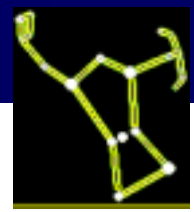
NREL



Distributed Energy Neural Network Integration System (DENNIS™)

Subcontract Number: AAD-0-30605-07

Principal Investigator: Thomas Regan

NREL Technical Monitor: Holly Thomas

Electric Distribution Transformation Program

2004 Annual Program and Peer Review Meeting,
October 28-30, 2003, Coronado (San Diego), California

Program Objective

- Integrate intelligence and control:

  "Next generation" technology for autonomous and distributed control for safe, reliable, optimized DG interconnection and dispatch in a wide range of operating conditions.

- Demand response: Demand-side management with autonomous "command and control logic" managing integrated DER for efficiency, meeting demand and market signals.

Why DENNIS™ and Why Now?

"We foresee a world of cleaner, smaller and more efficient units of power generation. We foresee more individual choice, more competition, and a closer approximation of a true market for energy in America. And we foresee increased reliability, increased supply, and lower prices."

Energy Secretary Spencer Abraham, July 26, 2001

DENNIS® provides the distributed intelligence needed to aggregate and dispatch large numbers of small DER. Through an integration strategy based on discretionary control, DER owners retain operational control at all times.

DISTRIBUTED ENERGY = ENERGY SECURITY

What is DENNIS™?

- OEC is developing DENNIS™, a neural network based on the Adaptive Resonance Theory (ART) capable of monitoring a group of signals and patterns to produce a pattern memory.
  - Signals include: weather, load, demand and generation capacity.
- Additional opportunities exist with combined heat and power applications from thermal load monitoring.
- DENNIS™ will optimize costs to determine whether to purchase from the grid, produce electricity on-site or send generation to storage for expected loads.
- DENNIS™ will determine the best method(s) to maximize the benefits to the generator, rather than the central utility.

Project Relevance – Identified Needs

(per Vision and Roadmap documents)

- Develop interconnection designs for connection of any device to a network incorporating safety, control and transactions management
- Ability to respond to the market signals, manage demand
- ‘Smart’ technology - intelligence and control technologies that integrate distributed resources into the electrical distribution system.

How can DG get fair market value pricing?

- Avoided cost and net metering models currently don't provide rates to make DR economically viable for mini-grids and distributed ad hoc grids.

- Intelligently integrate DR into grid
  - adaptable, knowing when to sell /store energy (if site has ability)
  - match generation to loads
  - aggregate small blocks of power production into blocks large enough to make and place bids to ISO-type entity.

Technical Approach

- Demonstrate DENNIS^{TM} capabilities utilizing the facilities at the University of Massachusetts Lowell (UML) Center for Energy Conversion (CEC).
- Transfer and implement developed software on distributed beta test sites.
- Develop an economic model/analysis of the potential impact of our method for aggregating and managing distributed power.
- Establish industrial contacts and relationships to allow effective product transfer into residential and business sectors.
- Demonstrate an integrated hardware/software product for commercial viability.
- Inform and demonstrate to the commercial community the potential of a “new business” in DENNIS^{TM} based generation communities or mini-grids.

Technical Approach (continued)

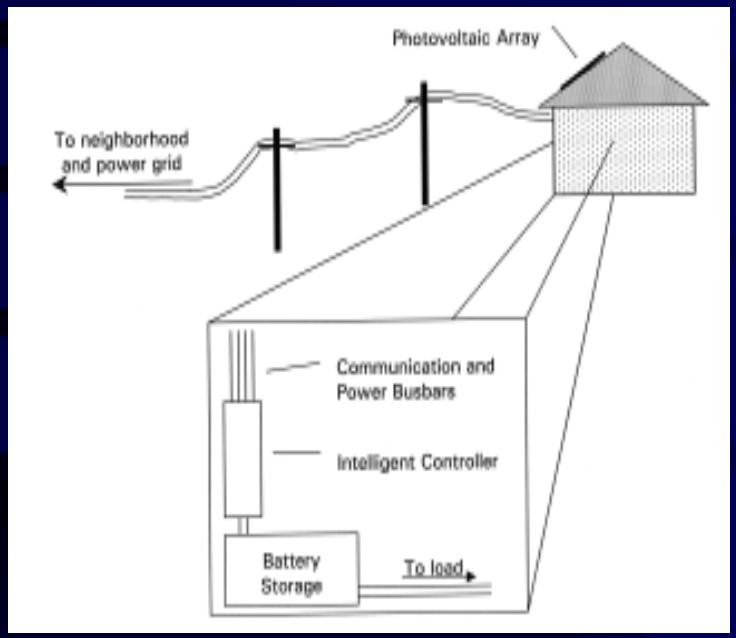
- Planned 3-phase project to develop a controller for small generators and demonstrate ability for a group of controllers to operate through the use of neural networks and fuzzy logic.
  - Providing smart, technologically sophisticated, simple, efficient and economic solution.
  - aggregates a community of small distributed generators into a virtual single large generator capable of selling power internally or externally to a utility, ISO or other entity, in a coordinated manner.
- Result – intelligent energy integration product for residential and commercial distributed generation applications.

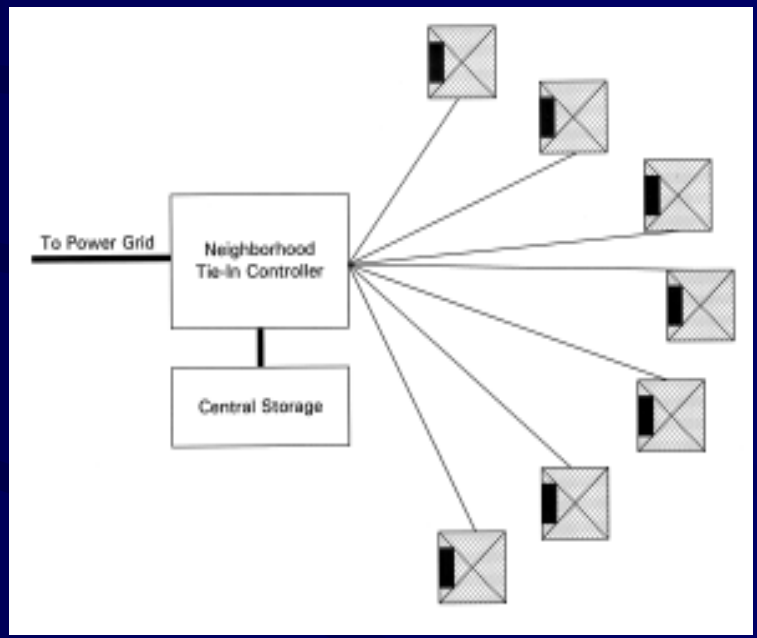
Technical Approach (continued)

How is DENNIS™ structured?

- A local generation controller interacts with larger group of controllers through neural network for a self-assembled, virtual neighborhood utility or mini-grid.
- Technologically-sophisticated programming of the DENNIS™ controller to optimize energy transactions on behalf of user with little effort from user.
- Simple, efficient and economic way to aggregate a community of small distributed generators into virtual single large generator to a utility or ISO.
- ***www.virtualgenerator.com*** links to the DENNIS™ pages of our web site.

DENNIS™ Block Diagram





Bulk Integration of DER

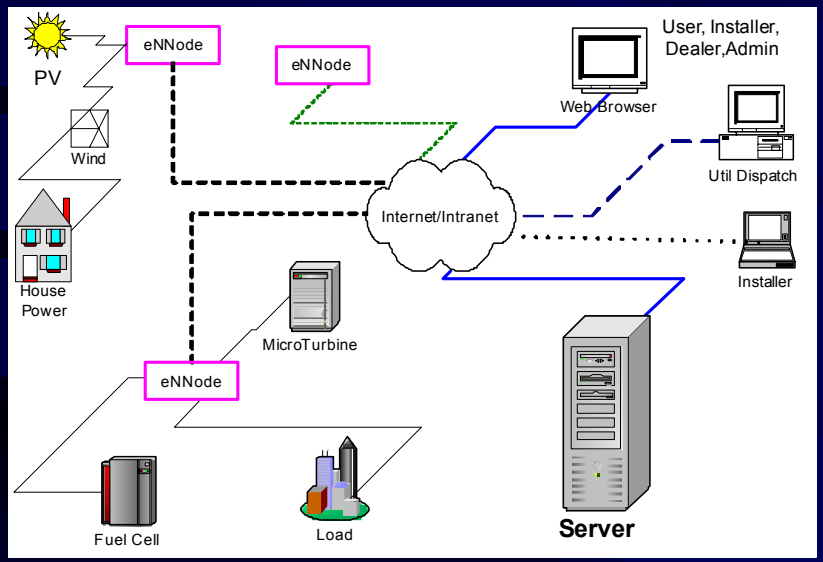
- Integrating small numbers of DER traditionally by simple on/off electronic controls or verbal requests to DER owner.
  - Not possible when DER scales to hundreds or thousands of units such as mini-grids.
- DENNIS™ an effective, scaleable solution
  - Distributed intelligence provides a more **secure** and **robust** bi-directional grid.
  - Management at DER level provides distribution support-demand side management
- Neurofuzzy logic learns and adapts to changing generation and usage patterns for optimal dispatch.
  - Intelligent controller proactively stabilizes real-time demand.
- DENNIS™ uses real-time pricing linked to demand makes economic decisions based on market signals

OEC Solution: DENNIS

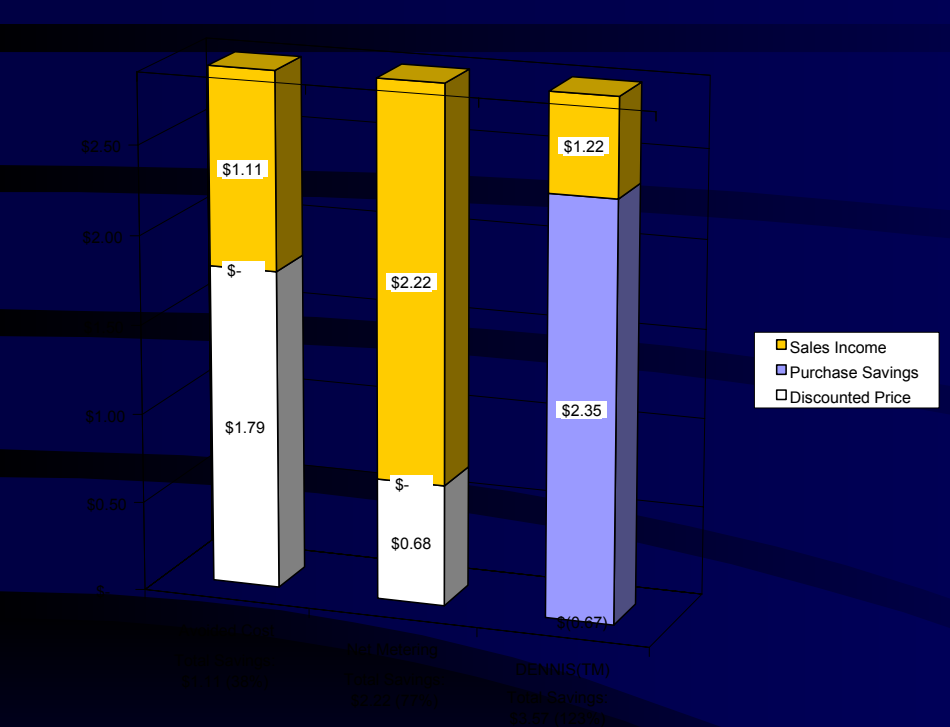
- Distributed Energy Neural Network Integration System (**DENNIS**™)
- DENNIS™ manages generation dispatch/distribution, not load!
  - Sites need an adaptive controller that predicts and manages the distributed energy generation capacity and power consumption
- Monitors weather, load, demand, market price and generation capacity.
- Capable of optimizing to a single user or to a larger group (mini-grid) utilizing real-time pricing.
- Provides ancillary benefits including voltage support and stability, contingency reserves, and black start capability.

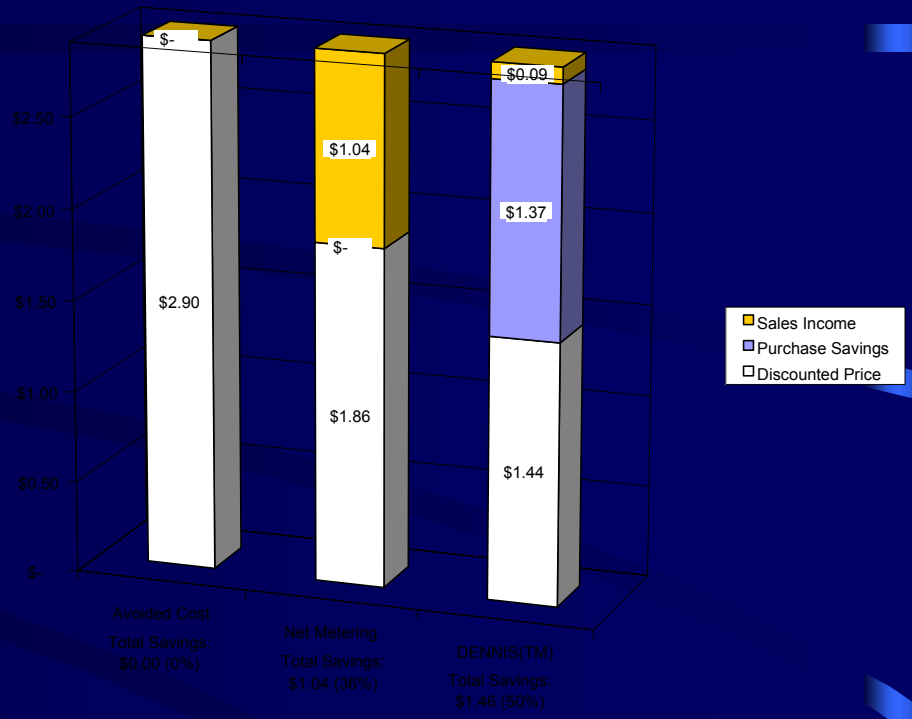
Current Results

Low-Cost Hardware and Operating Platform



Initial Economic Results

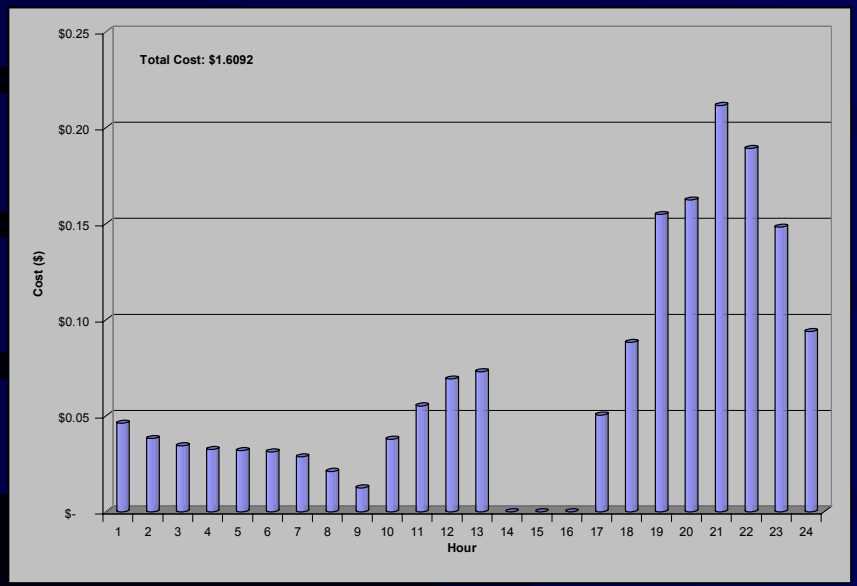


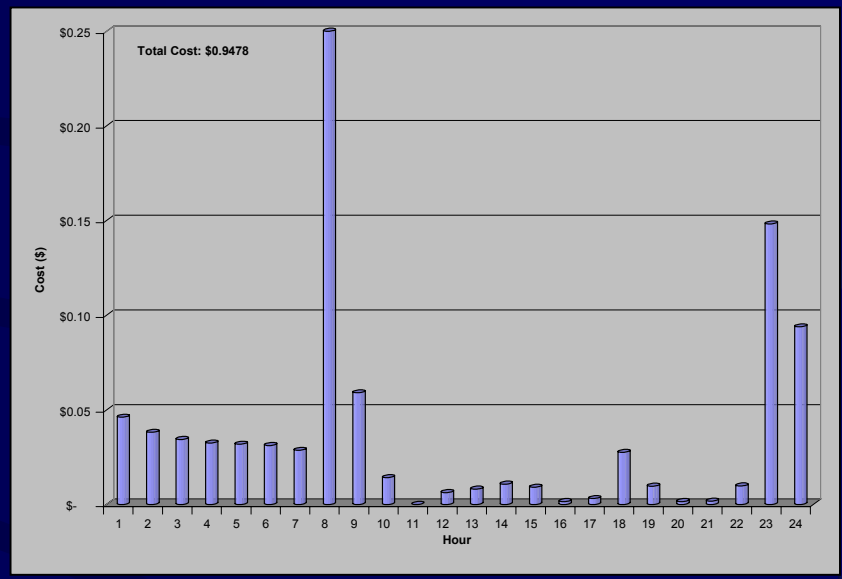


DENNIS® Savings: 90% to 125%
–35% Better Than Net Metering
–75% Better Than Avoided Cost

DENNIS® Savings: 50%
–15% Better Than Net Metering
–100% Better Than Avoided Cost

DENNIS™ Optimal Household Cost with PV





Default Operating Cost of a Household with Photovoltaic Generation on a Rainy Day

Optimal Cost for Household with Photovoltaic Generation and Storage on a Rainy Day

Life-Cycle Project Timeline

Task Schedule

Task 1 – Data Reduction and Analysis
Task 2 – Power Electronics
Task 3 – Fuel Cell Characterization and Integration
Task 4 – Power Quality Study and Control Switches
Task 5 – Pattern Database & Pattern Recognition
Task 6 – Control Law Generator
Task 7 – Preliminary Economic Analysis and Market Assessment
Task 8 – Control Site Development and Monitoring
Task 9 – External Site Deployment and Monitoring
Task 10 – Data Reduction and Economic Analysis
Task 11 – Utility Integration and Development
Task 12 – Neighborhood Controller Technology Assessment
Task 13 – Utility Integration and Technology Transfer
Task 14 – Controller Site Monitoring and Optimization
Task 15 – Expanded Controller Deployment and Monitoring
Task 16 – Data Reduction and Economic Analysis
Task 17 – Neighborhood Controller Field Testing

Life-Cycle Project Budget (continued)

Budgets	Total ($K)	DOE/NREL($K)	Subcontractor ($K)
Base Year (9-00 to 6-02)	284	170	114
Option Year 1 (6-02 to 07-03)	240	140	100
Option Year 2 (08-03 to 10-04)	244	142	102
Total	768	452	316

FY03 Progress and Accomplishments

- Completed:
  - Upgraded web communications with 3 remote test sites to post system status and site conditions.
  - Implemented FUZZY DENNIS™ at the UMLCEC
  - Developed innovative market strategy and strategic partnering plan with novel market development approach
  - Presented concepts seeking Venture Capital to enhance product development.
  - Initiated relationship with hardware developer capable of providing hardware and communications needed DENNIS™

Planned Activities for FY04

- D-2.6 Benchmarking of controller performance
- D-2.7 Complete revised economic analysis detailing saving potential for aggregation method.
- D-2.10/11 Option year One Final Report
- Partial Funding in FY04 is targeted at completing the following deliverables:
  - D-3.1 Initial partnering and technology deployment plan
  - D-3.2 Report of compiled data from external controller deployment
  - D-3.3 Pilot-scale test bed technology deployment plan
  - D-3.4 Report of commercially-available switchgear technology and acquisition plan

Deliverables for Full Funding (Unfunded Portion of Option Year Two)

- D-3.5 Report describing installation of controller units and data acquisition system
- D-3.6 Report detailing rule set and test plan for neighborhood controller integration
- D-3.7 Report of final economic model, including improved assessment of aggregated controller behavior
- D-3.8 Long-Term Partnering and Technology Deployment Plan
- D-3.9 Report of results of neighborhood controller integration testing
- D-3.10 Monthly Progress Reports
- D-3.11 Draft Annual Technical Progress Report
- D-3.12 Final Annual Technical Progress Report

Impacts and Benefits

- Technology will provide a needed solution to cost effectively integrate extremely large numbers of small distributed energy resources onto the grid
- Target price of hardware is below $200 per unit with monthly kW/h generation control fees.
- Allow new commercial to make significant inroads into markets previously limited to power generation companies.
- Can provide distribution management tool through market signals
- Stand alone intelligence allows system to continue optimal operation in the absence of grid power providing energy security/resilience to users.

Interactions & Collaborations

- University Partners:
  - University of Massachusetts Lowell
  - Boston University
- Industrial Collaboration
  - InterGrid, LLC
    - Submitted ACCP proposal utilizing Intergrid hardware with DENNIS™ overlayed to provide distributed intelligence.
  - Other participants
    - Plug Power, Beacon and National Grid

Conclusions

- Infrastructure investments and upgrades completed.
- Command, Control and Coordination algorithms coded and tested.
- Tested and evaluated beta versions of DENNIS™ utilizing the facilities at the University of Massachusetts Lowell CEC. Results yielded economic return that exceeded all other current forms of economic dispatch.
- Developed an economic model/analysis of the potential impact of our method for aggregating and managing distributed power. The OEC approach yielded a 35% improvement in return compared to net metering
- Established industrial contacts and relationships seeking additional capital to complete product development to transfer product to commercial and residential markets.