SunShot
U.S. Department of Energy

SHINES Kickoff Meeting 2016

AGENT-BASED COORDINATION SCHEME FOR PV INTEGRATION (ABC4PV)

Awarded to: CMU, NRECA, Aquion Energy

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Project Objectives and Expected Outcomes

- Motivation
- Technical Objectives
- Team
- Approach
- Project Objectives and Anticipated Outcomes
- Project Plan
- Discussion

Motivation

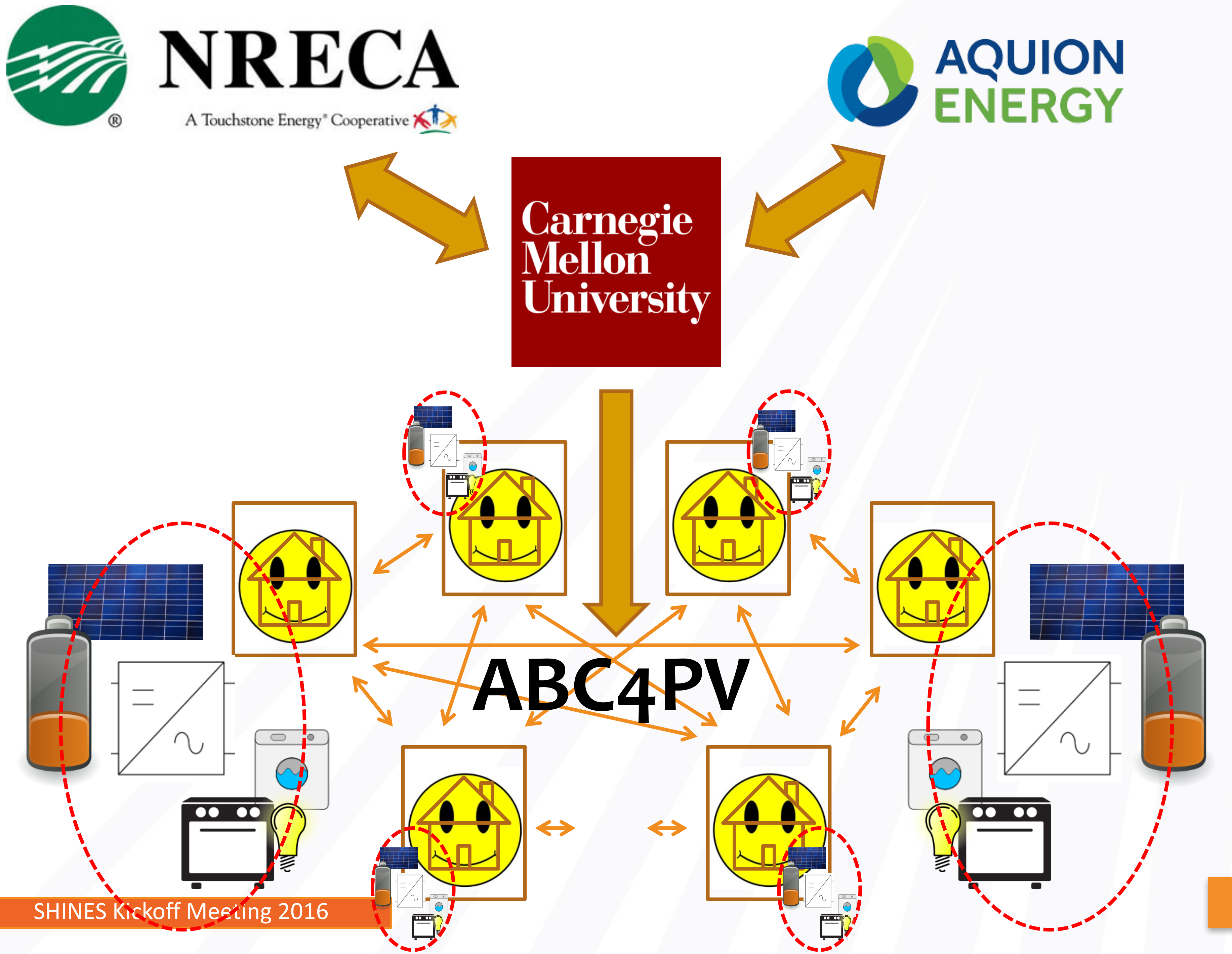
- Increased deployment of solar photovoltaic generators, distributed storage, demand response capabilities
- Distributed approaches as scalable solution for the optimal coordination of these technologies and effective integration of PV systems

⇨ Gap between theoretical approaches and actual application

Need for testbed for distributed algorithms particularly for the application of PV integration and actual implementation of such algorithms in a physical environment

Technical Objectives

- Project Goals
  - Development of distributed algorithm for the coordination of PV arrays, storage, flexible load
    - Extension of existing algorithm to coordination of arrays, storage, programmable thermostats
    - Stability and robust testing of algorithm via simulations
  - Setup of test-bed of 10 PV array + storage systems
    - Installation of physical devices at actual feeder in cooperation with co-op
    - Development of appropriate protocols and cyber tools to ensure interoperability and cyber security
    - Setup of communication network
  - Implementation and testing of proposed distributed algorithm in testbed with respect to robustness, performance and applicability
  - Study impact on storage performance and lifetime in context of the application and use data to improve storage subsystem

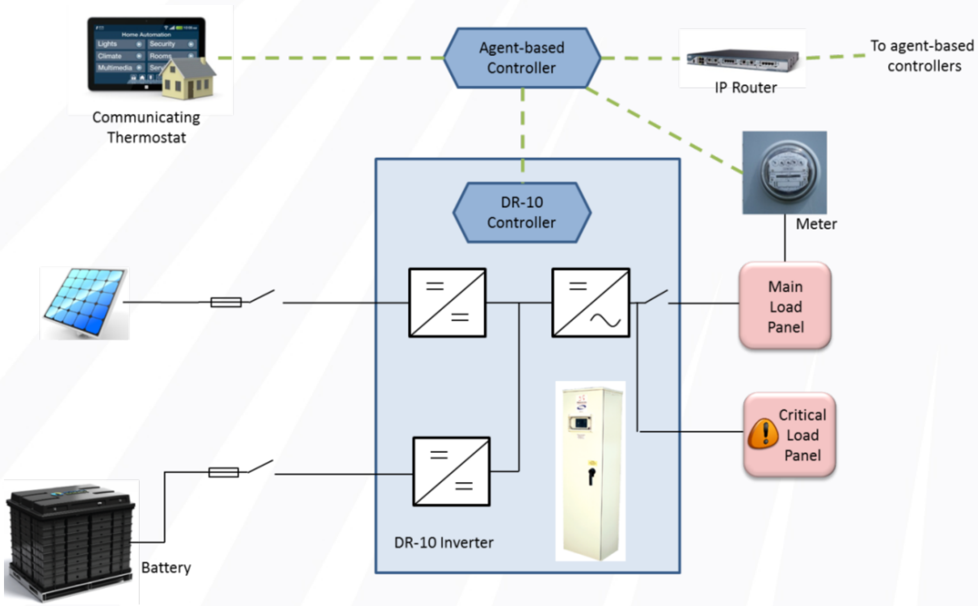

NRECA
A Touchstone Energy® Cooperative
AQUION ENERGY
Carnegie Mellon University
ABC4PV

Team

- CMU (Soummya Kar, Gabriela Hug, Jose Moura, Panayiotis Moutis, Jay Whitacre)
  - Operating control framework
  - Efficacy assessment (simulations & software implementation)
- NRECA (Craig Miller, Doug Danley, David Pinney)
  - Testbed development
  - Standardization of unit equipment
- Aquion Energy (Tom Madden, Tom Jackson)
  - Battery storage system physical integration and optimization

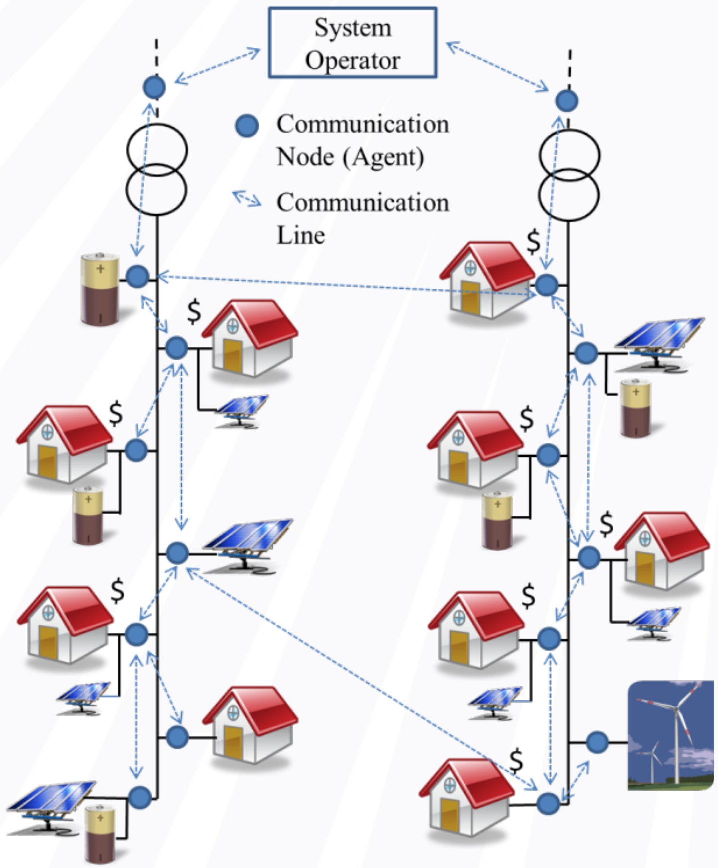
Approach: Unit-based integration and abstraction

- Schematic of ABC4PV unit
  - Unit subsystems deployed throughout feeder
  - Each subsystem consists of PV generator, battery, communicating thermostat and inverter and has communication capabilities



Approach: Inter-unit collaboration

- Agent-based distributed algorithm:
  - Subsystems communicate and share information with each other
  - Limited communication of some subsystems with system operator
  - Computations carried out locally



Approach: Distributed optimization framework

- Form of updates
  - Mathematical formulation based on consensus + innovation approach:

$$\lambda_j^{(i+1)} = \lambda_j^{(i)} - \underbrace{\beta_i \sum_{l \in \omega_j} \left(\lambda_j^{(i)} - \lambda_l^{(i)}\right)}_{consensus} - \underbrace{\alpha_i \hat{d}_j^{(i)}}_{innovation}$$

where λ is the consensus variable and innovation term ensures

$$\sum_{j=1}^{J} \hat{d}_j(\lambda_j) = 0,$$

Considered Application:
Consensus: ensure cost optimality
Innovation: fulfill power balance

⇒ Low computational effort required

Broad Project Objectives

- Integration of PV, storage & load control in a “unit” paradigm
  - Maximize value from integration rather than combinations
  - Modular and plug-in character of paradigm
  - *A priori* employment of common interface and control
- Units to optimize performance locally and/or in coordination
  - Scalable, generic, distributed, risk-aware operation framework
  - Forecast, procure, respond and adapt
- Validate efficacy in simulation environment & actual test bed
  - Extensive analysis and benchmarking on multiple platforms
  - Cyber-security assessment
  - Test-bed of 10 units in an actual coop network

Anticipated Outcomes

- Key Project Products
  - Test bed consisting of feeder with 10 solar and storage combinations including communication capability among these devices
  - Mathematical formulation of distributed algorithm for the optimal coordination of PV systems, distributed storage and demand side management participants and its implemenation in test bed
- Major Outcomes:
  - Pathway towards efficient integration of up to 100% solar generation at a feeder by the means of distributed coordination of flexible demand and storage
  - Functioning testbed for distributed algorithms for the coordination of PV, storage and flexible demand

Project Plan

- Distributed Control Methodology
  - Design and Development of Distributed Resource Coordination and Control Methodology (Years 1, 2)
  - Software Implementation of Algorithms (Years 1, 2)
  - Cybersecurity Assurance (Years 1, 2, 3)

- Testbed Development
  - Installation of Physical Components and Test-bed Setup (Years 1, 2)
  - Performance Testing in Test-bed (Years 2, 3)

- Functional and Economic Assessment and Optimization
  - Value of Solar (Years 2, 3)
  - Value of Storage (Years 2, 3)
  - Energy Storage Sub-System and Full System Assessment and Control Optimization (Years 2, 3)

Distributed Control Methodology Development

Task 1: Design and Development of Distributed Resource Coordination and Control Methodology

Subtasks

1. Modeling of Cost/Objective
   - Objective function of the optimization problem
2. Modeling of Constraints (Operational and Uncertainty)
   - Component operation constraints, e.g. min/max inverter power
   - Network constraints, e.g. line loading limits
3. Formulation of Iterative Distributed Control
   - Employ optimization algorithm to the problem
4. Performance Analysis and Real-time Guarantees
   - Benchmarking of convergence and time complexity
5. Simulation of Test-bed

Task 2: Software Implementation of Algorithms

Subtasks

1. Network Design
   - Assessment of candidate feeders for test bed implementation
2. Implementation of Code on Embedded Site Controller and Communication
   - Validate performance of operation framework in simulation
   - Validate performance of operation framework *in situ*
3. Write Host Program to Collect and Format Data

Task 3: Formulation of Iterative Distributed Control

Subtasks

1. Security Design
   - Analysis of cyber-security concerns and suggested measures
2. Secure Software Testing
   - Testing cyber-security performance of developed framework
3. System and In-Situ Testing
   - Cyber-security testing on the test-bed implementation

Testbed Development

Task 4: Installation of Physical Components and Test-bed Setup

Subtasks

1. Identification of Suitable Feeder
   - Promote project to candidate coop feeders
2. Design/Sizing of Devices
   - Determining exactly the components of each unit
3. Initial Deployment and Validation
   - Assessment of unit components (inter-)operability
4. Full Deployment and Validation
   - Unit fine-tuning based on cost assessment and final installation

Task 5: Performance Testing in Test-bed

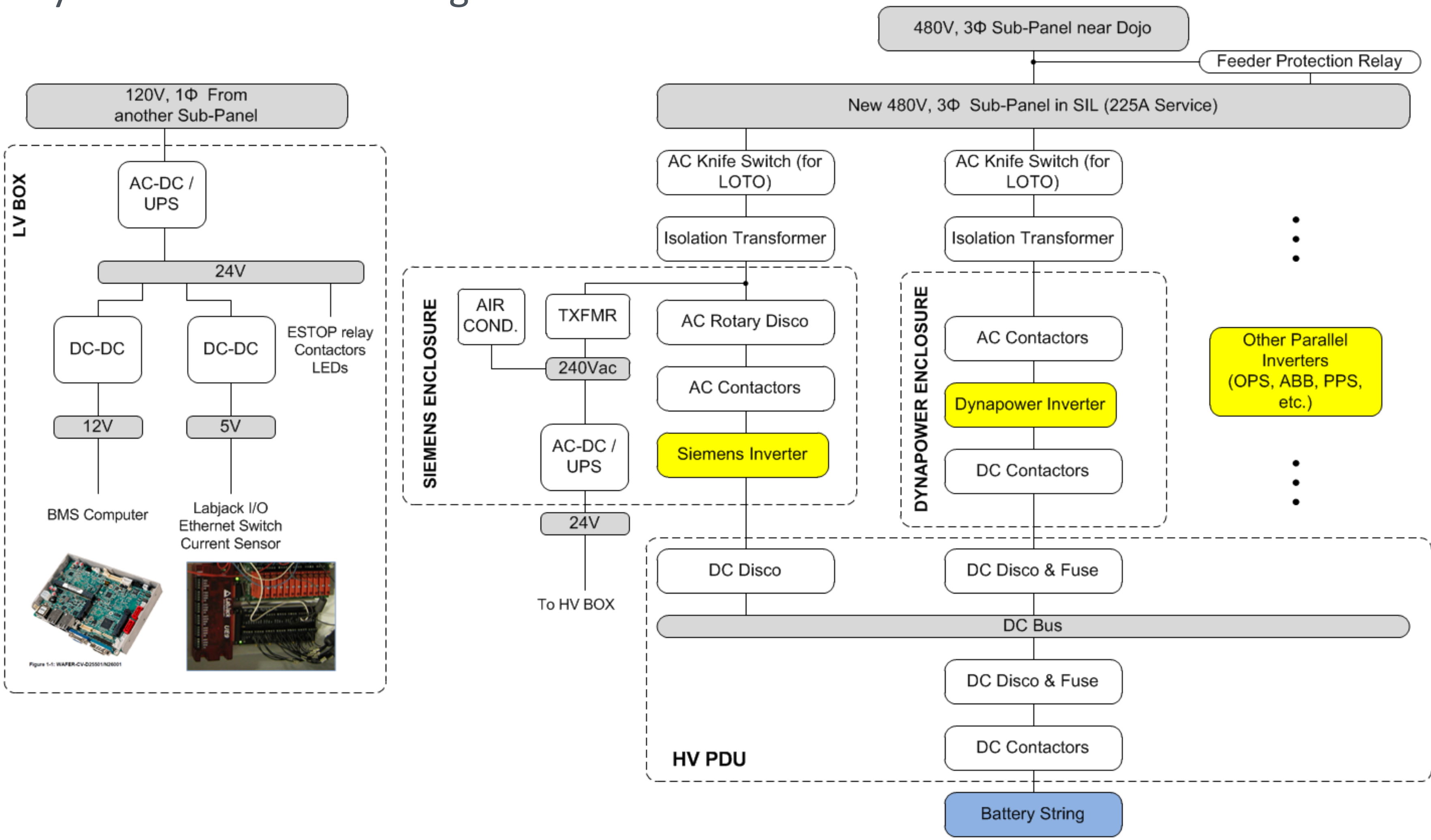
Subtasks

1. Design of Default Operation
   - Strictly local operation according to current practice
2. Normal Operation
   - Assessment assuming no communication failure
3. Performance under Communication Failure
   - Assessment of fail-safe mechanisms
4. Adjustments in Algorithm
   - Fine tuning according to aforementioned assessment in the Task

Initial ABC4PV Unit Setup and Testing: Aquion

Testbed equipment: Aquion

System Power Block Diagram



Task 6: Energy Storage Sub-System and Full System Assessment and Control Optimization

Subtasks

1. Analysis of Performance and Applications Data
   - Assessment of battery data and comparison to lifetime model
2. Follow on Testing/Analysis
   - Update control depending on aforementioned assessment
3. Techno-economic Modeling of Sub-system and System-level Performance
   - All-inclusive and conclusive techno-economic assessment of the project

Questions?