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Advanced SmartGrid Modeling and Simulation using High Performance Computing

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Outline

- SmartGrid Characteristics
- SmartGrid Technical Concerns
- Sandia Physics Based Modeling Enabling SmartGrid Development
  - Model Validation: Physics Model Abstraction
  - Digital Control/Analog Function Interactions
  - Transient Dynamic Analysis of Renewable Energy Sources
- Sandia's Unique High Performance Computing Resources and Capabilities

SmartGrid Characteristics

Characteristic	Definition
Self Heals	**Automatically detects and responds to actual and emerging transmission and distribution problems. Focus is on prevention. Minimizes consumer impact.**
Motivates and includes the consumer	**Informed, involved and active consumers. Broad penetration of Demand Response.**
Resists Attack	**Resilient to attack and natural disasters with rapid restoration capabilities.**
Provides power quality for the 21st century	**Quality of power meets industry standards and consumer needs. PQ issues identified and resolved prior to manifestation. Various levels of PQ at various prices.**
Accommodates all generation and storage options	**Very large numbers of diverse distributed generation and storage devices deployed to complement the large generating plants. "Plug-and-play" convenience. Significantly more focus on and access to renewable**
Enables markets	**Mature wholesale market operations in place; well integrated nationwide and integrated with reliability coordinators. Retail markets flourishing where appropriate. Minimal transmission congestion and constraints.**
Optimizes assets and operates efficiently	**Greatly expanded sensing and measurement of grid conditions. Grid technologies deeply integrated with asset management processes to most effectively manage assets and costs. Condition based maintenance.**

From: National Energy Technology Laboratory, A Vision for the Modern Grid, United States Department of Energy

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SmartGrid Technical Concerns

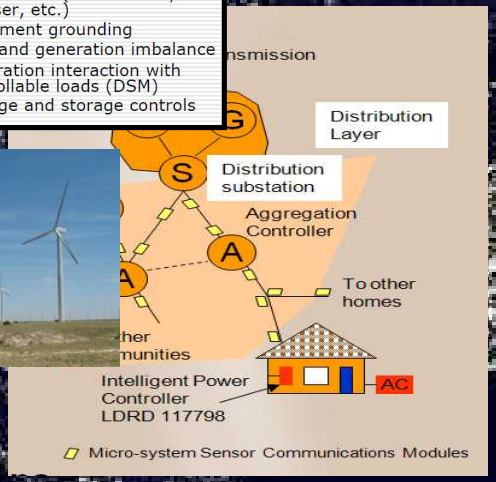
Technical Concerns of New Grid

Large Solar and Wind (Bulk System Connected Generation)

- Steady state and transient stabili analysis
- Load/Generation Coincidence (Pe Load and Variability of Source)
- Regulation Requirements
- Integration with Automatic Generation Control (AGC)
- Incorporation of renewable resource forecasting
- Examine current operating practice and new concepts to enable high penetration;

Distributed Solar and Small Wind (Distributed Generation)

- Unintentional Islanding
- Protection design and coordination (short circuit, recloser, etc.)
- Equipment grounding
- Load and generation imbalance
- Generation interaction with controllable loads (DSM)
- Storage and storage controls

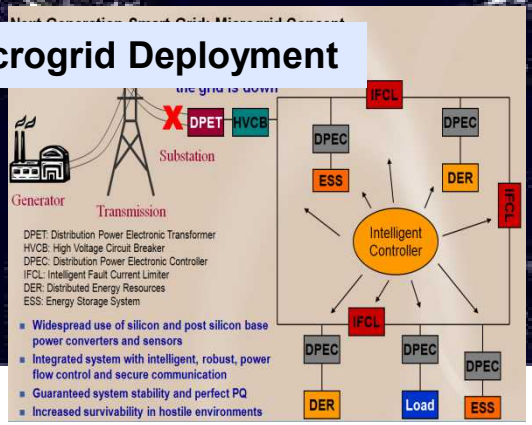


Renewable Energy Sources

2003 Blackout Area

Reliability/Failure Analysis

SmartGrid/Microgrid Deployment



Grid Integrations

- ✓ Multi-Scale (Temporal, Capacity) Storage Technologies
- ✓ High-Power Switching Devices
- ✓ Embedded Sensors and Controls
- ✓ Secure Communications
- ✓ Hostile Environment Survivability

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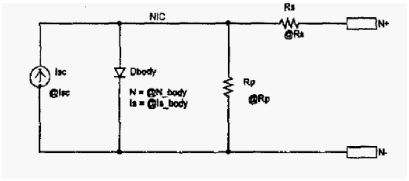
Sandia Physics Based Modeling enables SmartGrid Development

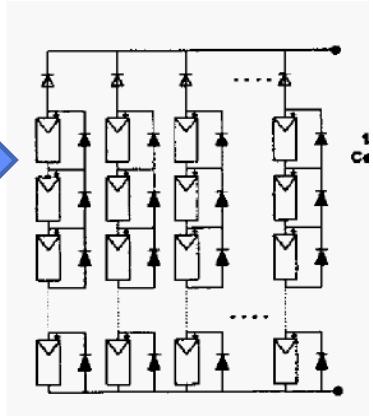
SmartGrid Characteristic	Technical Concern	Physical Phenomena	Physics based modeling activity
Resists Attack	**Effects of Solar Storms**	**Induced currents on transmission lines**	**•Model Validation •Digital Control/Analog Function Interactions**
Provides power quality for the 21st century	**Introduction of distributed small scale renewable energy sources**	**Power Quality (Harmonics, Flicker, DC Injection)**	**•Model Validation •Digital Control/Analog Function Interactions •Renewable energy source transient dynamic analysis**
Accommodates all generation and storage options	**Introduction of renewable energy sources**	**Dynamic grid stability**	**•Renewable energy source transient dynamic analysis**

Model Validation:
High Fidelity Physics Based Models

Physics based PV Station



Single PV Cell



PV Array

Transient Dynamic Simulation

Behavioral PV Station

Behavioral Model

Use detailed physics based circuit models to develop and validate higher level models

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Digital Control/Analog Function Interactions

- **Detailed control/grid interaction simulations (Microgrid and smaller)**
- **Failure Analysis (Identification of unknown positive feedback loops)**
- **Response of transient effects (solar storms, surges, instabilities, etc)**

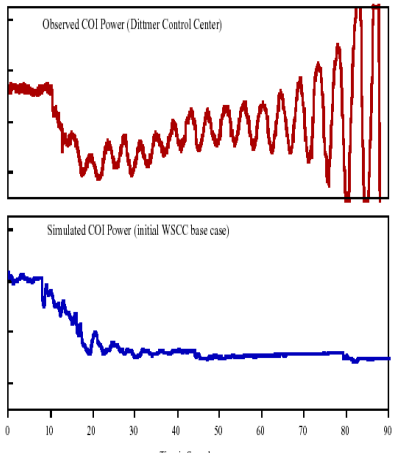
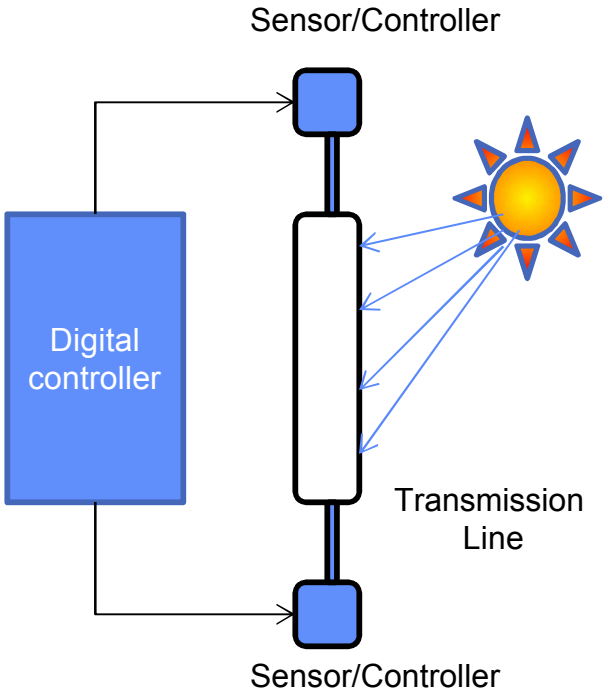


Figure 1: Modeling failure for August 10, 1996 California blackout. The figure shows the observed verses predicted power. From J. Hauer, T. Overbye, J. Dagle, and S. Widergren, "Advanced Transmission Technologies," National Transmission Grid Study Issue Papers, May 2002.

Failure Analysis



Understanding Solar Storm effects on System

Mixed Signal Simulations

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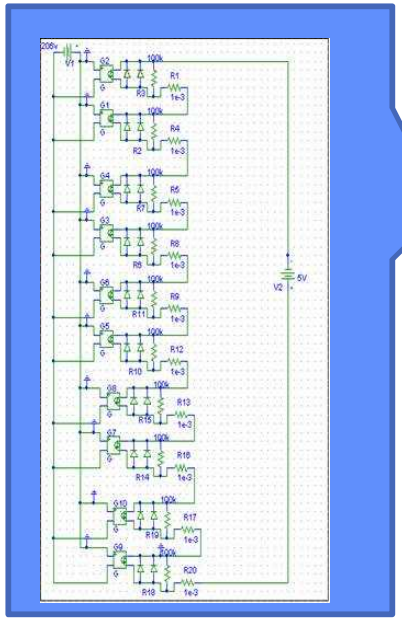
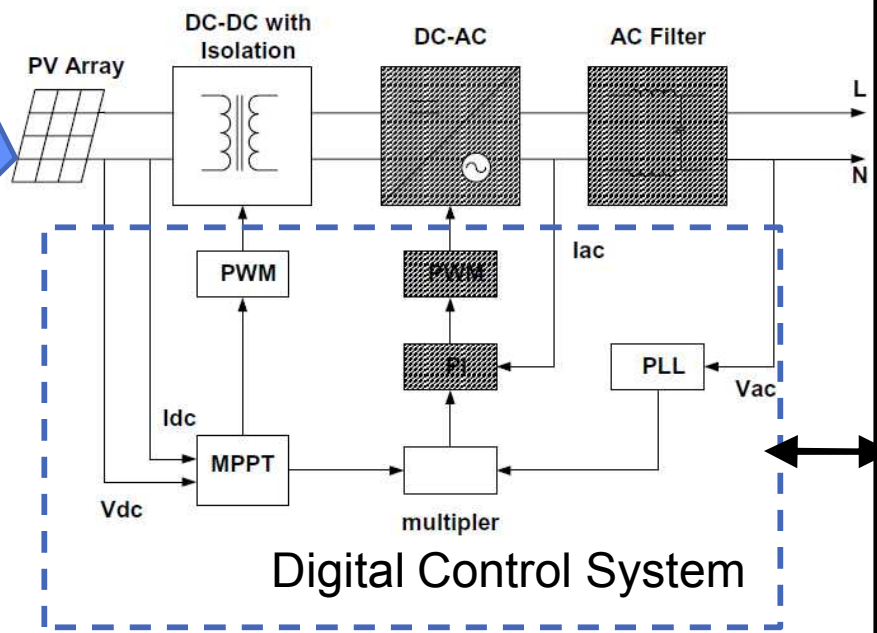
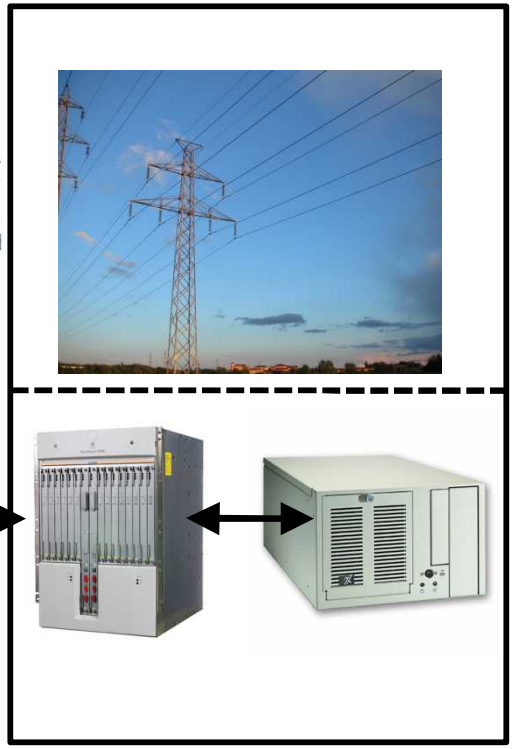
Transient Dynamic Analysis of Renewable Energy Sources

- Impact of distributed energy sources on the electrical grid
- Improved design and integration of distributed energy sources



PV Array Model





Detailed physics based digital/analog simulation

SmartGrid

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Sandia's Unique High Performance Electrical/EM M&S Capabilities

Computing Hardware

TLCC
272 compute nodes or 4,352 processor cores
2.2 GHz AMD quad socket/quad core processors
32 GB DDR2 RAM per node
8.7 Terabytes of total RAM
38 TeraFlops of Sandia computing power/installation
3 Sandia installations

Thunderbird
Sandia's largest capacity cluster.
4,480 compute nodes
Dual 3.6 GHz Intel EM64T processors
6 GB RAM/node

Electrical/EM Modeling and Simulation Codes

Habanero – Mixed Signal Simulations (Digital/Analog)
Xyce – Circuit Simulations
Emphasis – Time domain EM simulations
Eiger – Frequency Domain EM Simulations

Circuit Modeling

Transient Dynamic Modeling
Functional Performance Evaluation
Harsh Environment Performance Modeling
Aging Electronics
Sensitivity and Margin Analysis
Mixed Signal Simulations (Digital/Analog)
Physics Model Abstraction

Device Modeling

Diode
Passives
Transformer
Parasitics
Parasitic Extraction
Model Validation
Transistor (MOSFET/BJT/JFET/Power)
Digital Models (Verilog/VHDL)
Parameter Extraction
Device Environmental Interactions
Aging Effects (Device/Board/Assembly)

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Conclusions

- Sandia has the tools and expertise to enable Smart Grid Development
  - Parallel electrical modeling and simulation for large scale problems
  - Physics based models
  - Analog/digital capability in one simulator
- Sandia is a National Laboratory that can work with private industry, universities, and other government agencies

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