# California Energy Commission
# PIER
# Smart Grid Roadmap Study
# May 14, 2009




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KEMA Inc, Oakland, CA

## Project Scope and Contents

- Steps in Project
  - Market Analysis of Smart Grid Technologies
  - Trends Analysis
  - Growth Patterns
  - Market Factors  Affecting Market Development
  - Regulatory Issues Affecting Market Development
  - Design (Technical) Factors Affecting Market Development
  - Analysis of Relationship of Renewables Penetration to Smart Grid Technologies
  - Gap Analyses and R&D Recommendations / Prioritization
- What is “Smart Grid” in Project Context?
  - Transmission:  Phasors, FACTS devices, new technologies, Substation Automation
  - Distribution:  Substation and Distribution Automation; Advanced Planning and Engineering Software; Communications
  - Storage
  - Advanced Metering
  - Home Automation; Building Automation; Distributed Renewables; Distributed Storage
  - Renewables Integration – Planning, Operations, Markets

## Facilitating Renewables Penetration

- Reduce Capital Costs
  - Interconnection
  - Capacity Ratios
- Renewables Operating Economics
  - Market Participation
  - Reduced T&D Costs
  - Reduced Output Limits/Curtailments
- Facilitate Interconnection
  - Bidirectional distribution circuits
  - System Reliability Issues
- Power System Capital Costs
  - Transmission Expansion
  - Distribution Capacity
  - Conventional Generation (Back up, ancillaries)
- Wholesale Economics
  - Congestion Costs
  - Losses
  - Capacity Payments
  - Generation Capacity
  - Energy Prices
- Functional Value to Consumer
  - Reduced Energy Prices
  - Less Inconvenient Demand Management
  - Improved Reliability



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## Smart Grid Tactics for Facilitation

- Visibility of Renewable Production
- Visibility of Renewable Capacity
- Control of Renewable Production
- Dispatchable Renewables
- Balancing / Levelizing Renewable Production
- Green PHEV Charging
- Improved Circuit Ratings
- Improved Volt / Var Coordination
- Enable Hourly Pricing
- Behind the Meter Demand Integration
- Behind the Meter Renewables Integration
- Increased Demand and Renewables Participation in Markets
- T&D Asset Management
- Distribution Reliability Improvements
- Transmission Reliability Improvements



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# Smart Grid Technologies to Support Tactics

- Intelligent Electronic Devices
  - Phasor Measurements
  - Bidirectional Protection and Control
- Application Support Systems and Software
  - Transmission Operations
  - Distribution Planning
  - Distribution Operations
  - Advanced Asset Management
- Substation and Feeder Automation and Communications
  - Incorporate Variability and Bidirectional Operation
  - Substation Storage
- Electricity Storage
  - Grid Connected
  - Distributed / Community Storage
  - Behind the Meter Storage
  - Storage at Large Central Renewable Sites
- Building Automation
  - Autonomous Demand Response
  - Integrated Renewables and Storage Control
- Home Automation
  - Behind the Meter Renewables Integration
  - PHEV Charging
  - Low Voltage Wiring
  - Smart Appliances
- PHEV Integration
  - Managed Charging
  - Meter on the Vehicle
- Grid Stabilization
  - Synthetic Inertia
  - Synthetic Governor Response



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# Renewables Facilitation Objectives – Smart Grid Tactics

| Smart Grid Renewables Facilitation Matrix | Renewables Facilitation Objectives ↓ | Smart Grid Tactical Objectives • → | Facilitation Objective Rank > | | Visibility of Renewable Production | Visibility of Renewable Capacity | Dispatchable Renewables | Control of Renewable Production | Balancing / Leveling Renewable Production | Green Charging PHEV Integration | Improved Circuit Ratings | Improved Volt/ Var Control | Enable hourly pricing | Behind the Meter Demand Integration | Behind the Meter Renewables Integration | T&D Asset Management | Distribution Reliability | Transmission Reliability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reduce Renewables Capital Costs | Interconnection Costs | | Ref | | | | | | | | | | | 27 | | | 32 |
| | | Capacity Ratios | | Ref | 1 | 7 | | | 16 | 24 | | | 20 | | | | | |
| | Improve Renewables Operating Economics | Market Participation | | Ref | 2 | | 20 | 10 | | | | | 21 | 26 | 27 | | | |
| | | Reduced T&D Losses | | Ref | 3 | | 20 | | | | 18 | 19 | | | | 28 | | |
| | | Reduce Limitations on Output | | Ref | | | 20 | | 16 | | 18 | | | | | | | |
| | Facilitate interconnection | System Reliability | | Ref | 4 | 7 | | 11 | | | | | | | | 28 | | 30 |
| | | Bidirectional Flow | | Ref | 5 | | 21 | 12 | | | | | | | | | | |
| | System Capital Costs | Transmission expansion | | Ref | 6 | 8 | 22 | 13 | 17 | | 18 | | 22 | | | 28 | | 30 |
| | | Distribution Capacity | | Ref | 6 | 7 | | 13 | | | | 19 | | | 27 | | | |
| | | Conventional Generation | | Ref | | | 22 | | | | | | | | | | | |
| | Indirect Wholesale Power System Economics | Congestion costs | | Ref | | | 23 | 14 | 19 | | 18 | | | | | | | |
| | | Losses | | Ref | | | | 14 | | | | | | | | | | |
| | | Capacity Payments | | Ref | | | 23 | | | | | | | | | | | |
| | | Generation Capacity | | Ref | | 9 | | | | | | | | | | | | |
| | | Energy Prices | | Ref | | | 23 | | | 24 | | | | 26 | | | | |
| | Functional Value to Consumer | Reduced Energy Costs | | Ref | | | | | | 25 | | | 23 | 26 | | | 29 | |
| | | Less Inconvenient Demand Management | | Ref | | | | | | 25 | | | 24 | 26 | 27 | | 29 | |
| | | Improved Reliability | | Ref | | | | | | | | | | | | | 29 | |

Cells link to description/exposition and to Rankings



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# Smart Grid Tactics - Smart Grid Technologies

| | CEC Renewable Categories | Smart Grid Technologies | Smart Grid Tactical Objectives → | | Viability of Renewable Production | Viability of Renewable Capacity | Dispatchable Renewables | Control of Renewable Production | Balancing / Leveling Renewable Production | Green Charging PHEV Integration | Improved Circuit Ratings | Improved Volt/ Var Control | Enable hourly pricing | Behind the Meter Demand Integration | Behind the Meter Renewables Integration | Increased Demand and Distributed Renewables Participation in Markets and Operations | T&D Asset Management | Distribution Reliability | Transmission Reliability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Smart Grid Renewables Facilitation Matrix | Categorized as Integration | IEDs | Wide Area PMU Score = | Ref | | | | | | | | | | | | | | | |
| | | | BiDirectional Protection | Ref | | | | | | | | | | | | | | | |
| | CEC Trasnmission & Distribution Category Area | Application Support Systems | Distribution Planning | Ref | | 6 | | | | | | | | | | | | 47 | |
| | | | Transmission Operations | Ref | 1 | 6 | 9 | 15 | 20 | | 31 | 32 | | | | 40 | | | 51 |
| | | | Distribution Operations | Ref | 1 | 6 | 9 | 15 | 20 | | | 32 | | | | | | 47 | |
| | Categorized as Integration | Building Automation | Auto-DR | Ref | | | | | | | | | | 24 | | 41 | | | |
| | | | Integrated Renewables Control | Ref | 2 | 6 | 9 | 15 | 20 | | | | | 24 | 38 | 41 | | | |
| | | | Integrated Storage Control | Ref | | | | | 23 | 27 | | | | | 38 | 41 | | | |
| | CEC Consumer Category Area | Home Area Networks | Behind the Meter Generation | Ref | 3 | 7 | 10 | 16 | 21 | | | | | 56 | 39 | 42 | | | |
| | | | PHEV Charging Control | Ref | | | | | | 27 | | | 55 | 54 | | 42 | | | |
| | | | Smart Appliances | Ref | | | | | 21 | | | | 55 | 54 | | 42 | | | |
| | | | Low Voltage DC Wiring | Ref | | | | | | | | | | | 60 | | | | |
| | CEC Distribution Category Area | Feeder & Substation Automation and Communication Systems | Incorporate Variability | Ref | 4 | 8 | 11 | 17 | 22 | | | | | | | | | | |
| | | | Substation Storage | Ref | | | 11 | | 22 | 27 | | | | | | | | | 53 |
| | | Functional Value to Consumer | Incorporate BiDirection | Ref | 4 | 8 | | | | | | | | | | | | 47 | |
| | | | Advanced Asset Monitoring | Ref | | | | | | | | | | | | | 46 | 48 | 52 |
| | CEC Trasnmission & Distribution Category Area | Electricity Storage | Behind the Meter Storage | Ref | | | 12 | | 23 | 27 | | | | | | 43 | | | |
| | | | Community Distributed Storage | Ref | | | 12 | | 23 | | | | | | | 43 | | 49 | |
| | | Functional Value to Consumer | Grid Connected Storage for Operations | Ref | | | 12 | | 23 | | 23 | | | | | | | | 53 |
| | | | Storage at Large Scale Renewable Generation | Ref | | | 12 | | 24 | | | | | | | | | | |
| | CEC Consumer Category Area | Vehicle to Grid (V2G) | PHEVBreen/Managed Charging | Ref | | | 13 | | 25 | 27 | | | | | | 44 | | | |
| | | Functional Value to Consumer | Meter on the Vehicle | Ref | | | 13 | | 25 | 27 | | | | | | 44 | | | |
| | Not Categorized by the CEC | Distributed Resources | Synthetic Inertia / Governor Response | Ref | | | | | | | 33 | 33 | | | | | | | 53 |
| | | | BiDirectional Protection | Ref | | | | | | | | | | | | | | 50 | |

Cells link to description/gap analyses and to Rankings



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# R&D Initiative – High Speed Grid Reliability Enhancement

## Vision

**High Speed Monitoring and Control of Grid to Enhance System Stability and Robustness**

## Issue

- High RPS alters system dynamics in a fundamental way, especially when fewer conventional generators are on line
  - lack of inertia and governor response, different excitation; different locations of renewables.

## Technologies

- Synchrophasors and high speed wide area networks
- Integrated control of high speed system resources (inverter based renewables and large scale fast grid connected storage)

## Research & Development

- Grid dynamics under high RPS
  - Definitive studies on stability impacts of high RPS levels
  - Control algorithms and technologies to utilize high speed resources for stabilization
  - Analysis of where to deploy high speed resources
  - Visualization concepts and technologies
  - New algorithms for dynamic grid control and stabilization



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# Renewables and Dynamic Performance

## Vision

**Renewables provide dynamic performance to assist in system stability and control**

## Issue

- Inverter electronics lack inertia, governor response, excitation control for stability

## Technologies

- Power electronics and control algorithms
  - o Synthetic voltage dynamics, governor response, inertia

## Research & Development

- Power electronics and control algorithms to achieve synthetic excitation stabilization, inertia, governor response
- System performance under high RPS
  - o With and without dynamic performance
  - o Integration with wide area PMU based stability augmentation



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# Electricity Storage

## Vision

**Storage is located throughout the electric infrastructure to support renewables penetration in terms of reliability, economics, operations, and deferred capital. Appropriate storage technologies are integrated in light of applications.**

## Issue

Regulatory Treatment of Storage & Asset Classification

Matching Technologies to Applications

Deployment and Control Strategies Linked to Renewables

## Technologies

Market and Operations Analysis and Simulation

Existing and Developing Storage Technologies, Capabilities, and Economics

## Research & Development

- Modeling and analysis to determine how much storage is required/necessary to support California renewable goals
- What role will storage play in helping the state achieve zero net energy residential and commercial new construction goals
- What are appropriate regulatory, market, and incentive treatments to encourage storage in support of renewables?
- Identifying the control technologies and algorithms necessary to ensure storage can seamlessly work with Wind, Grid requirements when integrating CA renewables to the electricity grid
- Continued investigation of emission benefits of storage technologies – i.e. Commercial & Industrial uses
- When storage is used in a multi-purpose application (as at a substation) how to allocate costs and benefits for cost recovery?



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# Distributed Renewable Resources

## Vision

**Distributed renewables are dispatchable to provide system operations flexibility and are capable of participating in energy markets; allocation of costs and benefits (especially capital deferral) reflects the full value of renewable resources to the grid**

## Issues

- Requirement needs for dispatchable DG
  - Communications
  - Controls
- Tariff structures
- Metering
- Integrating advanced inverters

## Technologies

- Storage – DG configurations
- Utilizing internet-Wifi for transferring energy information and energy management
- IEDs
- Next Generation inverters
- HAN and BAS with integrated demand response

## Research & Development

- Renewable controllability/renewables and storage
- Demonstrating residential solar-storage applications and testing of dispatchable, guaranteed responses.
- Low cost communications and control
- Market protocols for forecasting, scheduling, integration and capacity, metering standards
- Metering strategies and tariff structures that will facilitate increased penetration of renewables, enhanced DR capability and improved ability to achieve statewide zero net energy goals
- Demand forecasting and elasticity R&D



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# Green Charging

## Vision

**PHEV and EV owners can enroll in green charging that matches vehicle charging to specific renewable power production and obtain incentives, RECs and tariffs that facilitate enhanced renewable penetration**

## Issues

- PHEV and EV load is behind the meter
- Currently no separate measurement and control
- PHEV and EV mobility
- Back office billing and settlement

## Technologies

- Wireless Internet and GPS
- Metering on vehicles
- Cloud computing
- HAN with integrated demand response

## Research & Development

- Vehicle metrology and applications
- Market/rate structures
- Separate settlements process



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# Flexible Distribution Circuits

## Vision

**Distribution circuits capable of supporting high RPS will require adaptive protection, automation and the possibility for bidirectional flows and ability to adapt to high variability**

## Issue

- Current engineering, protection, and operations are non-adaptive and provide for radial flows only

## Technologies

- Distribution automation
- Intelligent Electronic Devices
- Substation automation
- Stochastic circuit analysis for planning and operation

## Research & Development

- Cost benefit analysis of bidirectional flow
- Analytics for planning and operations
- Software upgrades to field devices (IEDs)
- Communications



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# Price Responsive Load
# (Dynamic Pricing or Time Variant Pricing)

## Vision

**Building Automation Systems (BAS) in commercial buildings and residential Home Area Network (HAN) systems can interact with hourly prices to create demand price elasticity in the markets**

## Issues

- Lack of market protocols
- Difficulties in forecasting
- Lack of BAS / HAN applications support
- Communications and Settlements
- Rate Structures
- Device Compatibility and Interoperability

## Technologies

- Internet
- Device Networking
- Local optimization devices

## Research & Development

- Econometrics and forecasting
- Market structures and mechanisms
- Elasticity metrics
- Optimization strategies
- Time Variant pricing strategies to harness power of distributed generation resources
- Uniform definitions of device object and attributes and binding rules



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# Home Automation Networks and DC Power Distribution

## Vision

**Future Zero Net Energy Buildings will have low voltage DC wiring linked to Distributed Renewable generation and storage – role of 120/240 V AC is limited to grid interconnection**

## Issues

- Eliminate conversion losses and stand-by demand
- More “natural” for distributed renewables
- Lack of standards for commercial lighting / electronics today

## Technologies

- LED Lighting
- Solid state low voltage protection / controls
- Electronics with standard DC supplies

## Research & Development

- Standards (UL, Building Code, electronics industry)
- Cost benefit analysis considering future electronics products and pricing and any new / existing construction costs
- DC motor and drives in larger appliances
- Transition of HAN communications to DC wiring base, Low Voltage DC PLC
- Embedded revenue grade metering and home area network connectivity in large appliances
- Software defined radios and agile frequency transceivers for HAN Gateways



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## Prioritizing R&D Objectives

- KEMA Assessment Provides a First Pass at Prioritization
- Stakeholder Workshops Utilizing the Matrix Artifact a Possibility
  - Prioritize Renewable Facilitation Objectives
  - Prioritize Impacts of Smart Grid Tactics on Faciliation Objectives
  - Prioritize Impacts of Smart Technologies on Tactics
  - Compute Technology Rankings as Prioritization