IOWA STATE UNIVERSITY
Department of Economics, Department of Electrical & Computer Engineering

Q14 Report:
Project DE-OE 0000839

Flexible Service Contracting for Risk Management within Integrated Transmission and Distribution Systems

Iowa State University Project Team

PI Zhaoyu Wang & Co-PI Leigh Tesfatsion

Grad Research Assistant: Swathi Battula

DOE Webex Meeting, 31 August 2020

Presentation Outline

- Project goals
- Project publications and reports
- Q14 project task & activities: Summary
- Q14 project task & activities: Details
- Q15 planned activity

Project Goal 1

- **Goal-1 (Done):** Develop an IDSO-managed bid-based *Transactive Energy System (TES)* design (Refs. [2,3,5,6,8])

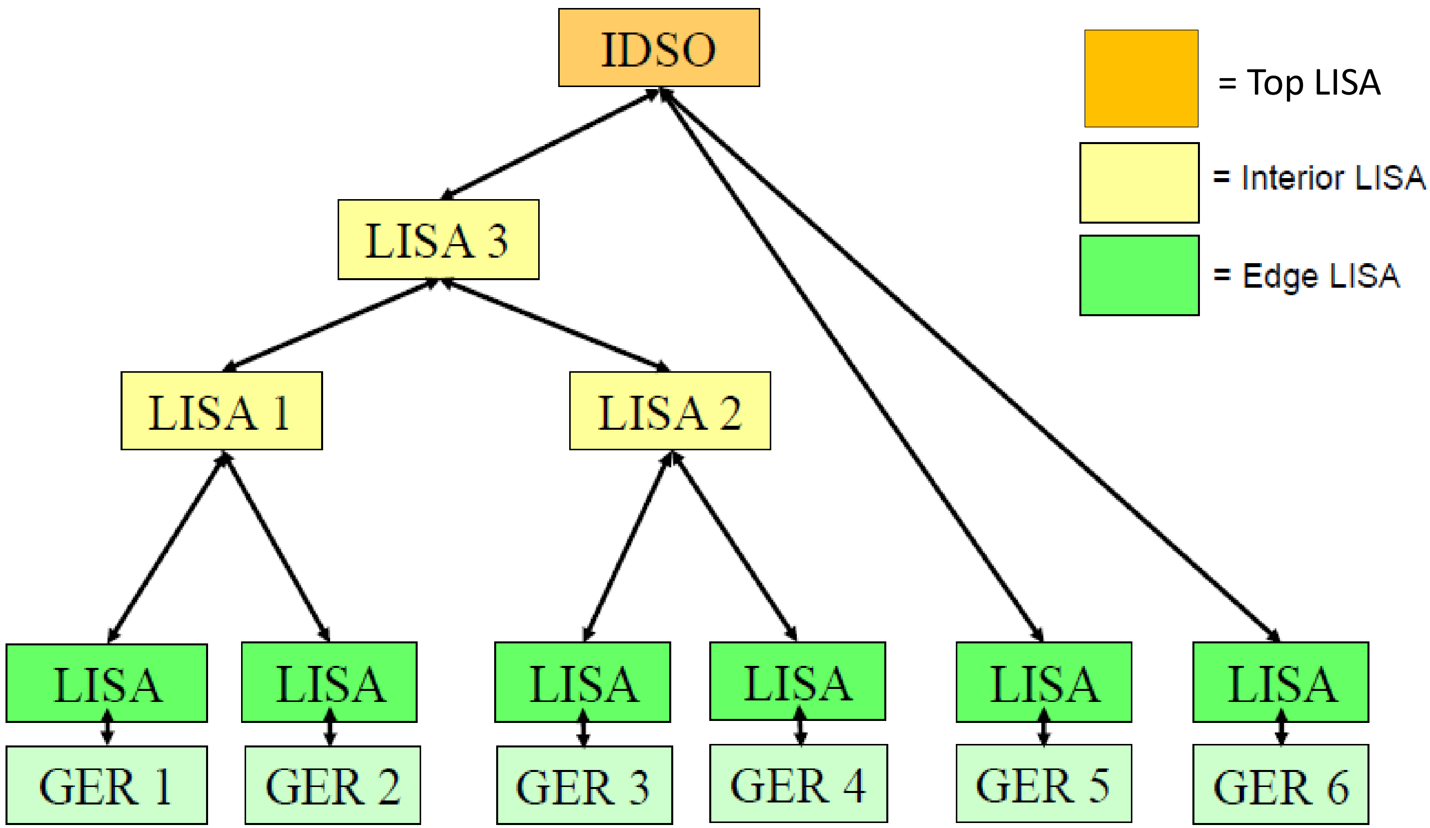

Fig. 1: Illustrative communication network of Local Intelligent Software Agents (LISA) for an IDSO-managed bid-based TES design with Grid-Edge Resource (GER) participants

Project Goal 2

- **Goal-2 (Done).** Develop swing contracts permitting IDSOs to offer flexible reserve (dispatchable down/up power paths) into ISO-managed wholesale power markets (Refs. [4,9,12])

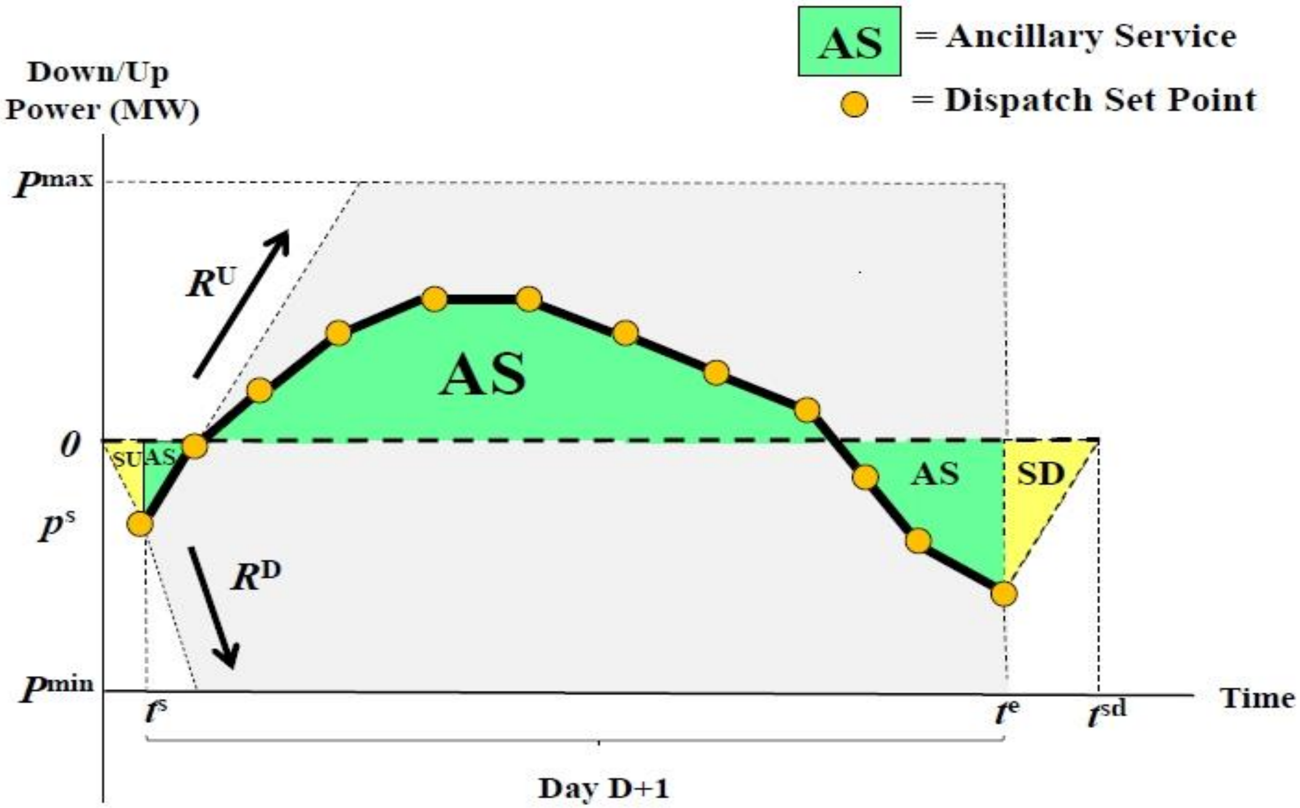

Fig. 2: One among many possible power paths an IDSO could be dispatched to deliver during day D+1 if its swing contract offering flexible down/up power & ramp is cleared in a day-D DAM

Project Goal 3

- **Goal-3 (Done).** Develop a platform permitting evaluation of our proposed IDSO-managed bid-based TES design within an *Integrated Transmission and Distribution (ITD)* system (Refs. [1,5,7,8,10,11])

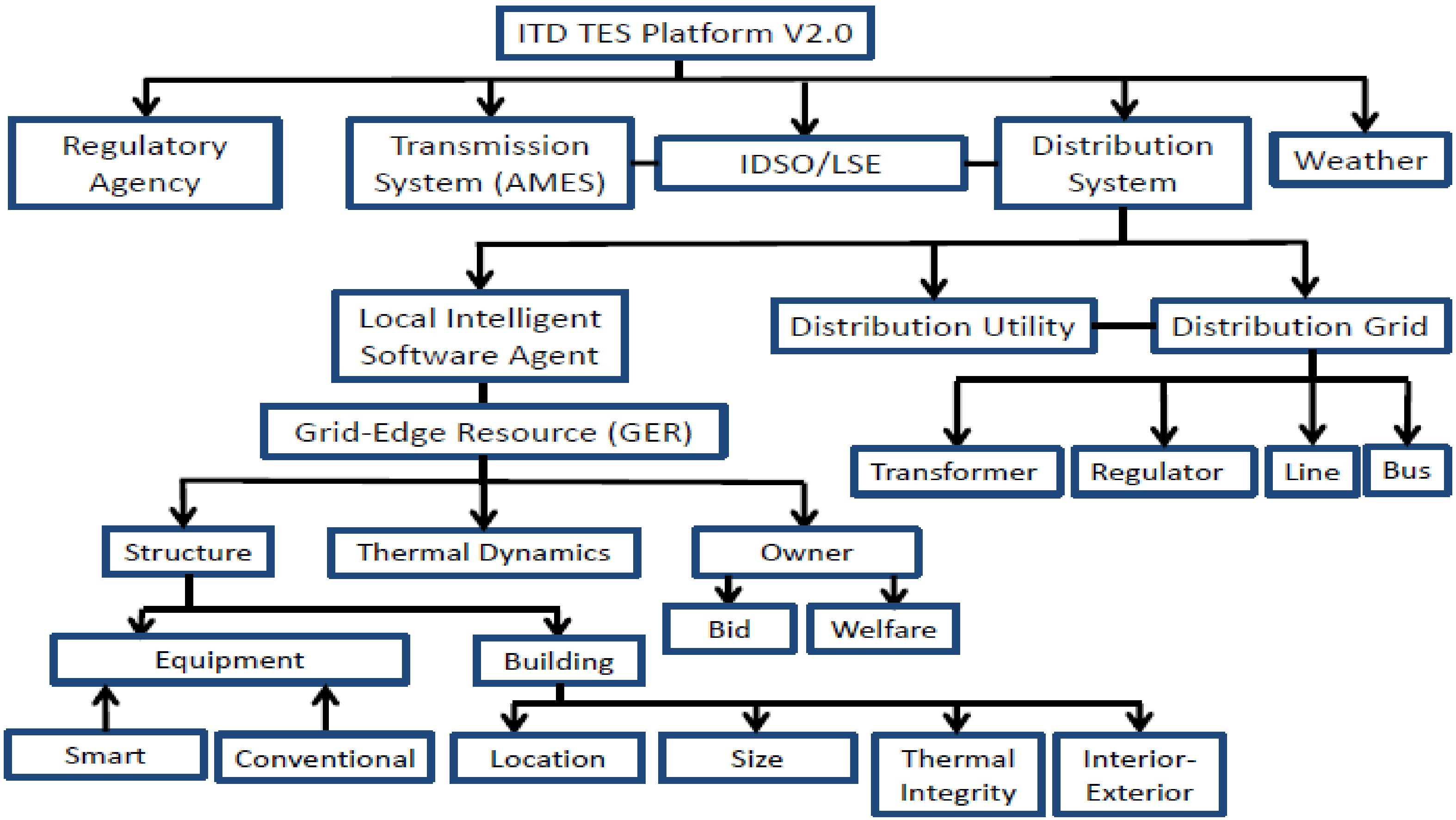

Fig. 3: Partial agent hierarchy for the ITD TES Platform V2.0

Project Goal 3 …

- *Transmission component for the ITD TES Platform V2*

— *AMES V5.0* **https://github.com/ames-market/AMES-V5.0**

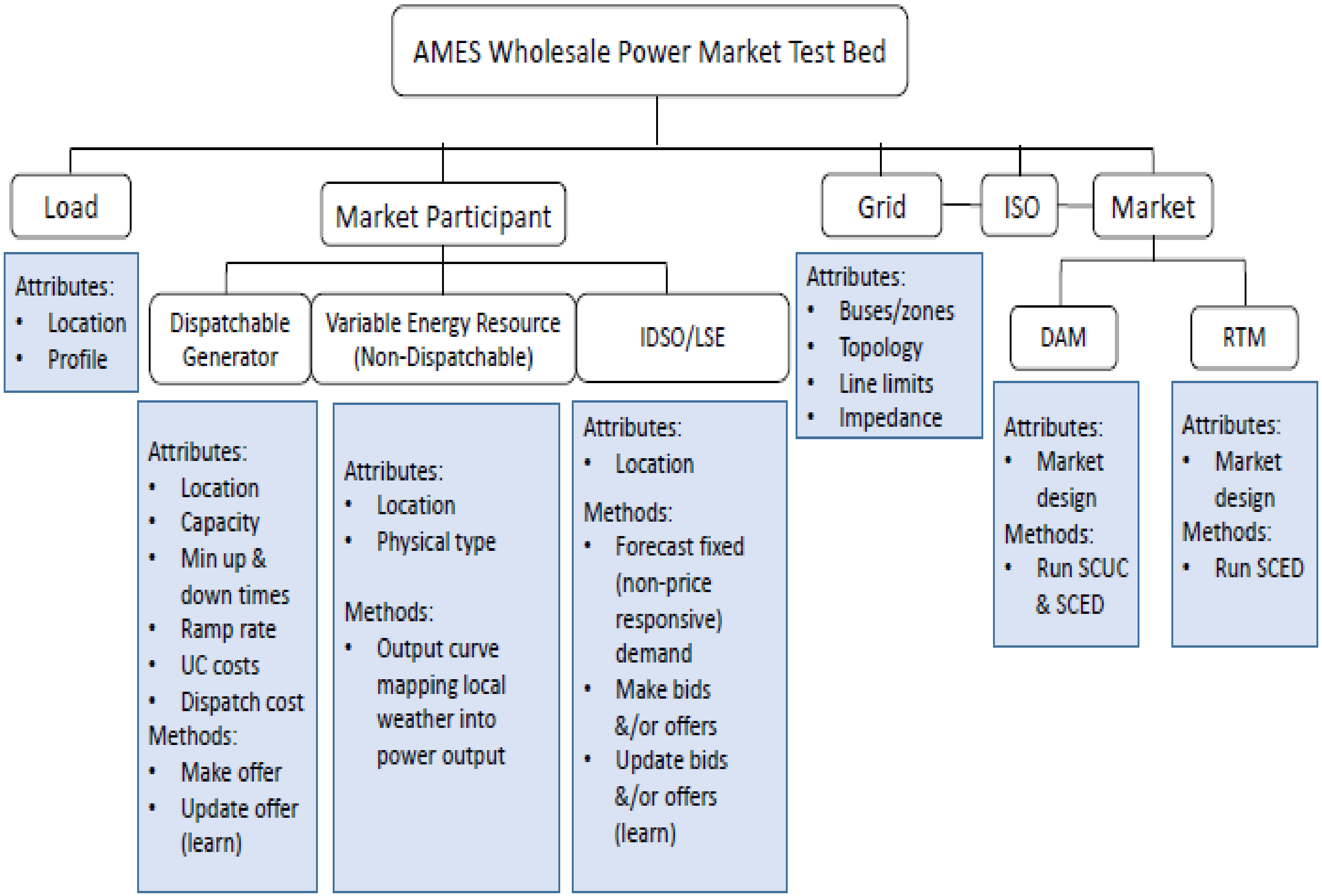

Fig. 4: Partial agent hierarchy for AMES V5.0

Project Goal 3 …

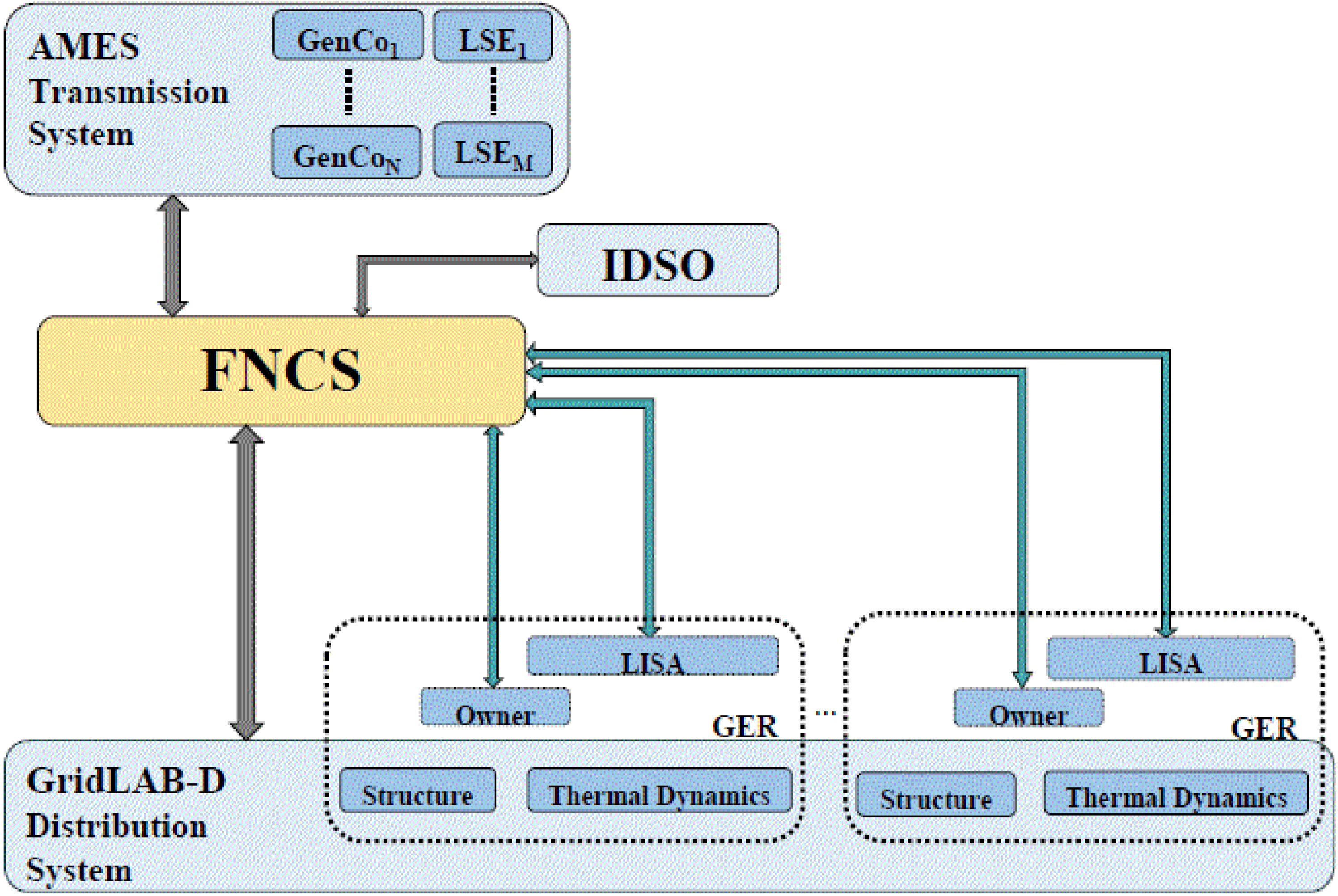

Fig. 5: Key software components for the ITD TES Platform V2.0

Project Goal 4

- **Goal-4 (In Progress):** Use ITD TES Platform V2.0 to evaluate the IDSO-managed bid-based TES design (Ref. [6] & ongoing work)

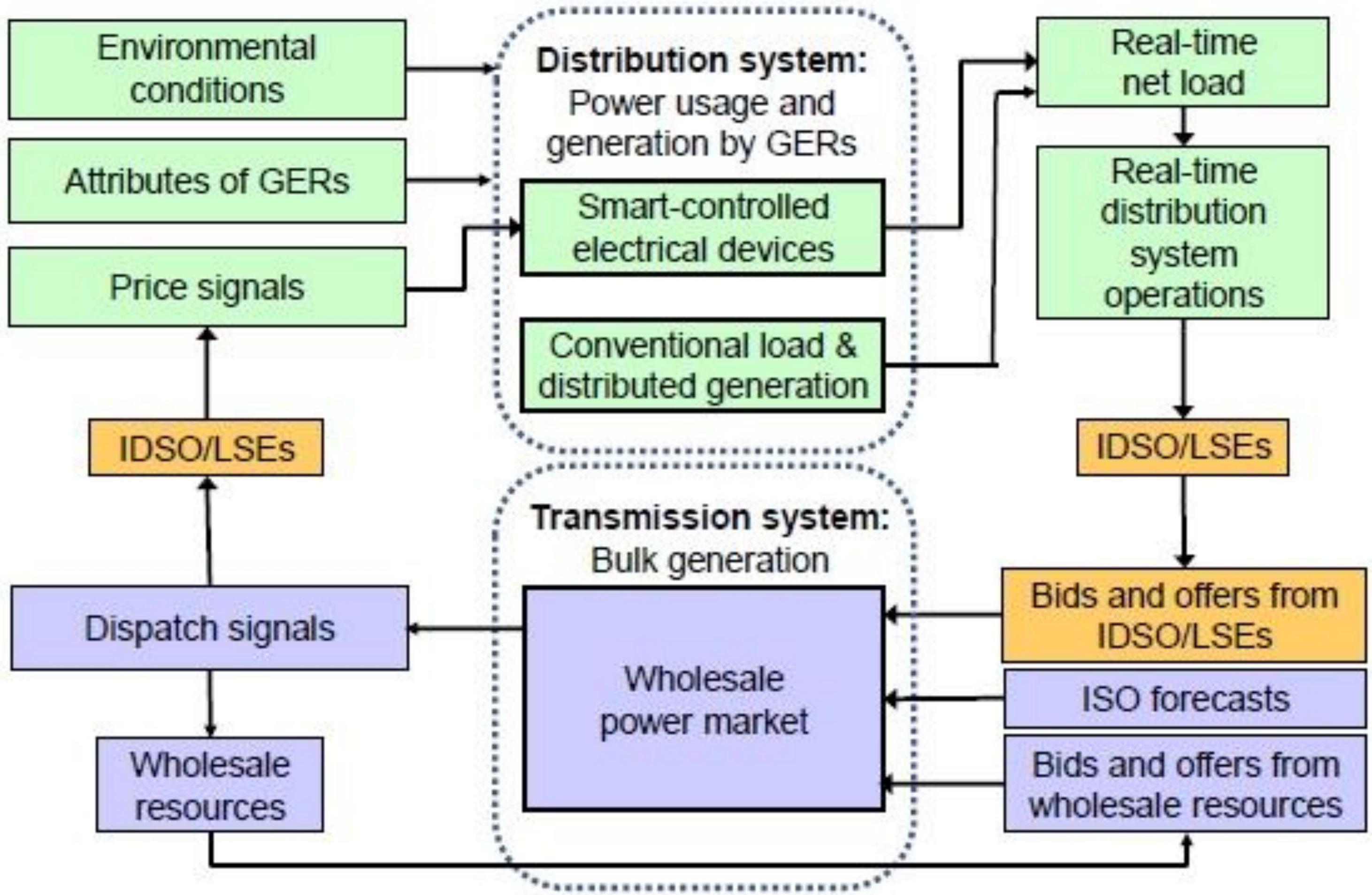

Fig 6: ITD TES Platform V2.0 modeling of an IDSO-managed bid-based TES design

Project Publications & Reports (Q14 in Blue)

[1] L. Tesfatsion, **2017**. "Modeling Economic Systems as Locally-Constructive Sequential Games," *Journal of Economic Methodology*, Vol. 24, Issue 4, 384-409.

[2] A. G. Thomas, **L. Tesfatsion**, **2018.** "Braided Cobwebs: Cautionary Tales for Dynamic Retail Pricing in End-to-End Power Systems," *IEEE Transactions on Power System,* Volume 6, Issue 33, 2018, 6870-6882.

[3] T. Lu, **Z. Wang**, J. Wang, Q. Ai, C. Wang, **2019**. "A Data-Driven Stackelberg Market Strategy for Demand Response-Enabled Distribution Systems," *IEEE Transactions on Smart Grid*, Vol. 10, Issue 3, 2345-2357.

[4] S. Ma, Z. Wang, **L. Tesfatsion**, **2019.** "Swing Contracts with Dynamic Reserves for Flexible Service Management," *IEEE Transactions on Power Systems*, Vol. 34, Issue 5, 4024-4037.

[5] H. Nguyen, S. Battula, RR. Takkala, Z. Wang, and **L. Tesfatsion, 2019.** "An Integrated Transmission and Distribution Test System for Evaluation of Transactive Energy Designs," *Applied Energy* 240, 666-679.

[6] S. Battula, L. Tesfatsion, and **Z. Wang, 2020.** "A Customer-Centric Approach to Bid-Based Transactive Energy System Design," *IEEE Transactions on Smart Grid*, to appear.

Project Publications & Reports …

[7] S. Battula, L. Tesfatsion, and T.E. McDermott, **2020**. “An ERCOT Test System for Market Design Studies,” *Applied Energy*, Vol. 275, October. DOI: 10.1016/j.apenergy.2020.115182

[8] L. Tesfatsion, **2018.** “Electric Power Markets in Transition: Agent-Based Modeling Tools for Transactive Energy Support,” Chapter 13 (pp. 715-766) in C. Hommes, B. LeBaron (eds.), *Handbook of Computational Economics 4: Heterogeneous Agent Models*. Handbooks in Economics Series, Elsevier.

[9] W. Li and **L. Tesfatsion**, **2018.** “A Swing Contract Market Design for Flexible Service Provision in Electric Power Systems,” Chapter 5 (pp. 105-127) in S. Meyn, T. Samad, I. Hiskens, and J. Stoustrup (eds.), *Energy Markets and Responsive Grids: Modelling, Control, and Optimization*, IMA Volume 162, Springer.

[10] L. Tesfatsion and **S. Battula , 2020.** “Analytical SCUC/SCED Optimization Formulation for AMES V5.0,” Economics Working Paper #20014, ISU Digital Repository, July.

[11] L. Tesfatsion and **S. Battula, 2020.** “Notes on the GridLAB-D Household Equivalent Thermal Parameter Model,” Econ Working Paper #19001, ISU Digital Rep., July.

[12] Leigh Tesfatsion, 2020. *A New Swing-Contract Design for Wholesale Power Markets*, 21 Chapters, 272pp., Wiley/IEEE Press, scheduled December 2020 release.

Q14 Project Task & Activities: Summary

			Q14 Activities	Comments on Q14 Activities
Q14 Task **Verify and evaluate the proposed flexible contracting system**	**6/30/2020**	**6/30/2020**	**A1:** Final revision, uploading, and proofing of the manuscript for our customer-centric bid-based TES design paper [6], to appear in the *IEEE Transactions on Smart Grid* (2020) **A2**: Final revision, uploading, and proofing of the manuscript for our ERCOT Test System paper [7], to appear in *Applied Energy* (2020) **A3:** New WP release [10] of documentation for AMES V5.0, the transmission system component of the ITD TES Platform V2.0. **A4:** Substantially revised version of working paper [11] providing important documentation for the distributions system component of the ITD TES Platform V2.0. **A5:** Continuation of ongoing conceptual and ITD TES Platform work focusing on the modeling of IDSO-managed bid-based TES designs, with a particular focus on swing-contract formulations permitting IDSOs to function as linkage entities between T-systems and D-systems	**A1-A4:** Links to our forthcoming journal publications [6] and [7] and to our new/revised working papers [10] and [11] are provided below in our listing of project work to date. **A5:** This Q14 report focuses on work undertaken for activity A5.

Q14 Project Activities (Goal 4): Details

- Suppose an IDSO operates at a T-D interface for an ITD system.
  - The IDSO can submit bids into the T-system wholesale power market for purchase/sale of power and ancillary service supply
  - The IDSO manages a bid-based TES design for the D-system to service the power needs of retail customers

Challenge: *Can T-system bids & a D-system bid-based TES design be formulated in a manner that permits the IDSO to align system goals/constraints with customer goals/constraints?*

- **Preliminary affirmative test cases** are reported in Ref. [6]:
  - [6] S. Battula, L. Tesfatsion, Z. Wang, 2020. "A Customer-Centric Approach to Bid-Based Transactive Energy System Design," *IEEE Transactions on Smart Grid*, to appear.

Test Case Features

- ITD system consists of 927 households populating an IEEE 123-bus distribution system connected to a 5-bus transmission system.
- Each household seeks to maximize its own net benefit subject to local physical constraints

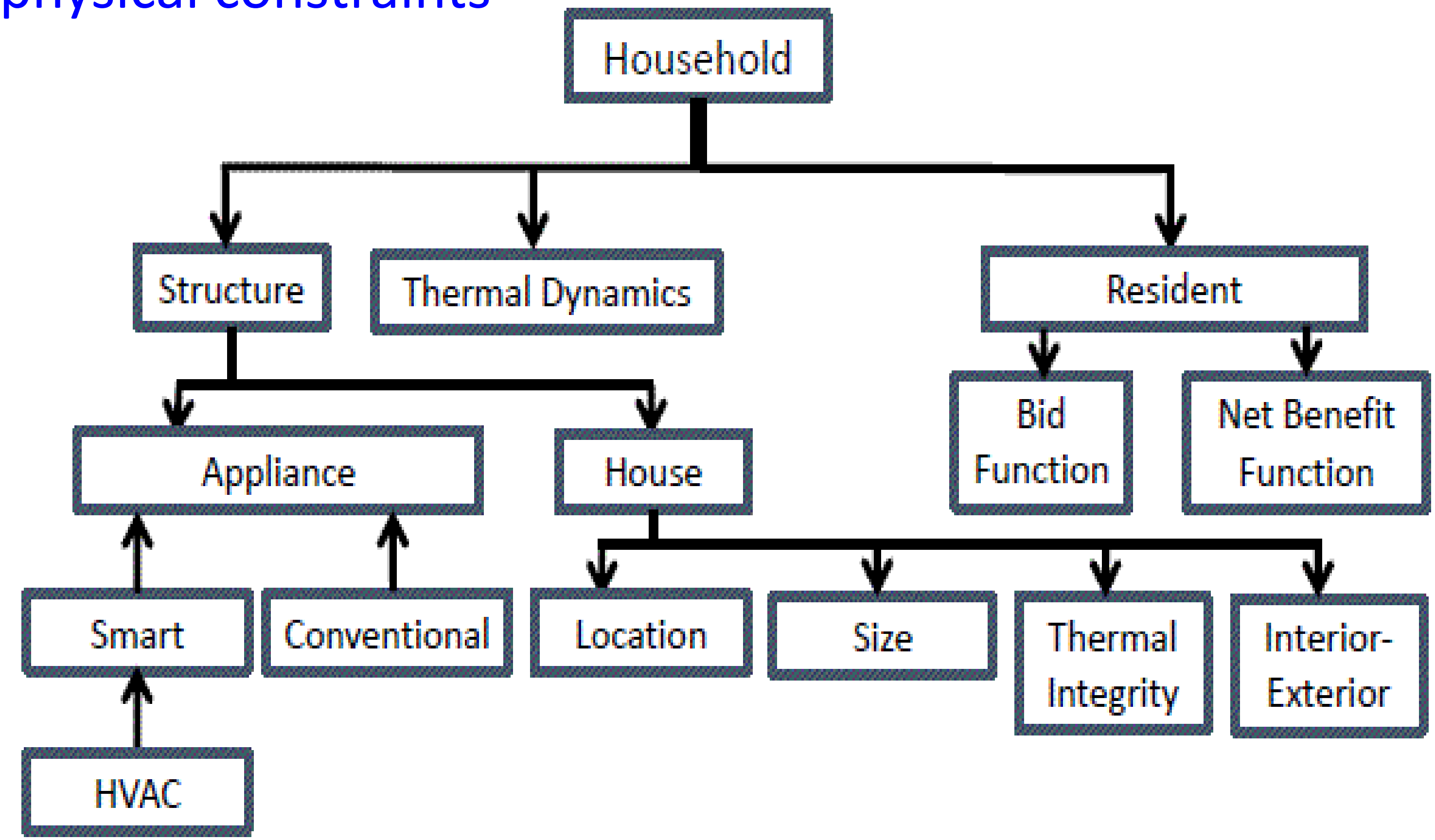

Fig. 7: Hierarchy of basic attributes characterizing a household

Test Case Feedback Loop

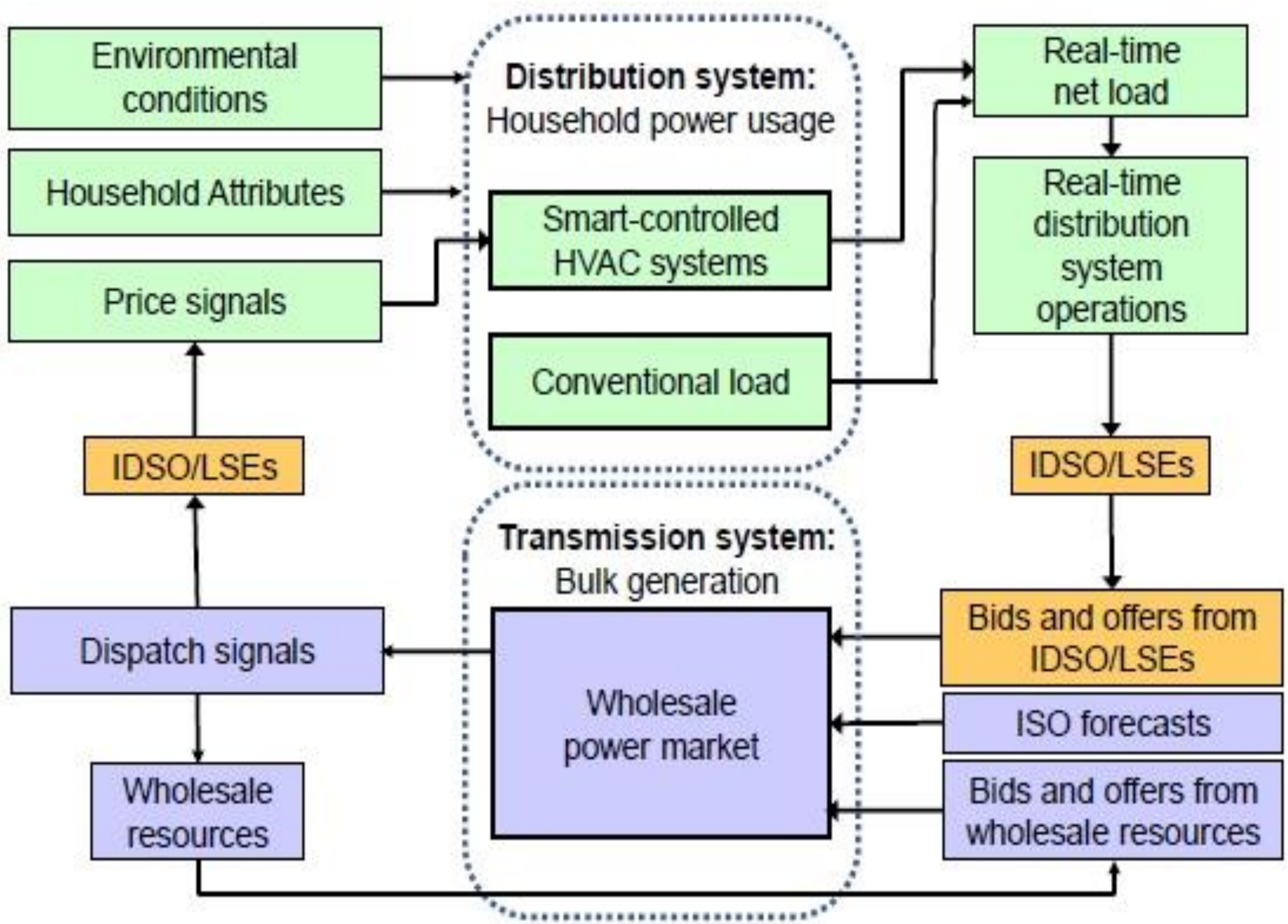

Fig. 8: ITD Feedback loop for each household test case

TES Design Communication Network

- The IDSO is the top-level ***Local Intelligent Software Agent (LISA)*** in a LISA communication network for D-system households

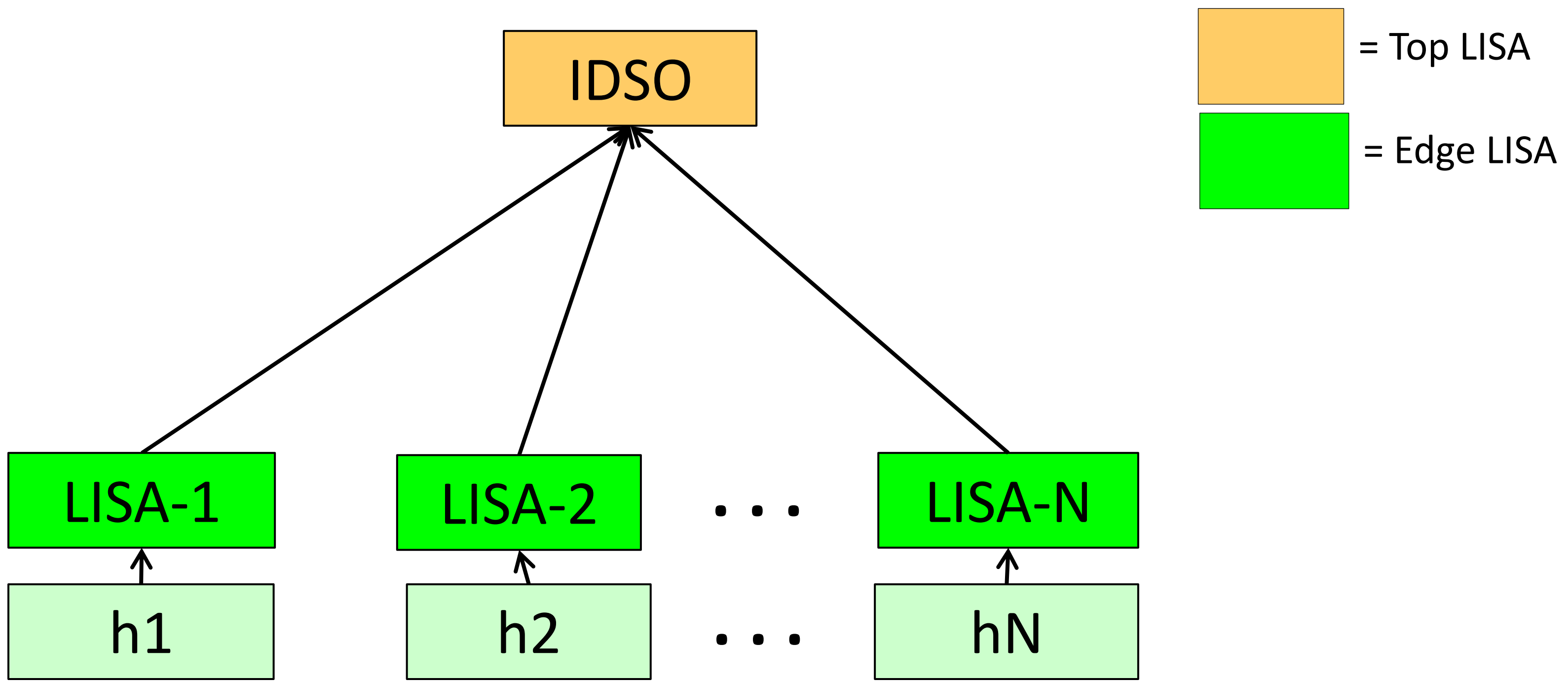

Fig. 9: Each household h has an HVAC system managed by a price-responsive HVAC controller (the edge LISA for h).

TES Design Implementation

- The IDSO seeks to align/achieve D-system and household goals by iteratively implementing the following *Five-Step TES Design*:

STEP 1: The HVAC controller for each household h collects data on h at a *Data Check Rate.*

STEP 2: The HVAC controller for each household h forms a state-conditioned bid function Bid(h) for HVAC power demand or HVAC ancillary service supply (power absorption) and communicates Bid(h) to the IDSO at a *Bid Refresh Rate*.

STEP 3: The IDSO combines the household bid functions Bid(h) into a vector **AggBid** of one or more aggregate bid functions at an *Aggregate Bid Refresh Rate*.

STEP 4: The IDSO uses **AggBid** to determine price signals that it communicates back to household HVAC controllers at a *Price Signal Rate.*

STEP 5 (Control-Step): The HVAC controller for each h inserts its latest received price signal into its latest refreshed state-conditioned bid function Bid(h) at a *Power Control Rate,* which triggers an ON/OFF power control action for the HVAC system.

Action Timing for the Five-Step TES Design

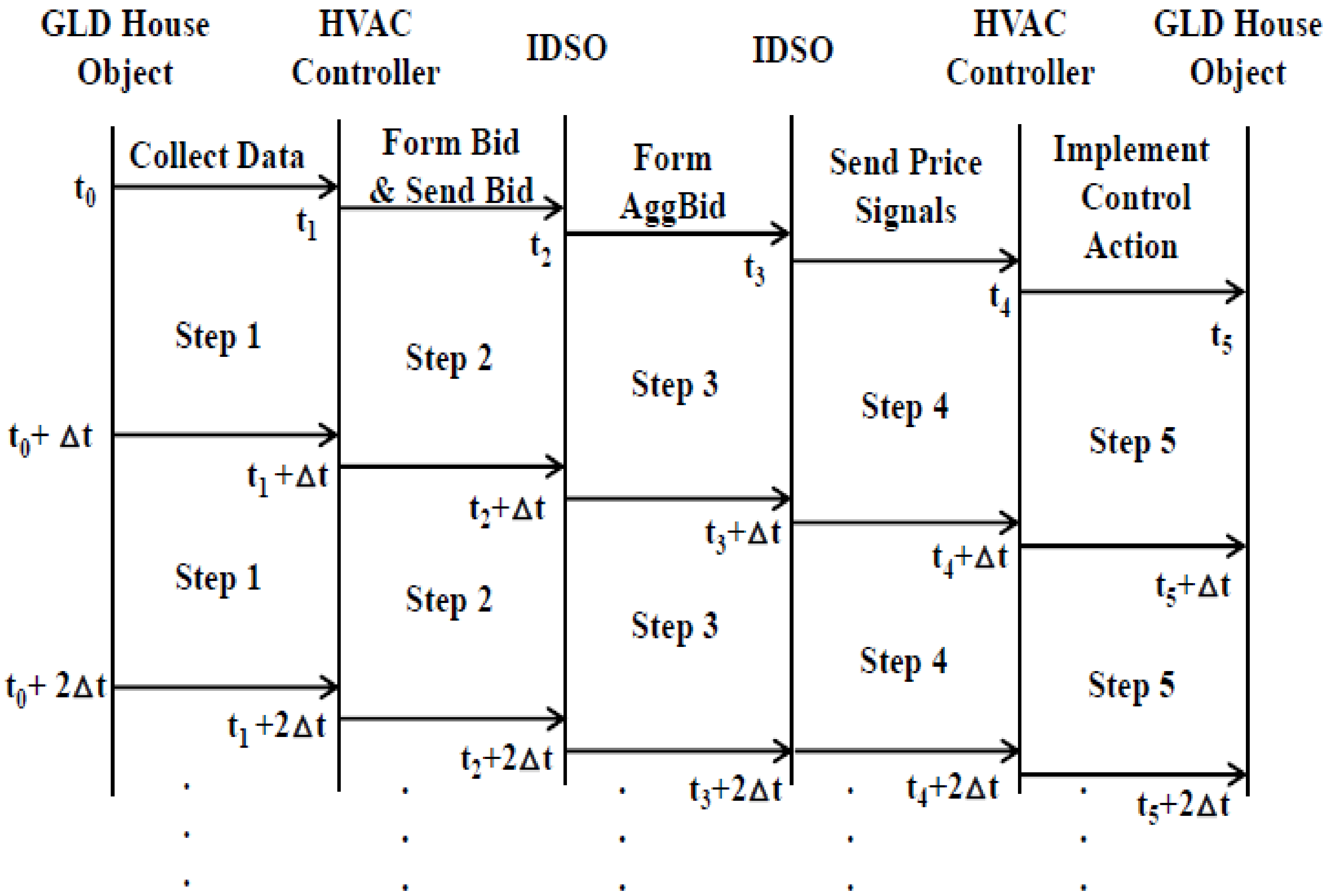

Fig. 10: Staggered implementation of the five steps comprising the Five-Step TES Design for household test cases. Each action time-rate is commonly set equal to 1/Δt with time-step Δt = 300s for each household test case reported below.

Household Bid Function B(h): Optimal Form for each Control-Step *n*

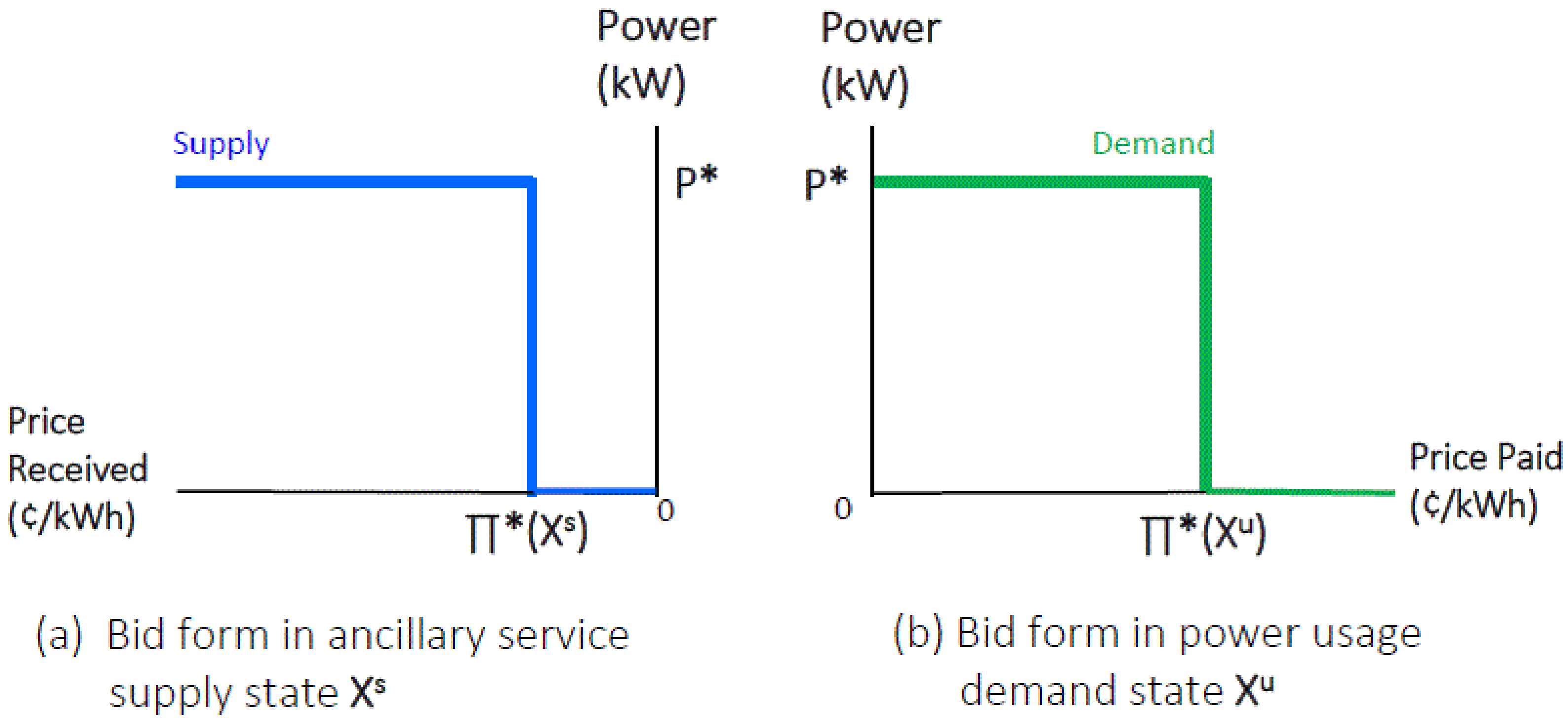

Fig 11: Depending on its state at the start of a control-step n, a household h either (a) offers to supply ancillary service as a function of price received or (b) demands power for usage as a function of price paid. A negative price denotes a supply price received and a positive price denotes a demand price paid.

Household Classification Into Types

- Classification is based on correlated physical attributes

- *Low Structure Quality:*
  - HVAC system with a relatively poor performance rating
  - House that has a relatively small size
  - House that has relatively poor thermal insulation

- *Medium Structure Quality:*
  - HVAC system with an average performance rating
  - House that has an average size
  - House that has average thermal insulation

- *High Structure Quality:*
  - HVAC system with a relatively good performance rating
  - House that has a relatively large size
  - House that has relatively good thermal insulation

IDSO Peak-Load Reduction Test Cases

- The IDSO on day D specifies a *Forecasted Peak Load (FPL)* for total household load (fixed + price-sensitive) during day D+1, assuming a flat hourly retail price (12₵/kWh).

- The IDSO on day D sets a *Target Peak-Load Reduction (TPLR)* for day D+1 with 0 < TPLR < FPL.

- The IDSO implements *peak-load price control* on day D+1 by means of the Five-Step TES Design in order to maintain total household load at or below

  Target Peak Load = [FPL – TPLR] .

- All households in the same state at the start of a control-step *n* receive the same price signal at the start of *n*.

- The TPLR for all peak-load reduction test cases is set to 0.5MW.

Peak Load Reduction Test Cases …

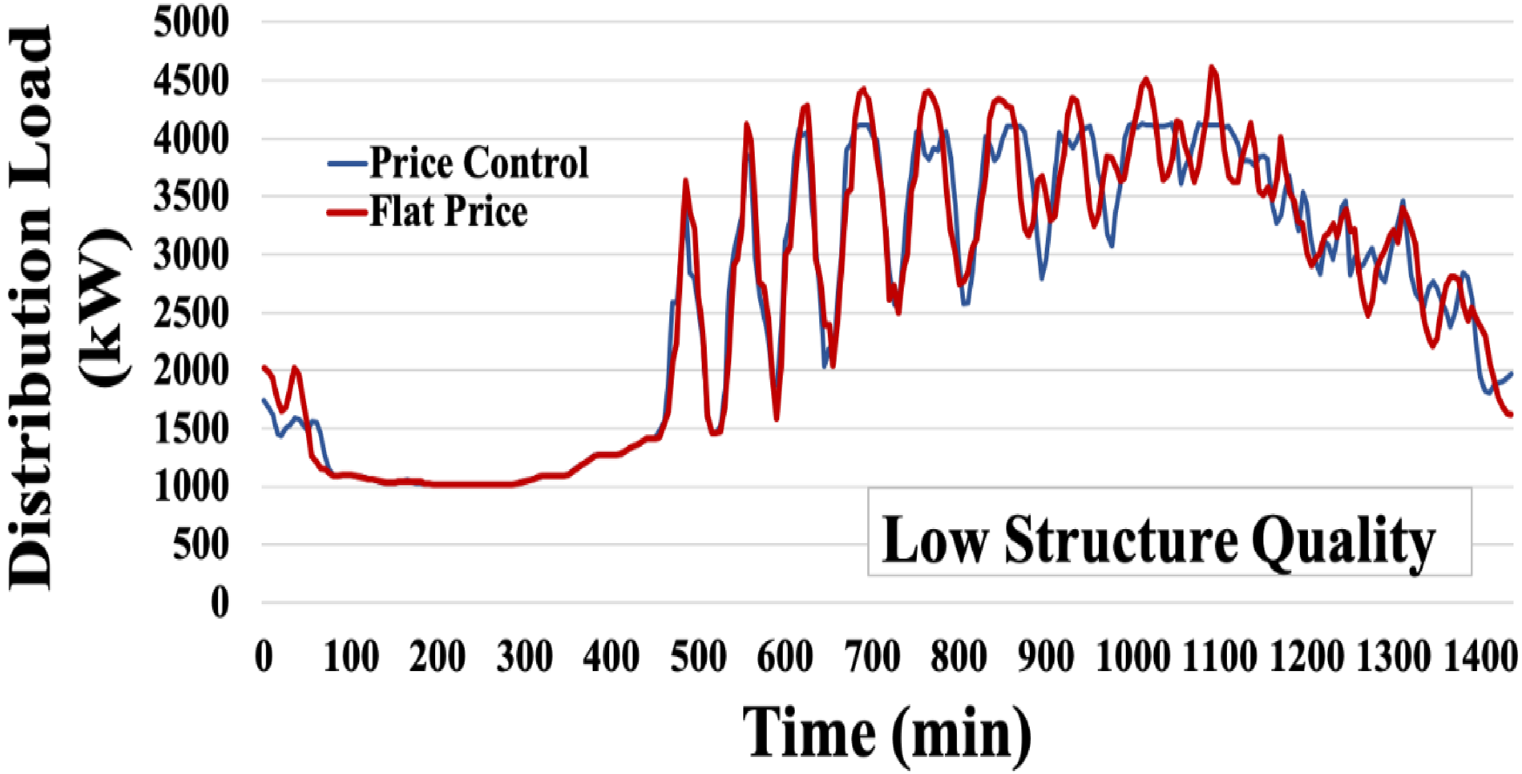

Fig. 12: Total household load outcomes on day D+1 under peak-load price control (relative to flat-rate pricing) when all households have Low structure quality type.

Peak Load Reduction Test Cases …

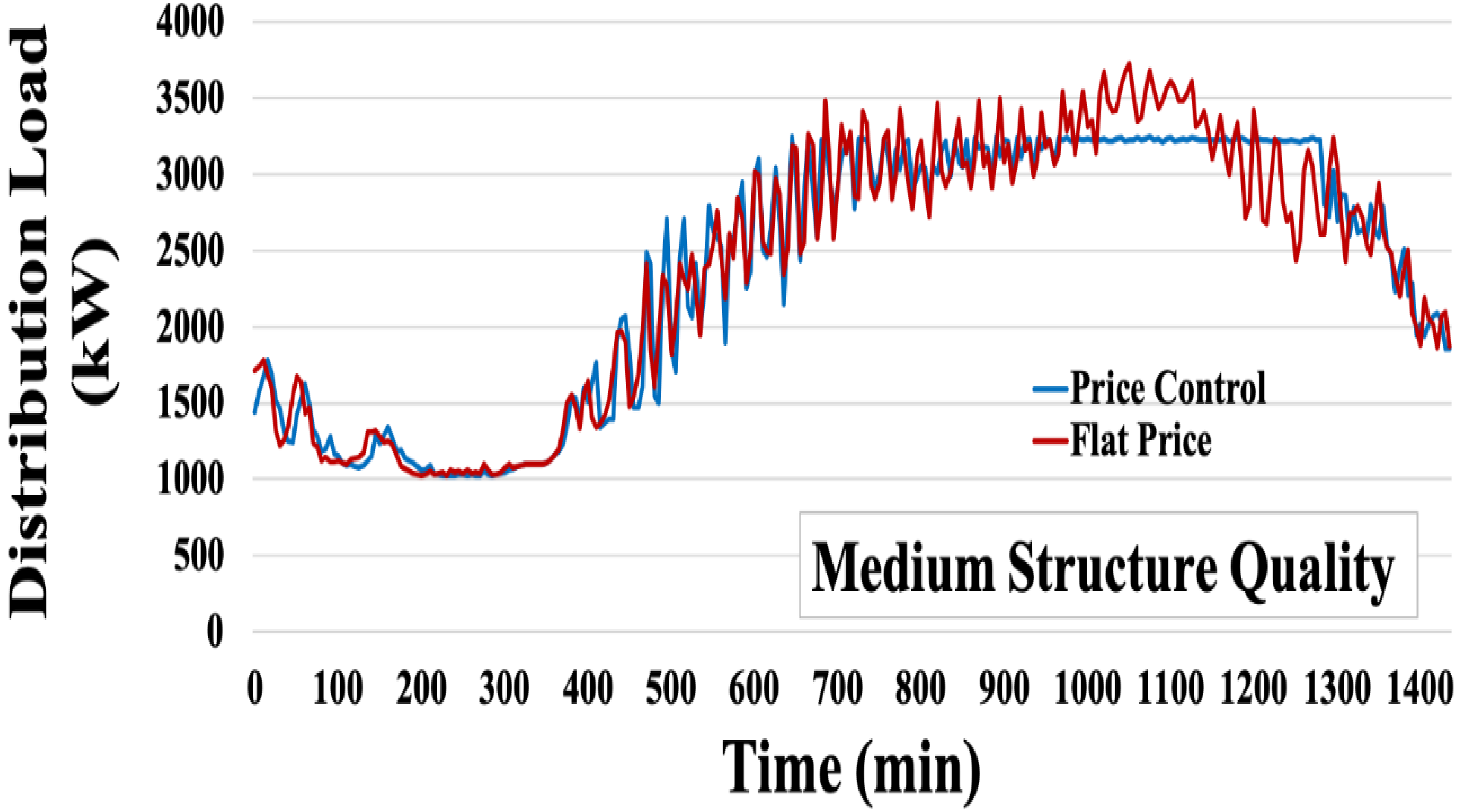

Fig. 13: Total household load outcomes on day D+1 under peak-load price control (relative to flat-rate pricing) when all households have Medium structure quality type.

Peak Load Reduction Test Cases …

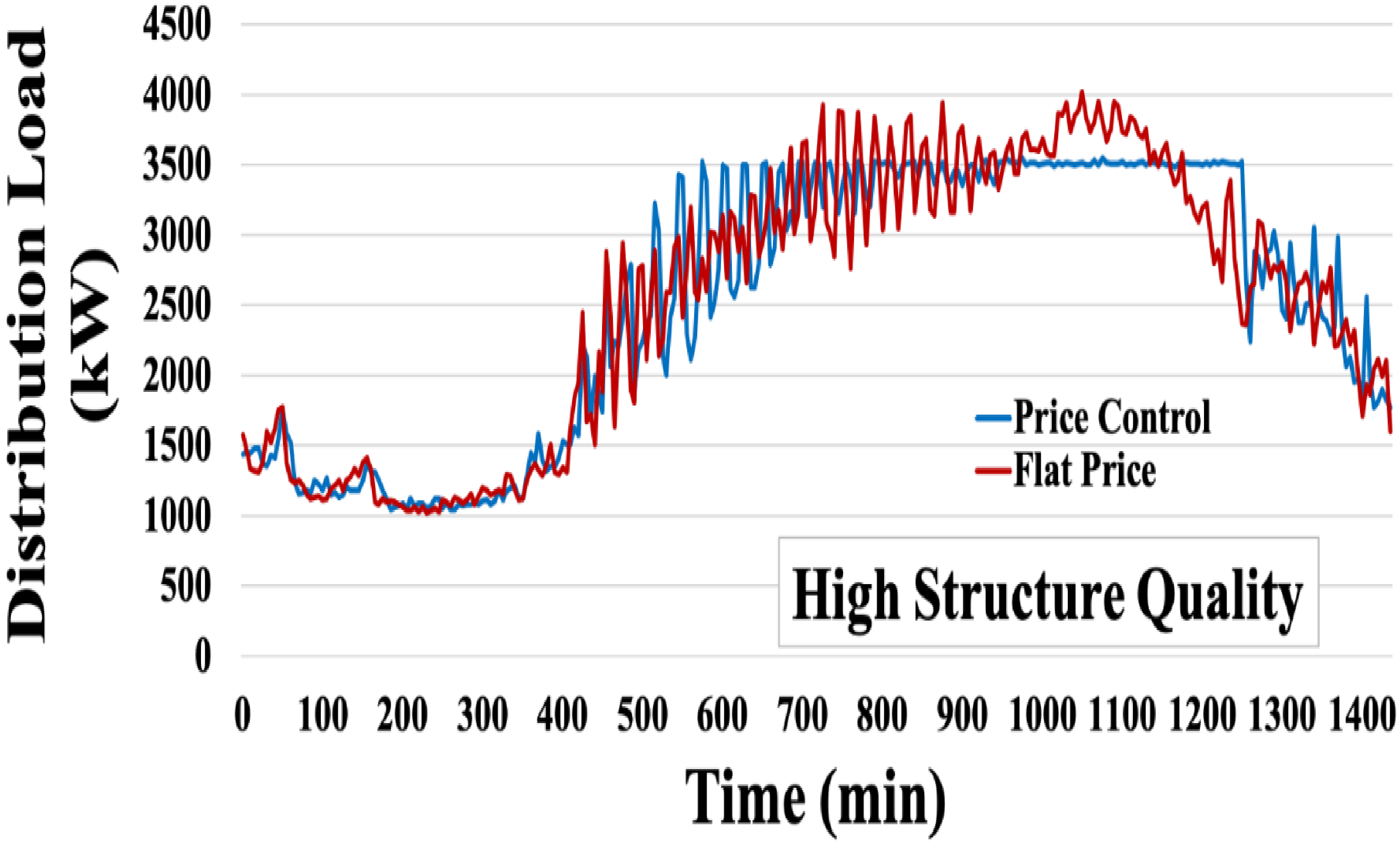

Fig. 14: Total household load outcomes on day D+1 under peak-load price control (relative to flat-rate pricing) when all households have High structure quality type.

Peak Load Reduction Test Cases …

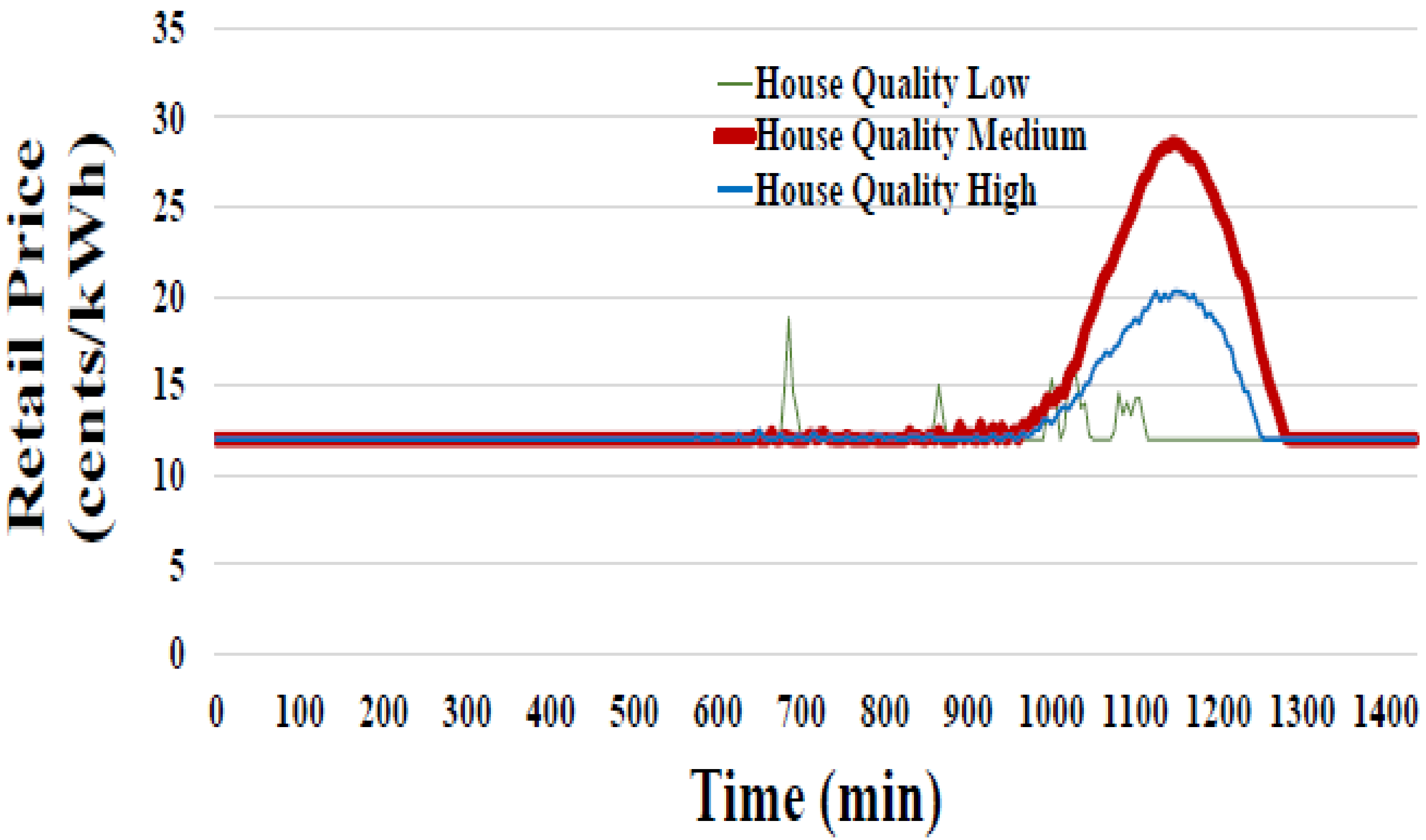

Fig. 15: Retail price outcomes on day D+1 under peak-load price control for the three cases depicted in Figs. 12-14 for which all households have the same structure quality: namely, all Low, all Medium, or all High.

IDSO Load-Matching Test Cases

- The IDSO on day D submits a fixed demand bid into the day-D DAM consisting of a 24-hour load profile L(D+1) for total household load (fixed + price-sensitive) during day D+1.
- The IDSO's goal is to ensure that total household load realized on day D+1 does not deviate from L(D+1). In pursuit of this goal, the IDSO implements price control on day D+1 by the Five-Step TES Design.
- A (1/3, 1/3, 1/3) mix of household structure quality types is used for each load-matching test case.
- All households in a *power demand state* at the start of a control-step *n* receive the same *positive price signal* at the start of *n*.
- All households in an *ancillary service supply state* at the start of a control-step *n* receive the same *negative price signal* at the start of *n*.

IDSO Load-Matching Test Cases …

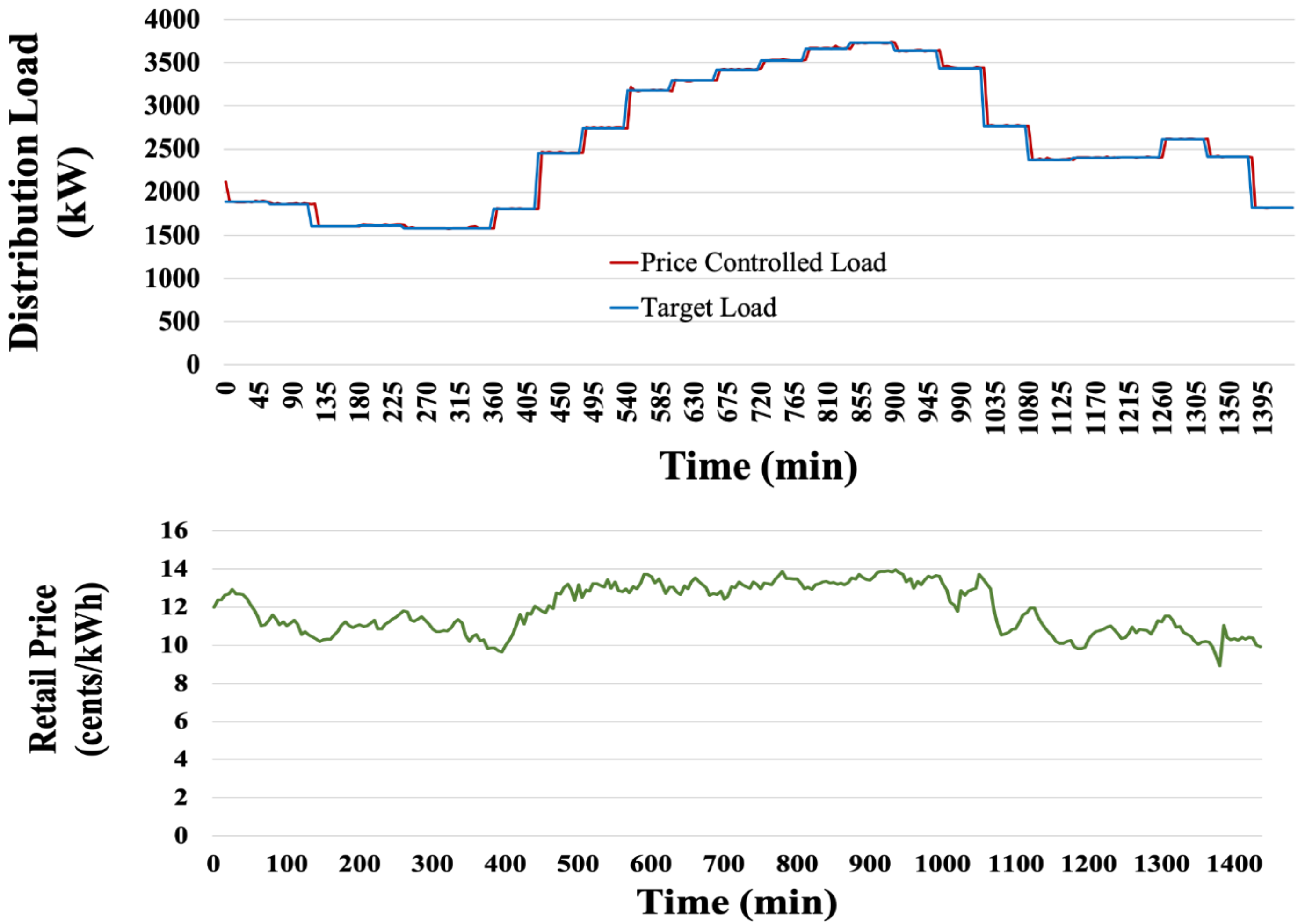

Fig. 16: Ability of the IDSO to match total household load on day D+1 to a target load profile, given by the IDSO's fixed demand bid submitted into a DAM on day D. No ancillary service procurement is needed for this load matching.

IDSO Load-Matching Test Cases …

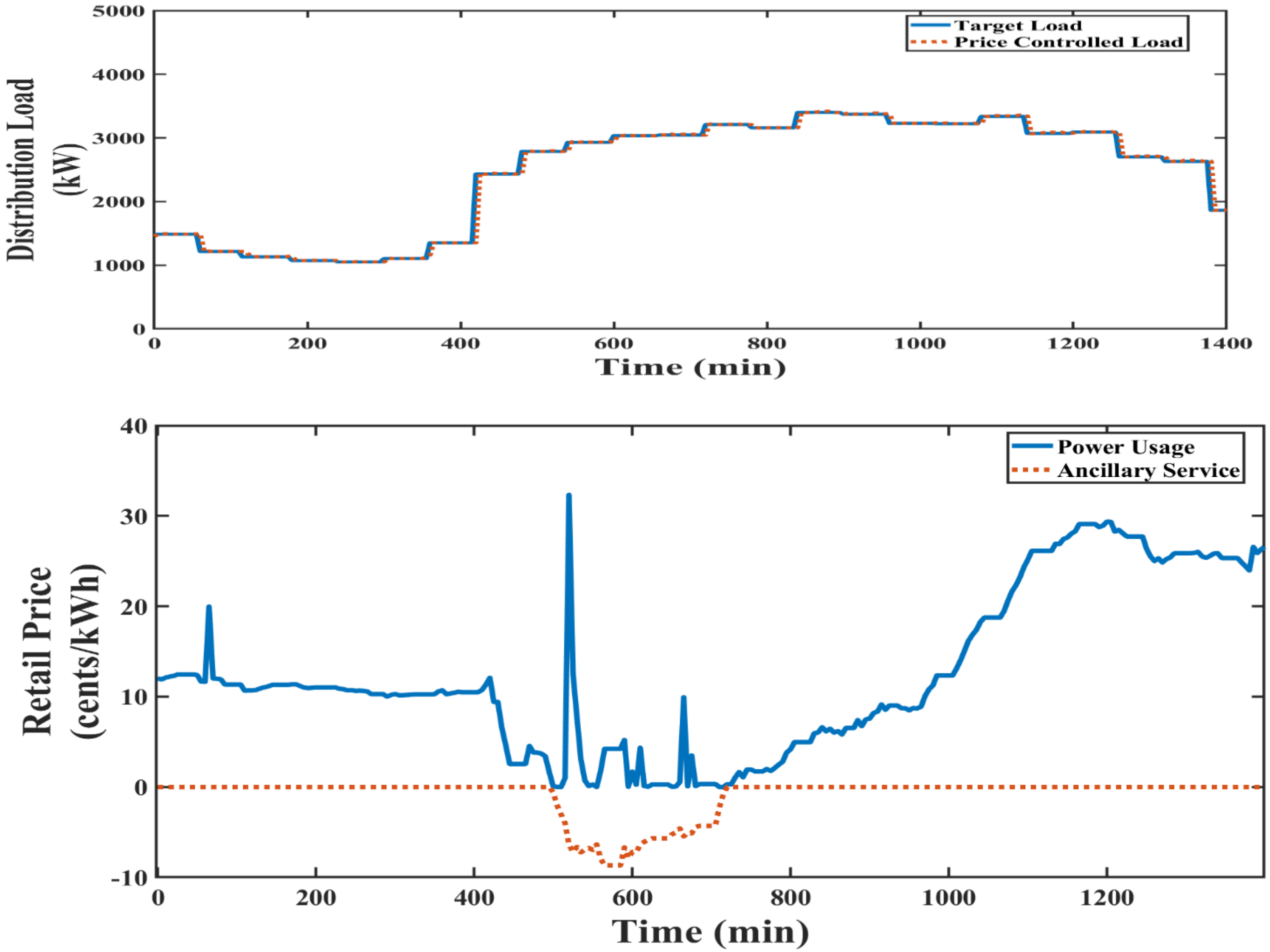

Fig. 17: Ability of the IDSO to match total household load on day D+1 to a different target load profile, given by a different fixed demand bid submitted by the IDSO into the DAM on day D. Ancillary service procurement is needed during some control steps in order to achieve this load matching.

Q15 Planned Activity

- We have received a no-cost continuation for our project work through September 2020.

- During this period we will continue to address the following two key questions for Goal-4, our final project goal:

  – Can our proposed IDSO-managed bid-based TES design facilitate the participation of IDSOs as ancillary service providers in U.S. RTO/ISO-managed wholesale power markets, such as ERCOT?

  – Can swing contracts provide useful support for this IDSO participation?