DOE/OE Transmission Reliability Program

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

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Washington, DC

Project Homepage and Research Team

- **Project Homepage:**

  http://www2.econ.iastate.edu/tesfatsi/ITDProjectHome.htm

- **Research Team:**
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  - Dr. Jianhui Wang (Co-PI, Southern Methodist University)
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- **DOE Project Manager:**
  - Joseph Dygert (NETL)

Presentation Outline

- ❑ **Overall Project Objective**
- ❑ **Summary of Project Tasks: 1/1/2017 - 6/30/2017**
- ❑ **Looking Back:**
  - Major accomplishments from 1/1/2017 (project start date) through 6/5/2017 (present date)
  - Deliverables and remaining schedule of activities to be completed under FY16 funding: 1/1/2017 – 6/30/2017
  - List of accepted publications
  - List of presentations
- ❑ **Looking Forward:**
  - Outline of planned activities, with time schedule

Overall Project Objective

- Investigate the ability of a *Distribution Utility (DU),* functioning as a *DER aggregator*, to use innovative types of *swing contracts* to ensure availability and real-time provision of power and ancillary services in flexible form.

- This availability and provision should support *Integrated Transmission and Distribution (ITD)* operations, thus facilitating robust efficient management of ITD risks and uncertainties.

Definitions:

DER Aggregator: Any entity capable of providing dispatchable real-time services from a collection of ***Distributed Energy Resources (DERs).***

Swing Contract (SC): A contract that permits a diverse spectrum of services (e.g., power, ramping) to be offered as ranges of values rather than as point values, thus permitting greater flexibility in their real-time implementation.

Overall Project Objective…continued

- Market-based distributed control methods to extract ancillary services from DERs need to be validated by a test system that incorporates *empirically-grounded representations* for physical grid and resource attributes, *market-based transactions*, and *financial feasibility* constraints.
- An **ITD Test System** is being developed to test these market-based methods in accordance with our 3-year project tasks (PMP, Table 5)
- The ITD Test System is being developed in three successive stages:
  - **V1.0:** DU uses econ/control methods to balance the distribution system
  - **V2.0**: DU uses econ/control methods to extract ancillary services (e.g., reserves) from DERs in support of distribution system operations
  - **V3.0:** DU uses econ/control methods to extract ancillary services from DERs in support of ITD operations in an ITD system with a ***Transactive Energy System (TES)*** design, i.e., a design based more fully on mutual (transactional) agreements rather than top-down controls

Summary of Project Tasks: 1/1/2017 – 6/30/2017

(From PMP, Table 5, Project Schedule)

- **Task 1.1.1:** Update PMP **Done (2/15/2017)**
- **Task 1.1.2:** Sign NDAs with ind. partners **Done (3/31/2017)**
- **Task 1.1.3:** Establish project website **Done (1/1/2017)**

- **Task 1.2.1:** Develop market-based distributed control methods for DERs **Modeling Done; Sensitivity Tests in Progress (see below)**
- **Task 1.2.2:** Quantify and model down/up ramping capability for DERs **Modeling Done; Sensitivity Tests in Progress (see below)**

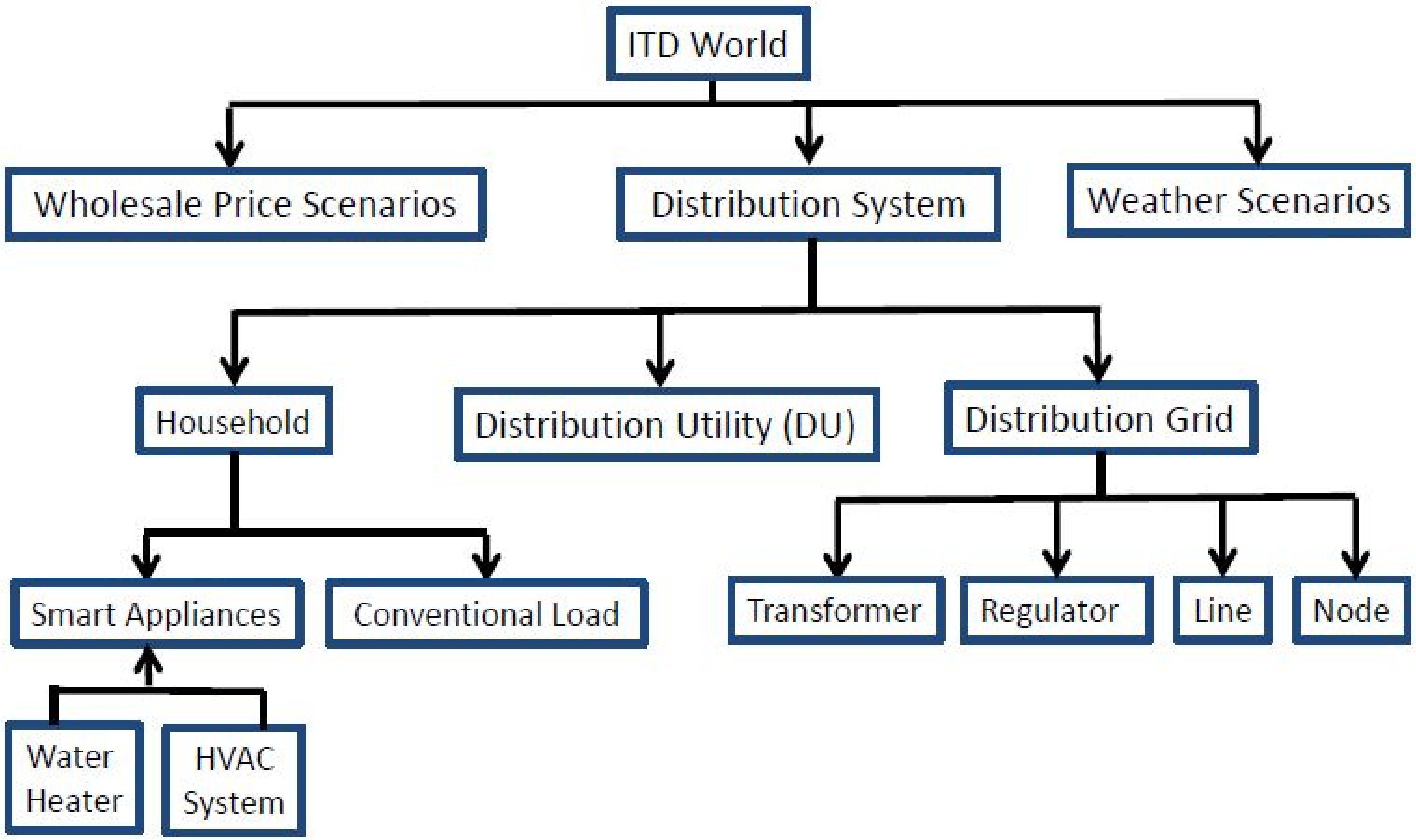
Looking Back: Summary of Major Accomplishments Since Last DOE Report (3/31/2017) To Present Date

❑ Task 1.2.1: Develop market-based distributed control methods for distributed resources

- Task 1.2.1 carried out via **ITD Test System V1.0**
  - Development, implementation, and testing of **physically-based household appliance models for an electric HVAC system and an electric water heater** and inclusion of these appliance models in ITD Test System V1.0
  - Inclusion in ITD Test System V1.0 of a **Distribution Utility (DU) agent with control methods** (voltage/power monitoring, regulator adjustment via tap settings) **and economic methods** (setting/signaling of retail prices)
  - Implementation of a **smart price-responsive controller for the HVAC system** responsive to DU-signaled retail prices as well as local weather conditions
  - The **13-bus distribution grid** for the ITD Test System V1.0 is adopted from the IEEE 13-Bus Distribution System

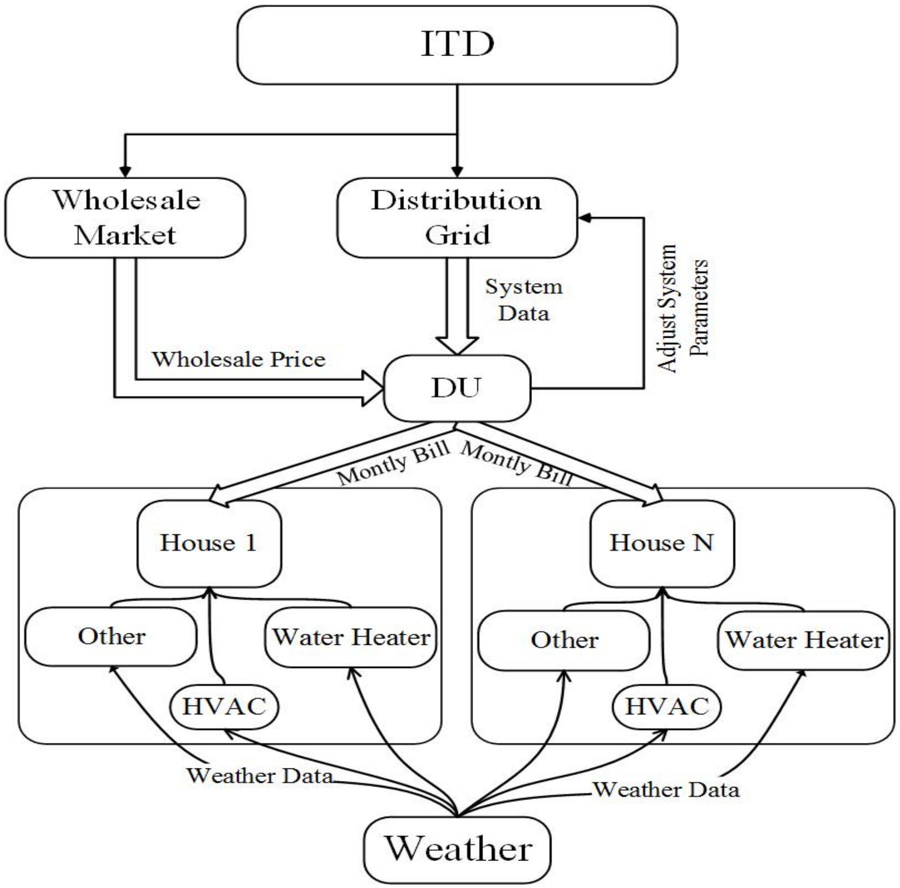
Task 1.2.1: ITD Test System V1.0 -- Details

Key Agent Types with "Has-A"↓ and "Is-A"↑ Relationships:



Task 1.2.1: ITD Test System V1.0 -- Details …

Flow Diagram Depicting Agent Interactions Over Time:



Task 1.2.1: ITD Test System V1.0 -- Details …

- **Control methods for DU agent**
  - **Monitor_voltages** : Bus voltages are monitored to check for voltage violation
  - **Regulator_adjustment**: Regulator is configured in ‘MANUAL’ mode and taps are adjusted if voltage violation is observed
  - **Monitor_power**: Power flows are monitored

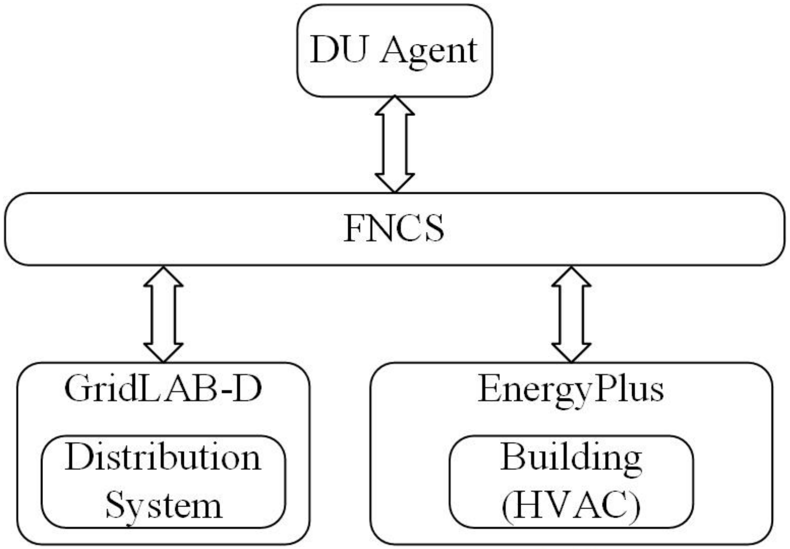
- **Economic method for DU agent**
  - **Price_signal**: Send retail price signals to designated Household agents

- **HVAC and water heater appliance models** are incorporated into the Household agent

- **Co-simulation of DU agent and IEEE 13-Bus Distribution System (GridLAB-D IEEE13.glm)**: Successfully carried out using PNNL’s ***Framework for Network Co-Simulation (FNCS)***

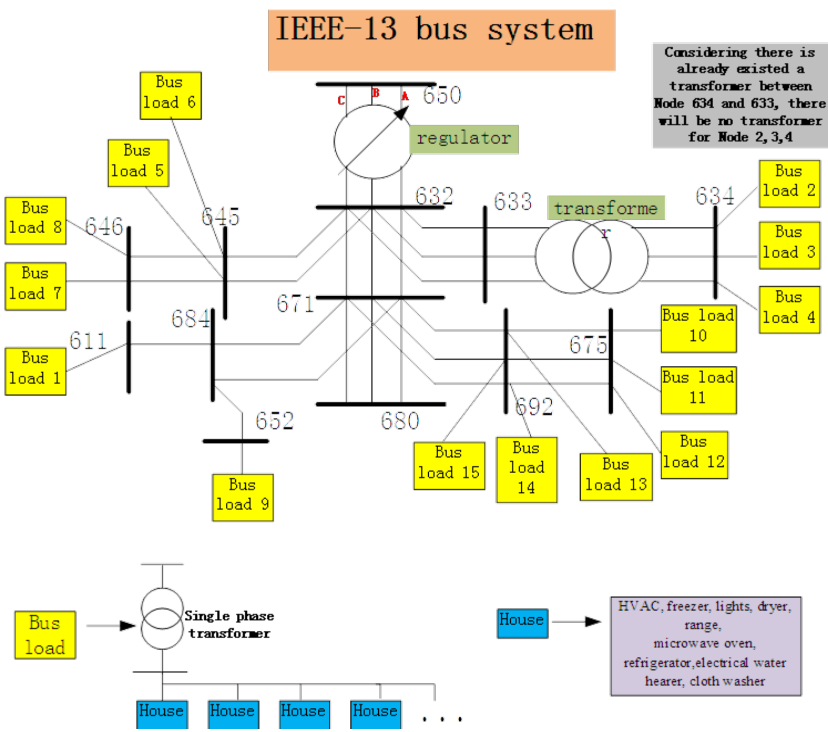
Task 1.2.1: ITD Test System V1.0
Test Case Development

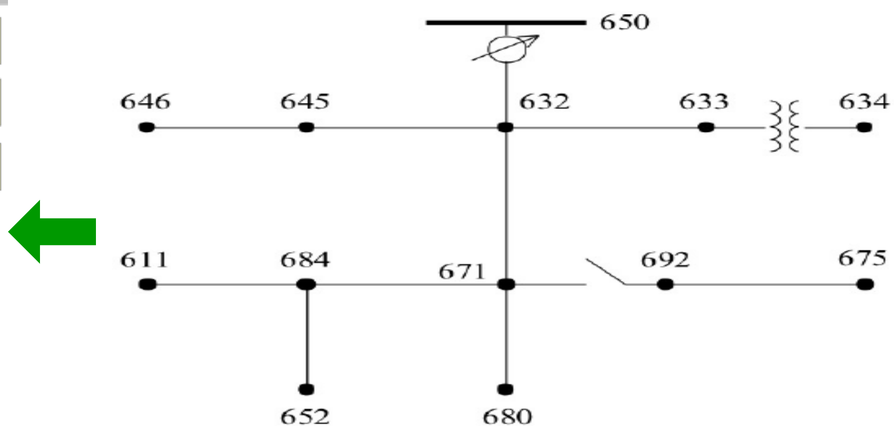
- Development of a simulation platform covering full ITD operations is difficult
- Many available power system platforms, but generally have a specific task focus
- This project is using FNCS (TCP/IP) to co-simulate multiple platform components:
  - GridLAB-D: Distribution system, e.g., IEEE 13-Bus Distribution System
  - EnergyPlus: Price-responsive thermal load modeling, e.g., a building's HVAC system
  - Future integration: Transmission system (Pypower, AMES), communication network (NS3), Graphical User Interface (GUI)
  - DU Agent: python
- ***Development of Two Test Cases for Task 1.2.1:***
  - **Voltage-Control Test Case:** DU performs load shedding, monitors voltage and power flows, and adjusts voltage (tap positions) in IEEE 13-Bus Distribution System
  - **Price-Control Test Case:** DU sends price signals to a building HVAC system (EnergyPlus) to adjust HVAC's power consumption.



Task 1.2.1: ITD Test System V1.0
Voltage-Control Test Case

- IEEE 13-Bus Distribution System is implemented in GridLAB-D
- GridLAB-D household agents are added at each bus





Task 1.2.1: ITD Test System V1.0

Voltage-Control Test Case … Continued

PNNL/LoadShed Example:

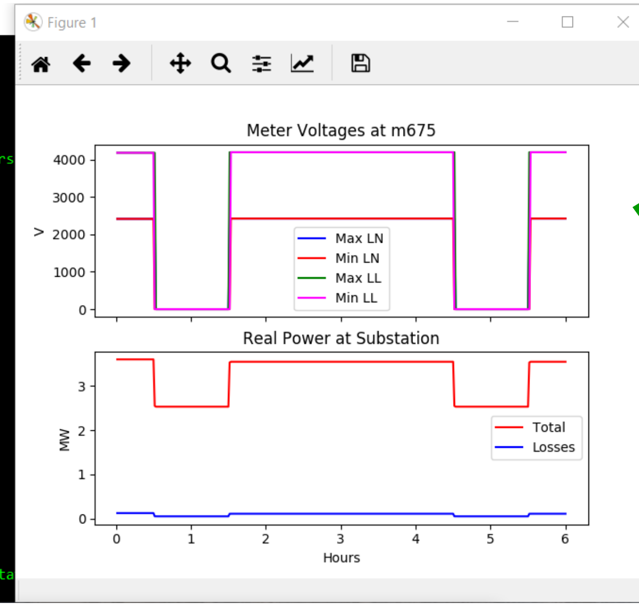
Plotting results from GridLAB-D (GUI will be developed)

Online message passing among different simulation platforms:

DU (python) <=FNCS=> IEEE13-Bus Distribution System (GridLAB-D)

Command Prompt - python plot_loadshed.py loadshed

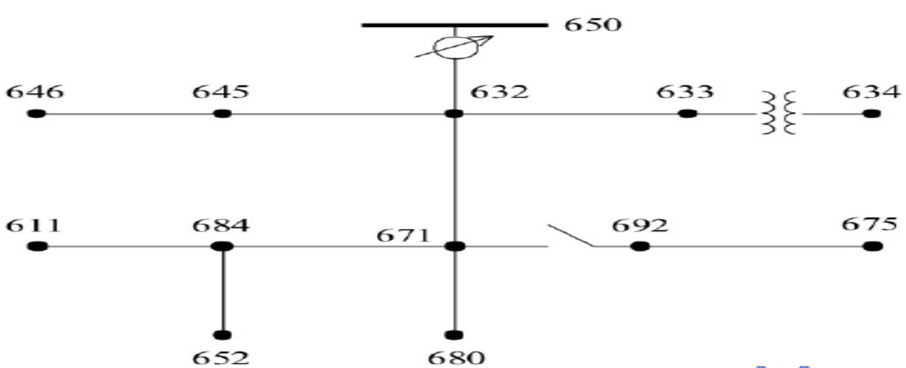
```
oltage_max 12 V
oltage_min 11 V
oltage_unbalance_avg 19 V
oltage_unbalance_max 18 V
oltage_unbalance_min 17 V

onstructed (2, 360, 30) NumPy array for Meters

ubstation Metadata for 1 objects
eactive_energy 9 VARh
eactive_power_avg 6 VAR
eactive_power_losses_avg 16 VAR
eactive_power_losses_max 15 VAR
eactive_power_losses_median 17 VAR
eactive_power_losses_min 14 VAR
eactive_power_max 5 VAR
eactive_power_median 7 VAR
eactive_power_min 4 VAR
eal_energy 8 Wh
eal_power_avg 2 W
eal_power_losses_avg 12 W
eal_power_losses_max 11 W
eal_power_losses_median 13 W
eal_power_losses_min 10 W
eal_power_max 1 W
eal_power_median 3 W
eal_power_min 0 W

onstructed (1, 360, 18) NumPy array for Substa
```



broker_trace - Notepad

File Edit Format View Help

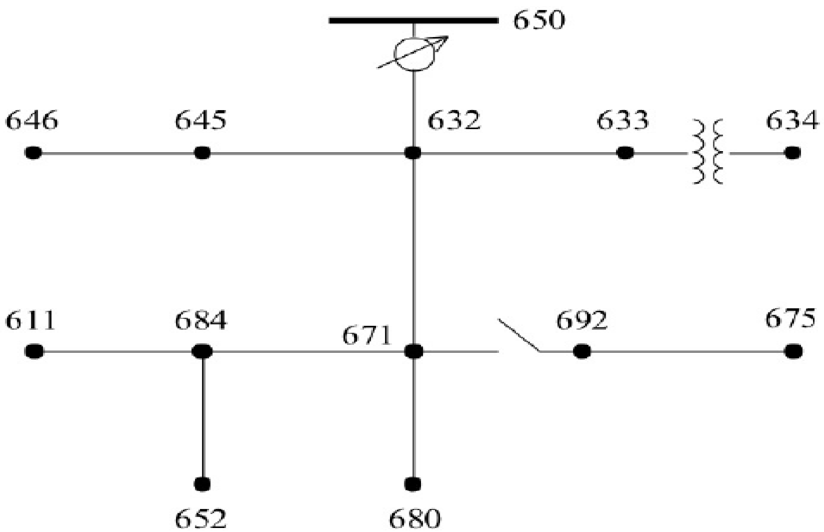
```
#nanoseconds      topic     value
0         player/sw_status          1
0         gridlabdSimulator1/distribution_load     +3.59447e+006+1.69829e+006j VA
1000000000        loadshed/sw_status        1
1800000000000     player/sw_status          0
1801000000000     loadshed/sw_status        0
1802000000000     gridlabdSimulator1/distribution_load     +2.52816e+006+1.54425e+006j VA
5400000000000     player/sw_status          1
5401000000000     loadshed/sw_status        1
5402000000000     gridlabdSimulator1/distribution_load     +3.54115e+006+1.55889e+006j VA
16200000000000    player/sw_status          0
16201000000000    loadshed/sw_status        0
```



IEEE 13-Bus Grid

Task 1.2.1: ITD Test System V1.0
Voltage-Control Test Case … Continued

- Voltage adjusted using Tap Regulator.
- Graphical User Interface will be developed.



- Currently we use trace.txt to monitor data.
- Future GUI will be built to replace txt file.

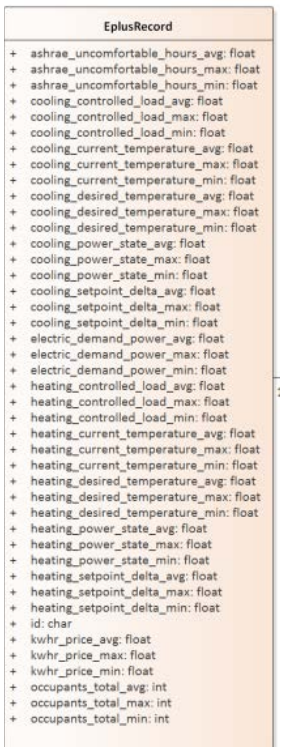
```
#nanoseconds    topic    value
0       gridlabdSimulator1/RtapC        0
0       gridlabdSimulator1/RtapB        0
0       gridlabdSimulator1/RtapA        0
0       gridlabdSimulator1/voltageM611CN        -1192.2+2176.56j V
0       gridlabdSimulator1/voltageM646CN        -1193.11+2127.45j V
0       gridlabdSimulator1/voltageM646BN        -1222.28-2079.72j V
0       gridlabdSimulator1/voltageM645CN        -1193.77+2127.27j V
0       gridlabdSimulator1/voltageM645BN        -1222.02-2080.52j V
0       gridlabdSimulator1/voltT650     +2401.78 V
0       gridlabdSimulator1/voltT632     +2401.78 V
0       gridlabdSimulator1/voltT630     +2401.78 V
0       gridlabdSimulator1/voltT633     +2401.78 V
1000000000      DSO/reg_statusTapA      0
1000000000      DSO/reg_statusTapB      1
1000000000      DSO/reg_statusTapC      1
2000000000      gridlabdSimulator1/RtapC        1
2000000000      gridlabdSimulator1/RtapB        1
2000000000      gridlabdSimulator1/RtapA        0
2000000000      gridlabdSimulator1/voltageM611CN        -1199.98+2190.15j V
2000000000      gridlabdSimulator1/voltageM646CN        -1200.76+2140.71j V
2000000000      gridlabdSimulator1/voltageM646BN        -1229.95-2092.76j V
2000000000      gridlabdSimulator1/voltageM645CN        -1201.42+2140.53j V
2000000000      gridlabdSimulator1/voltageM645BN        -1229.69-2093.55j V
3000000000      DSO/reg_statusTapA      0
3000000000      DSO/reg_statusTapB      2
3000000000      DSO/reg_statusTapC      2
4000000000      gridlabdSimulator1/RtapC        2
4000000000      gridlabdSimulator1/RtapB        2
4000000000      gridlabdSimulator1/RtapA        0
4000000000      gridlabdSimulator1/voltageM611CN        -1195.26+2131.44j V
4000000000      gridlabdSimulator1/voltageM646CN        -1202.09+2117.96j V
4000000000      gridlabdSimulator1/voltageM646BN        -1236.26-2120.2j V
4000000000      gridlabdSimulator1/voltageM645CN        -1202.75+2117.78j V
4000000000      gridlabdSimulator1/voltageM645BN        -1236-2120.99j V
5000000000      DSO/reg_statusTapA      0
5000000000      DSO/reg_statusTapB      3
5000000000      DSO/reg_statusTapC      3
6000000000      gridlabdSimulator1/RtapC        3
6000000000      gridlabdSimulator1/RtapB        3
6000000000      gridlabdSimulator1/RtapA        0
```

Control actions: Increasing tap positions

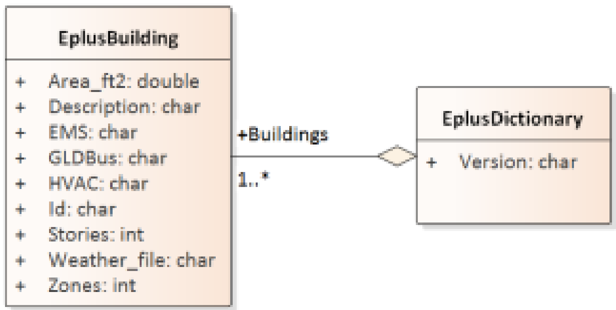
Voltage Measurement (<2400)

Task 1.2.1: ITD Test System V1.0
Price-Control Test Case

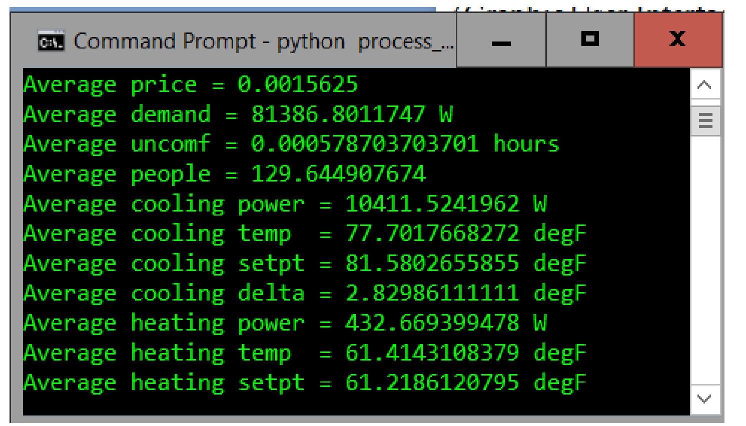
- EnergyPlus is used to model price-responsive HVAC system
- HVAC power consumption switches to OFF when the real-time price is high



Control variables of interest



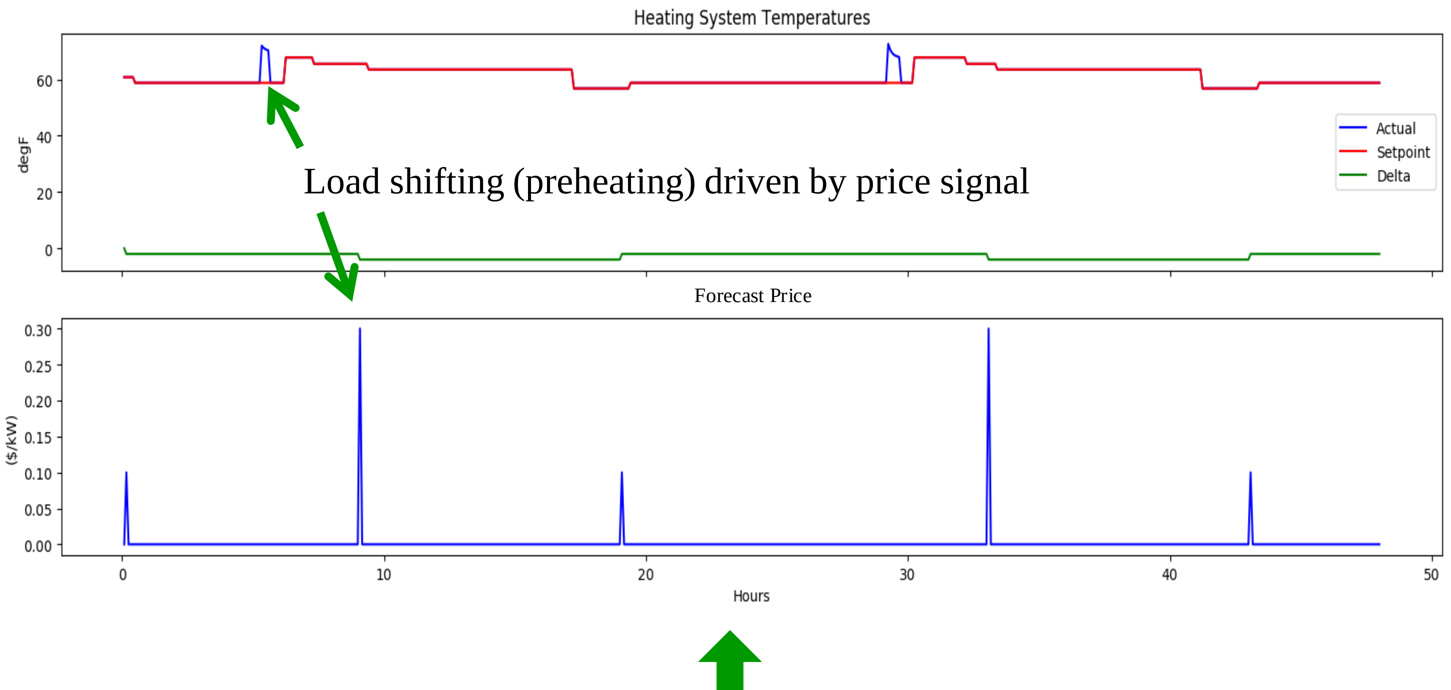
EnergyPlus data management via FNCS



Simulation report

Task 1.2.1: ITD Test System V1.0
Price-Control Test Case … Continued

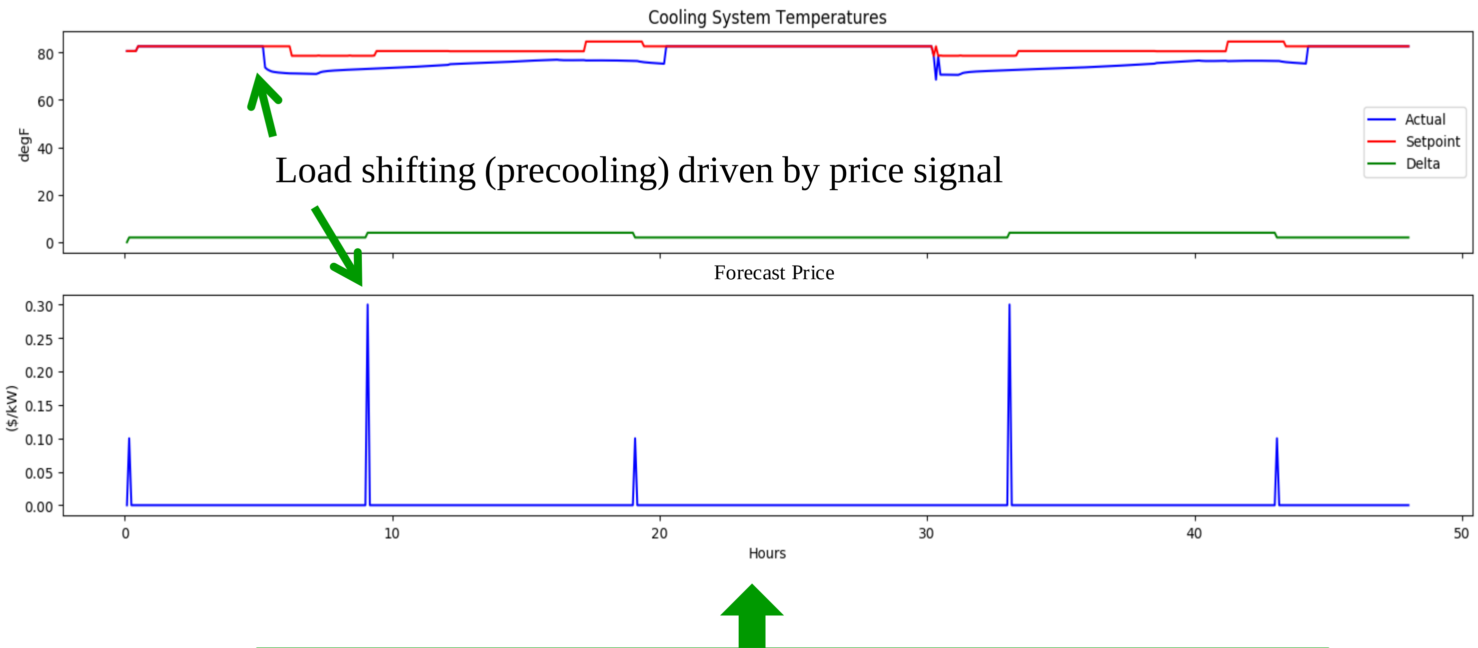
- EnergyPlus is used to model price-responsive HVAC system
- HVAC power consumption switches to OFF when the real-time price is high



Price is high => Power consumption is OFF
=> Temperature decreases (heating system)

Task 1.2.1: ITD Test System V1.0
Price-Control Test Case … Continued

- EnergyPlus is used to model price-responsive HVAC system
- HVAC power consumption switches to OFF when the real-time price is high



Price is high => Power consumption is OFF
=> Temperature increases (cooling system)

Task 1.2.2: Quantify & Model Down/Up DER Ramping

Task 1.2.2: Quantify and model down/up ramping capability of *Distributed Energy Resources (DERs)*

Key Conceptual Issue:

- Should all households be aggregated together?
- Or should sub-aggregates by formed based on household attributes?

Ramping Quantification (Measurement):

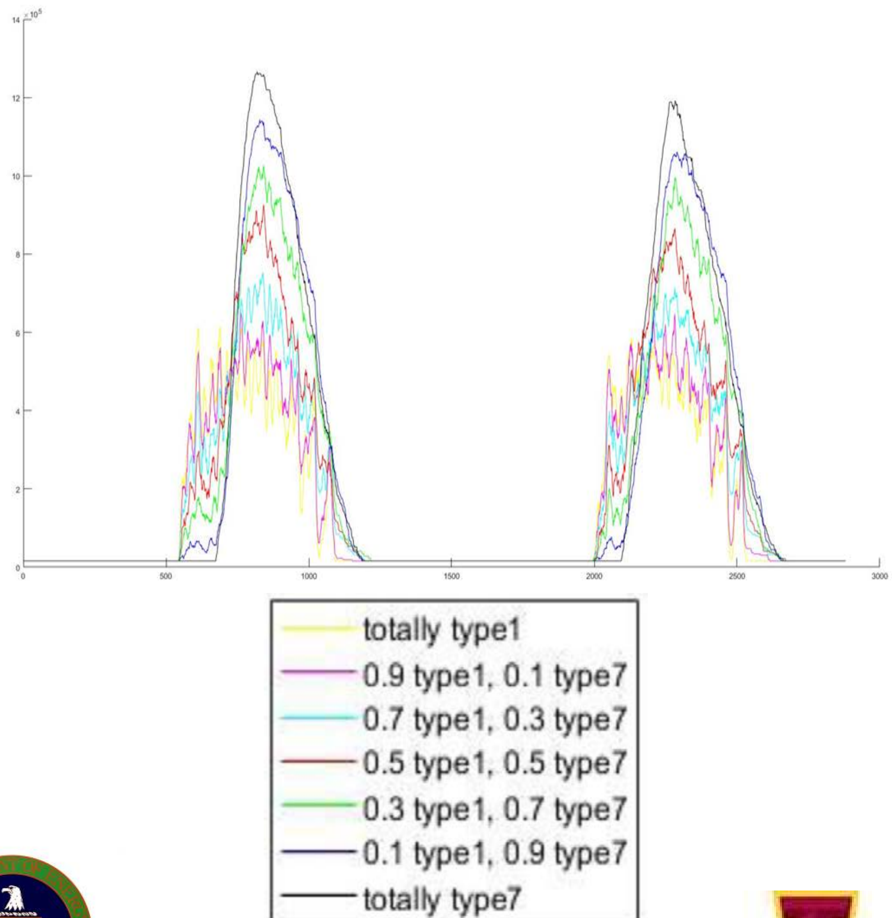
- Ramping is an intrinsic attribute of a power path.
- The ***ramp rate r*** for a power source, expressed in MW per minute, is the rate at which it can change its power output (up or down). Also of interest is a power source's ***range [r^{min}, r^{max}] of feasible down/up ramp rates***.
- Another basic ramping metric is ***power mileage (power path length/Δt).***
- ***Direct visualization of power paths*** under different conditions (including differentially controlled conditions) provides fullest understanding of ramping potential.

Test Cases for HVAC Power Paths and Ramp Rates

Test Case 1: Aggregation for seven mixes of two household types

Weather Data: 8/14/2015

Central Ames, IA



- T-cooling_setting = 60 fahrenheit;
- T-deadband = 7.2 fahrenheit;
- Plots for seven mixes of two household types;
- Each mix has 300 households in total;
- The two household types 1 and 7 have different structural aspects (see below).

Type 1 Household ("Small")

R_ceilings=11;
R_wall=4;
R_floor=4;
R_door=3;
h=7;
x=30;
y=30;
gl_material=1;
gl_treatment=randi([1,2]);
WF=1;
door=4;
I=1.5;
n=1;
WET=1;

Type 7 Household ("Large")

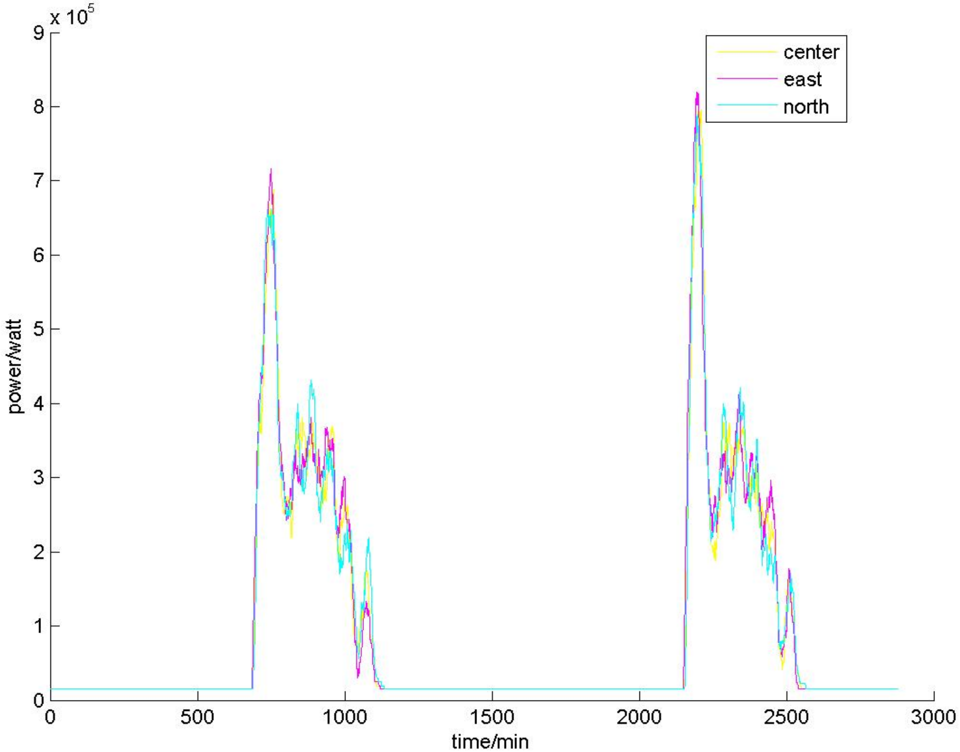
R_ceilings=48;
R_wall=22;
R_floor=30;
R_door=11;
h=8.5;
x=45;
y=50;
gl_material=5;
gl_treatment=randi([12,13]);
WF=4;
door=6;
I=0.5;
n=3;
WET=0.6;

Test Cases for HVAC Power Paths and Ramp Rates …

Test Case 2: Households aggregated by location (weather differences)

Weather Data: 8/14/2015

Ames, IA (Central, East, North)



- T-cooling_setting = 60 fahrenheit;
- T-deadband = 7.2 fahrenheit;
- Each location has 300 households;
- Each household has Type 3 structural attributes.

Type 3 Household ("Medium-Sized")

R_ceilings=19;
R_wall=11;
R_floor=11;
R_door=3;
h=8;
x=35;
y=35;
gl_material=3;
gl_treatment=randi([4,5]);
WF=2;
door=5;
I=1;
n=2;
WET=1;

Accepted Publications (1/1/2017 – Present)

1. H. Ding, P. Pinson, Z. Hu, J. Wang, and Y. Song, "Optimal Offering and Operating Strategy for a Large Wind-Storage System as a Price Maker," *IEEE Transactions on Power Systems*, to appear.
2. L. Tesfatsion, "Electric Power Markets in Transition: Agent-Based Modeling Tools for Transactive Energy Support," In C. Hommes, B. LeBaron (eds.), *Handbook of Computational Economics 4: Heterogeneous Agent Models*. Handbooks in Economics Series. Elsevier: Amsterdam, to appear.
3. L. Tesfatsion, "Modeling Economic Systems as Locally-Constructive Sequential Games," invited paper for the *Journal of Economic Methodology*.
4. W. Li and L. Tesfatsion, "A Swing Contract Market Design for Flexible Service Provision in Electric Power Systems," invited paper *for Energy Markets and Responsive Grids: Modelling, Control, and Optimization,* IMA Volumes in Mathematics and its Applications Series, Springer, to appear.
5. S. Ma, Z. Wang, and L. Tesfatsion, "Swing Contracts with Dynamic Reserves for Flexible Service Management," extended abstract submitted to the *IEEE Transactions on Power Systems*, Special Issue on Transactive Energy, accepted 5/1/2017 for full paper submission.

Presentations (1/1/2017 – Present)

1. L. Tesfatsion, "Electric Power Markets in Transition: Agent-Based Modeling Tools for Transactive Energy Support" (via Skype), Amsterdam Business School, the Netherlands, June 1, 2017.
2. Z. Wang, DOE Project Summary, ISU EPRC Annual Industry Advisory Board Meeting, May 16, 2017.
3. Leigh Tesfatsion, "Modeling Economic Systems as Locally-Constructive Sequential Games," Social Behavioral Modeling and Simulation Workshop, Sponsored by the Defense Advanced Research Project Agency (DARPA), RAND Corporation, Santa Monica, CA, April 3-4, 2017.
4. Leigh Tesfatsion, "Modeling Coupled Physical and Human Systems as Locally-Constructive Sequential Games," Discussion Session Position Paper, Agent-Based Modeling Symposium (ABM 17), Sponsored by the National Science Foundation (NSF), San Diego Marriott Mission Valley, San Diego, CA, April 20-22, 2017.

Looking Forward: Three-Year Task Schedule (PMP)

Proposed Tasks	2017				2018				2019			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1.1 Project management and planning	■	■	■	■								
Task 1.2 Development and evaluation of market-based net service schedules and publications	■	■	■	■								
Task 2.1 Swing contract design for DRAs					■							
Task 2.2 Development of optimal market clearing mechanisms						■						
Task 2.3 Evaluate ability of swing contracting to ensure robust risk and uncertainty management						■	■					
Task 2.4 Compare swing contracting with existing demand response contracting								■				
Task 2.5 Publications					■	■	■	■				
Task 3.1 Enhance IRW Test Bed									■	■		
Task 3.2 Explore broader array of flexible services									■	■		
Task 3.3 Verify and evaluate the proposed flexible service contracting system										■	■	
Task 3.4 Publications									■	■	■	■
Task 3.5 Final reports and documentations												■

Project Tasks for Next Quarter (7/1/2017 – 9/30/2017)
(From PMP, Table 5, Project Schedule)

❑ Task 1.2.3

- Develop estimated aggregate net service schedules for the *Distributed Energy Resource (DER) Aggregator*
- DER Aggregator will be the *Distribution Utility (DU)* agent in the ITD Test System

❑ Task 1.2.4

- Test and calibrate net service schedules and ramping capability models using systematic sensitivity studies
- Sensitivity studies will be carried out using the ITD Test System

Thank you!

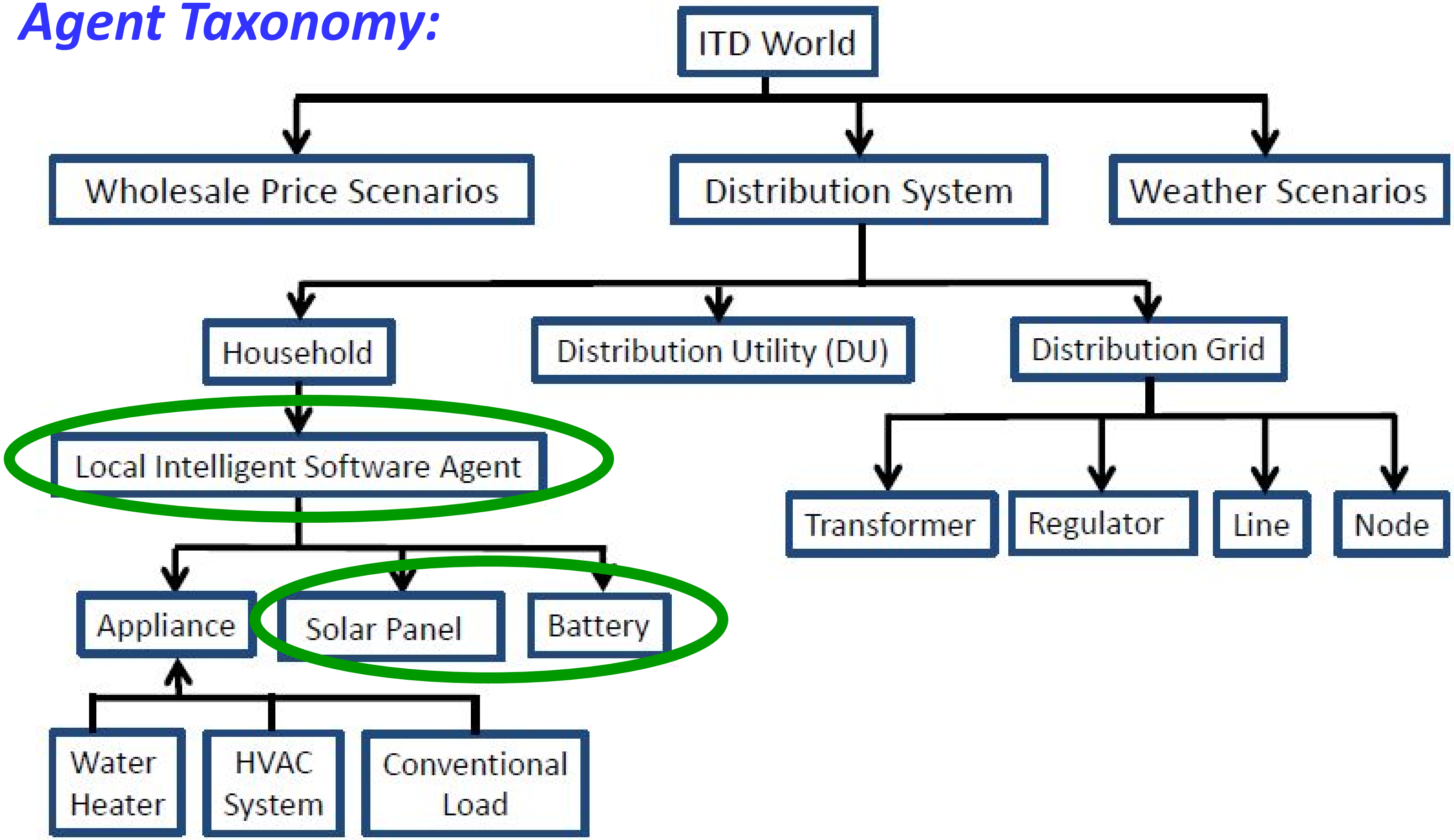
Q&A

Looking Forward: ITD Test System V2.0

- Households will be equipped with ***solar panels*** and ***batteries*** along with water heaters, HVAC systems, and conventional loads.
- A ***Local Intelligent Software Agent (LISA)*** will manage the appliances of each household.
- Each household LISA will have two-way communication with the Distribution Utility (DU) agent.
- Each LISA will submit price-responsive bids/offers ***to*** the DU and receive price signals ***from*** the DU in order to determine the scheduling of its managed appliances.

Looking Forward: ITD Test System V2.0 …

Agent Taxonomy:



Looking Forward: ITD Test System V3.0

- Demands/supplies for power & ancillary services will be determined by means of decentralized bid/offer-based transactions within an ***Integrated Transmission and Distribution (ITD)*** system.
- The wholesale power sector will be implemented using the ***AMES Wholesale Power Market Test Bed***
- The DU will use ***swing contracts*** to offer DER-extracted ancillary services into the wholesale power market.

Looking Forward: ITD Test System V3.0 …

Agent Taxonomy: