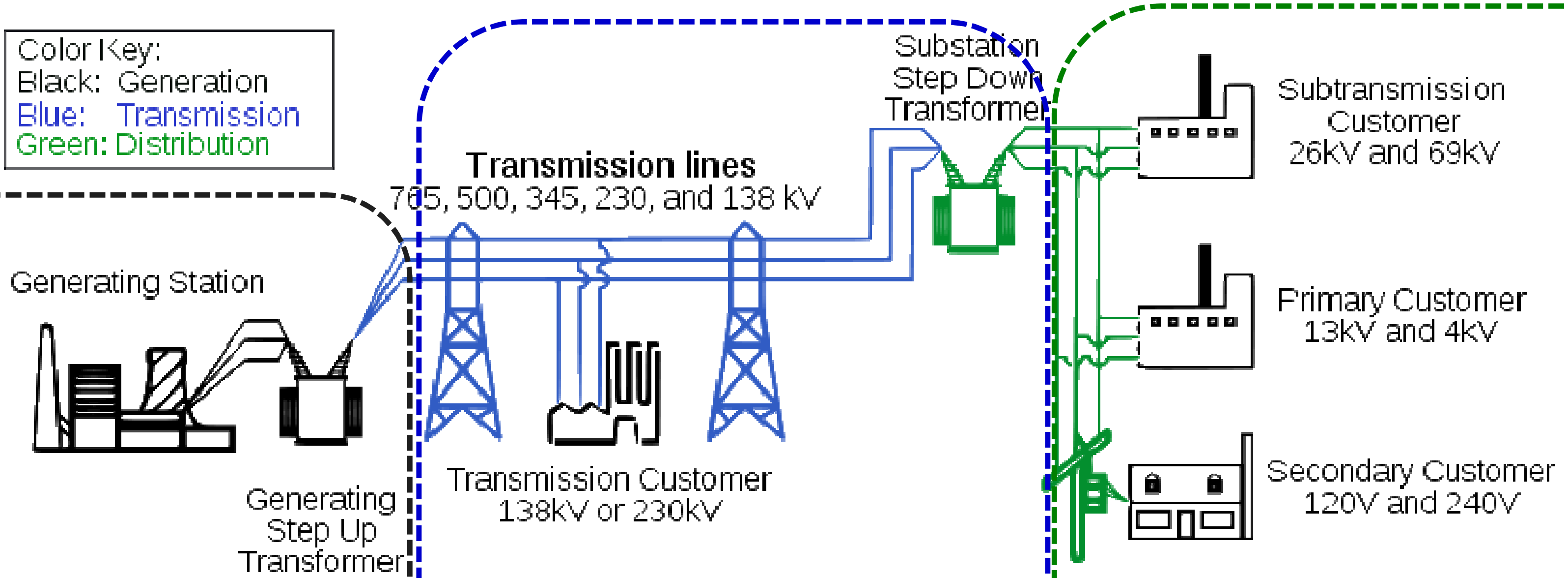
Next, leverage Smart Grid and GBS functionality (speed & control) to deliver additional operating modes of value

Metering, communications & IT enabling intelligent use of multi modes is the

SMART GRID

- **Dynamic Voltage Support**
- **Renewable Integration, Ramp Management**
- **T&D Support and Enhanced Performance**
- **Blackstart, Active Islanding**
- **Customer Choice (Demand Response '+')**

Regulatory Challenge
Grid Storage Is Effective across G, T, and D



Ancillary services
- Area regulation
- Synchronous reserve

Renewable integration
- Ramp management
- Peak shifting

New Asset Investment
Upgrade Deferral
Power Reliability
Bulk Renewable Integration

Power Quality
Network energy storage, CES
Distributed PV Integration
Microgrids