AGENT-BASED COORDINATION SCHEME FOR PV INTEGRATION (ABC4PV)

Awarded to: CMU, NRECA, Aquion Energy
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Project Objectives and Expected Outcomes

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- Technical Objectives
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- 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
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:

\[
\lambda_j^{(i+1)} = \lambda_j^{(i)} - \beta_i \sum_{l \in \omega_j} (\lambda_j^{(i)} - \lambda_l^{(i)}) - \alpha_i \hat{d}_j^{(i)}
\]

where \(\lambda\) 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 implementation 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?