Agent-Based Platforms for Electric Power Systems: Teaching, Training, and Research

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Presentation Outline

- What is **Agent-Based Modeling (ABM)** ?
- Three Illustrative ABM Platforms (Open Source, Java/Python/C++/GridLAB-D)
  - **AMES V5.0 Platform**: ABM platform for grid-supported RTO/ISO-managed wholesale power markets
  - **ERCOT Test System**: Specialization of AMES V5.0 to **E**lectric **R**eliability **C**ouncil of **T**exas (**ERCOT**)
  - **ITD TES Platform**: An ABM platform for the study of **T**ransactive **E**nergy **S**ystem (**TES**) designs implemented for **I**ntegrated **T**ransmission and **D**istribution (**ITD**) systems **(FERC Order 2222 Compliance)**
- Bridging the "Valley of Death" for Electric Power System Design
- Concluding Remarks: Why ABM Platforms for Electric Power Systems?
- Background References [1]-[3] & Code/Data Repositories [4]-[8]

What is **A**gent-**B**ased **M**odeling **(ABM) ?** Ref. [1]

- Computational modeling of processes as open-ended dynamic systems of interacting agents
- An ***agent*** is a software entity within a computationally constructed world capable of acting on the basis of its own ***state***, i.e., its own ***internal data, attributes, and/or methods***.

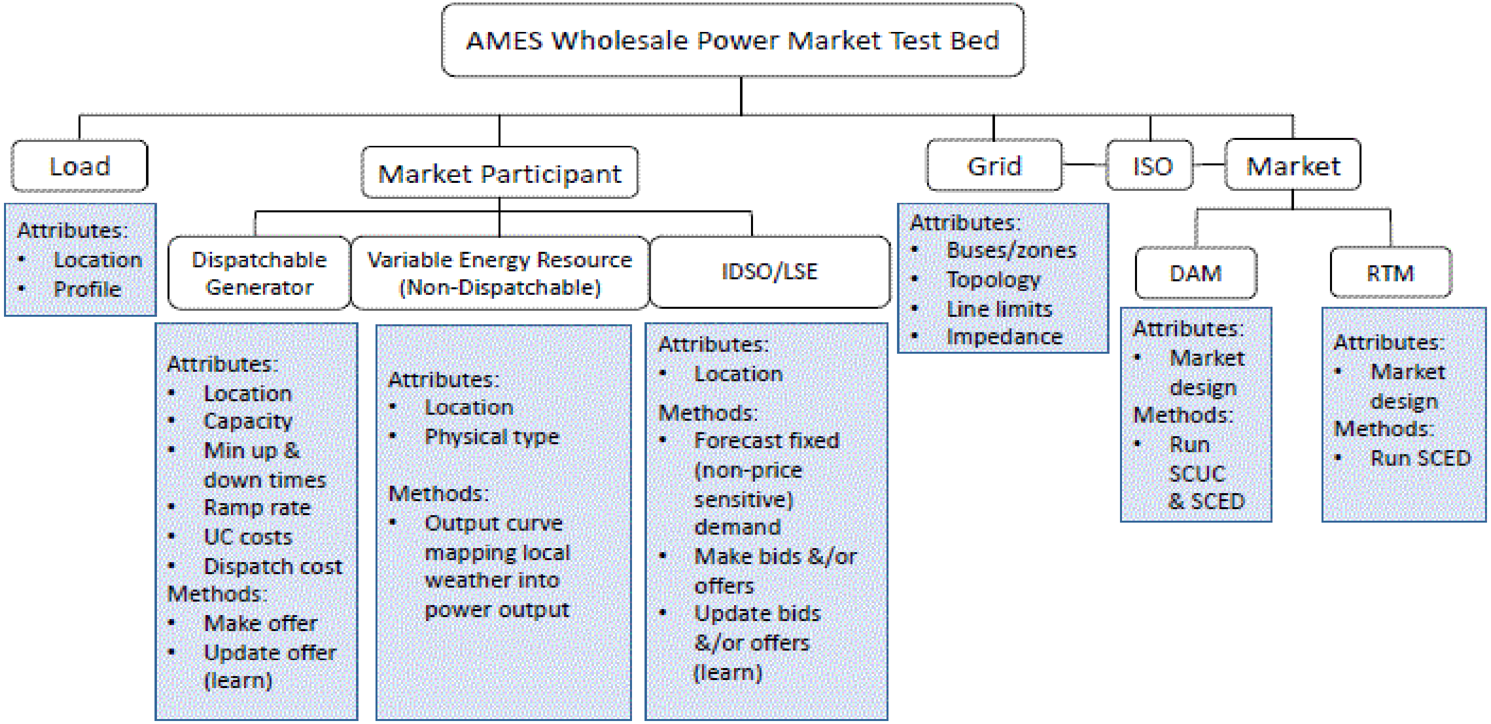
ABM Goals for the Modeling of Real-World Systems

— Permit agents to be as free to act within their virtual ABM world as their empirical counterparts within the real world (verisimilitude);

— Permit events to be fully driven by agent interactions, starting from user-specified initial conditions (culture-dish modeling);

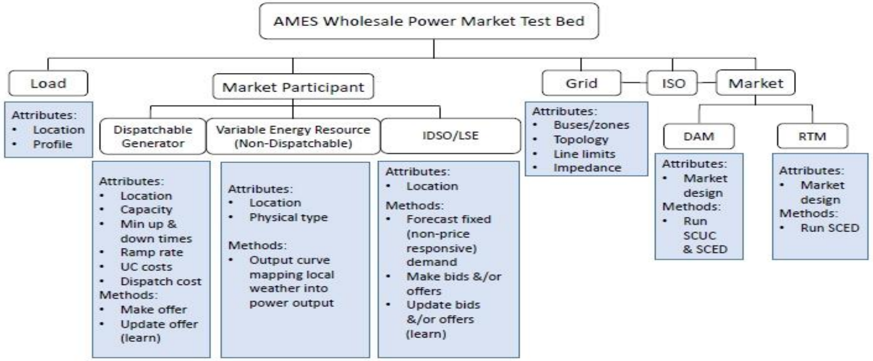
— Permit comprehensive empirical validation (input validation; process validation; descriptive output validation; & predictive output validation).

- AMES V5.0 Platform (Java/Python): GitHub Repository [3]



ERCOT Test System (Java/Python): GitHub Code/Data Repository [6]

AMES V5.0 agents specialized to ERCOT



AMES V5.0 constraints specialized to ERCOT

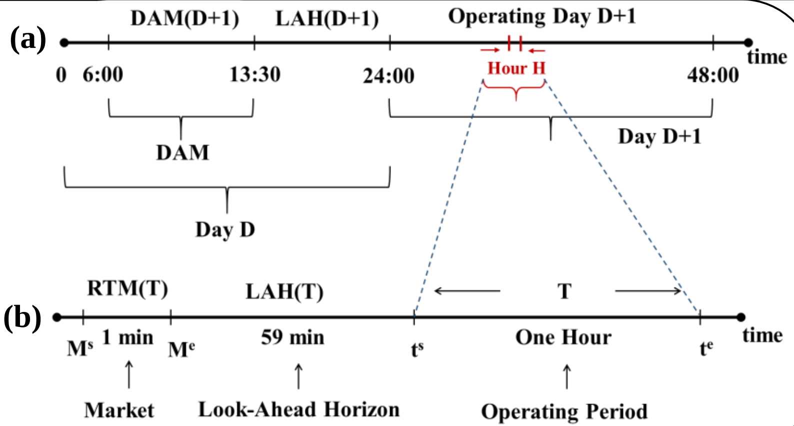
System constraints for SCUC/SCED in DAM & RTM

- Transmission line power flow limits
- Power balance constraints
- Generator capacity constraints
- Dispatchable generator ramp constraints for start-up, normal, and shutdown operating conditions
- Dispatchable generator min up/down-time constraints
- Dispatchable generator hot-start constraints
- System-wide reserve requirement constraints
- Zonal reserve requirement constraints

AMES V5.0 market timing specialized to ERCOT

(a) ERCOT Test System timing configuration for a DAM conducted on day D to facilitate net load balancing during the following day D+1

(b) ERCOT Test System *default* timing configuration for an RTM whose purpose is to facilitate net load balancing for a near-term operating hour T



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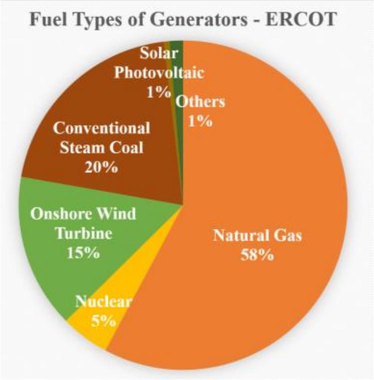
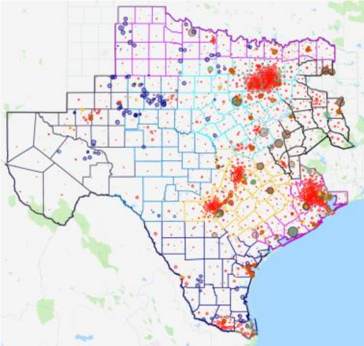
ERCOT Test System Grid: Specialization of AMES V5.0 Transmission Grid to ERCOT

Data



ERCOT generation proportions by major fuel types (2016)



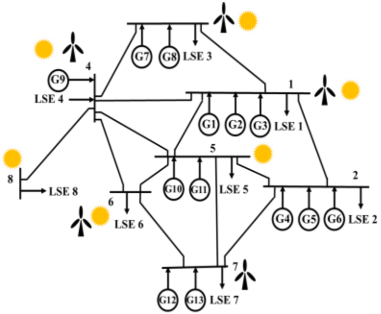
Initial load and generation nodes

Grid Construction*

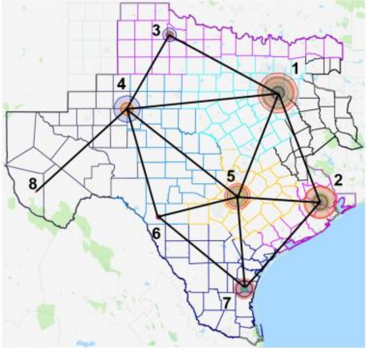
1. Specify the desired number of buses (NB)
2. Obtain ERCOT generation and load data
3. Use the ERCOT data to specify NN initial pure-load and pure-generation nodes, where NN ≥ NB
4. Use a hierarchical clustering algorithm to cluster these NN nodes into NB buses (node clusters).
5. Use a Delaunay Triangulation method plus ERCOT transmission line data to construct transmission lines connecting pairs of the NB buses formed in Step 4.
6. Prune the resulting grid to achieve greater empirical realism for the application at hand, e.g., remove lines that traverse areas outside the energy region of interest.

* Synthetic grid construction method is adapted from: Overbye et al.: https://electricgrids.engr.tamu.edu

Grid Illustration



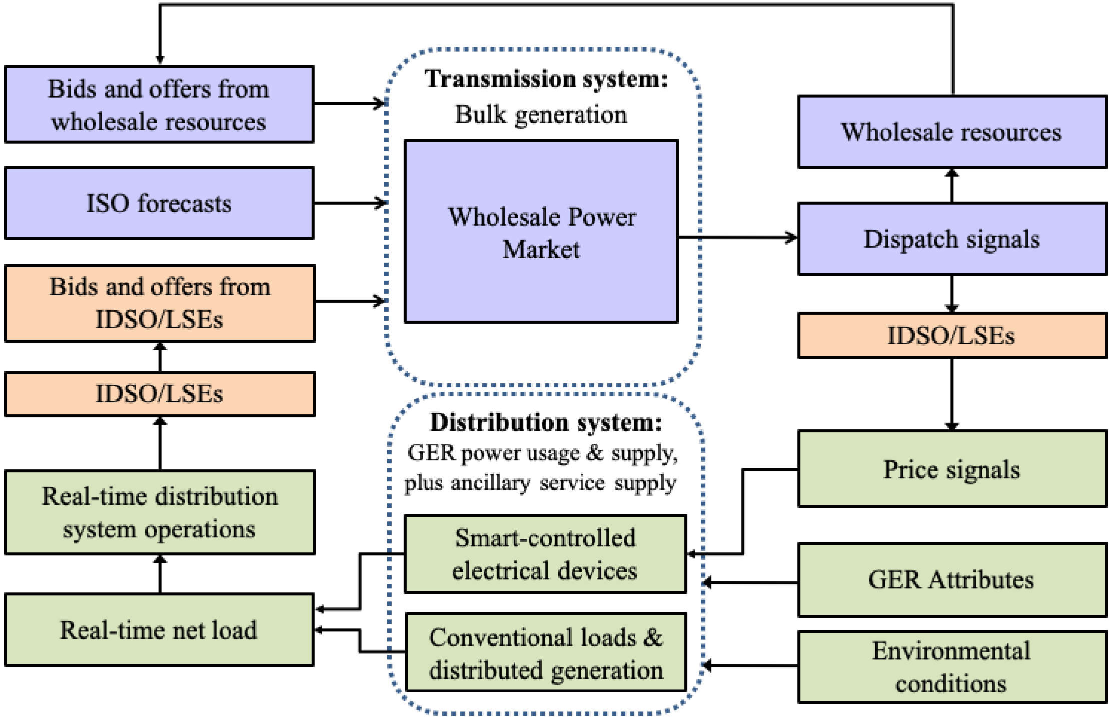
Eight-bus ERCOT test grid



Eight-bus ERCOT test grid superimposed on ERCOT region

ABM Platform for ITD Transactive Energy System (TES) Design Studies

❑ ITD TES Platform (Java/Python/GLD) Refs. [3, Chapters.17-18], [7], & [8]

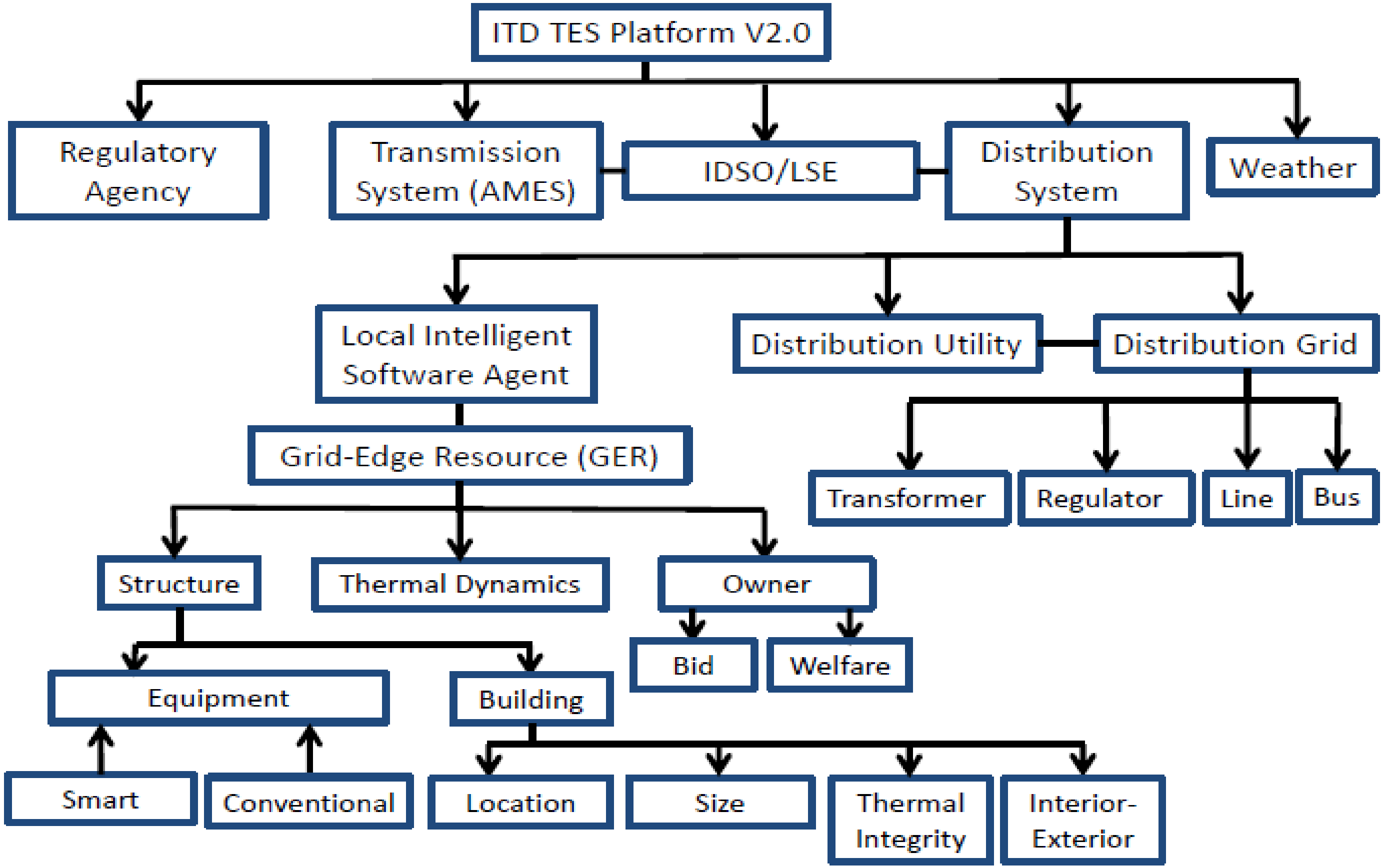


The ITD TES Platform implements an Integrated Transmission and Distribution (ITD) system.

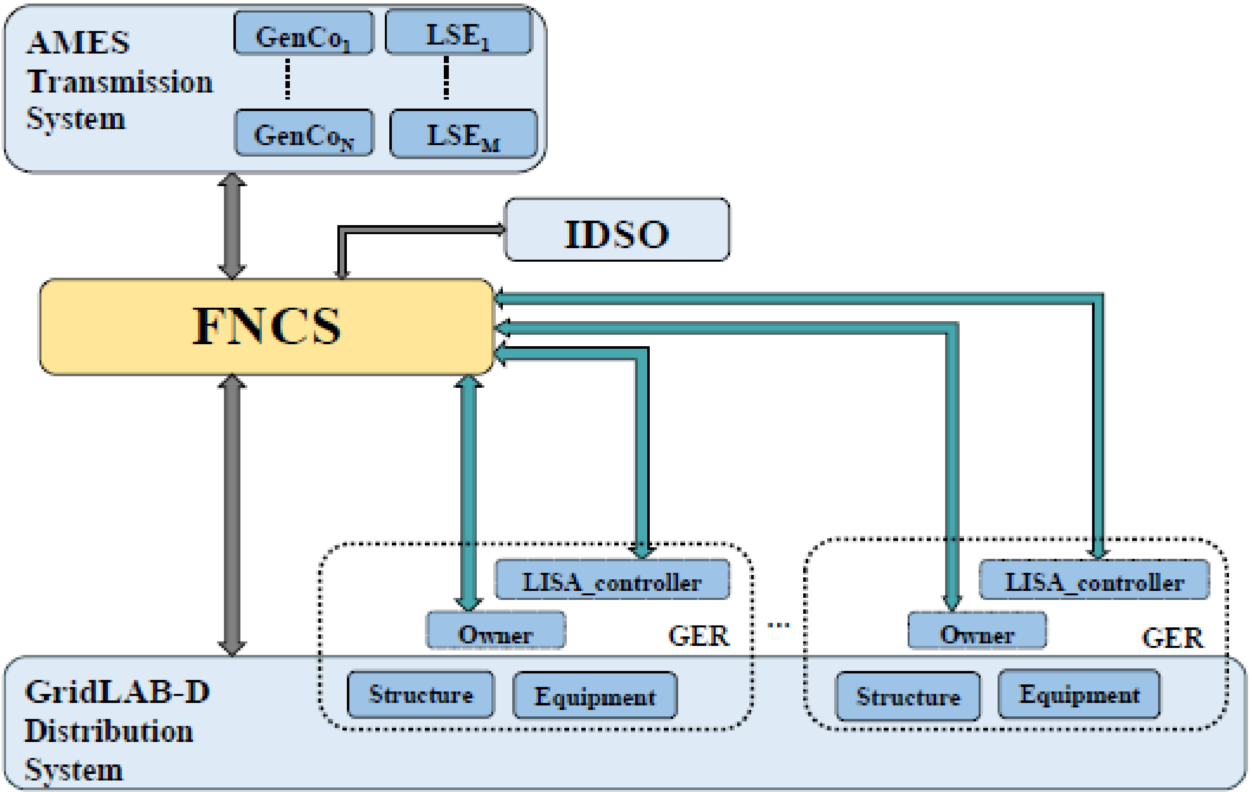
Independent Distribution System Operators (IDSOs) & Load-Serving Entities (LSEs) function as linkage agents at T-D interfaces.

GER = Grid-Edge Resource
= Power resource with a point of connection (POC) to a distribution grid

ITD TES Platform: Hierarchy of Agents



ITD TES Platform: Key Software Components



FNCS = **F**ramework for **N**etwork **Co**-**S**imulation (developed at PNNL)

LISA = **L**ocal **I**ntelligent **S**oftware **A**gent ("Smart Controller")

GER = Grid-**E**dge **R**esource

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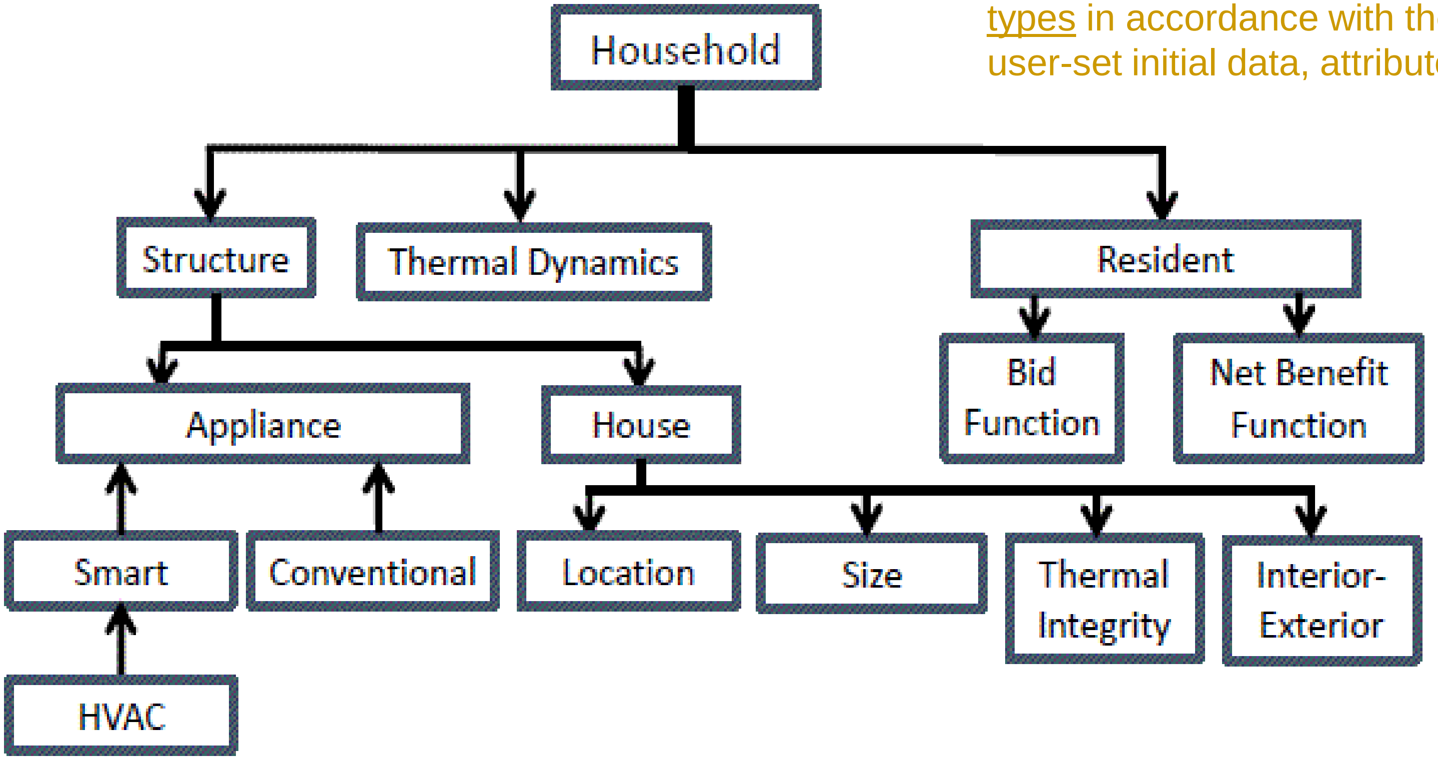
ITD TES Platform Household Module: GitHub Code/Data Repository [8]

Note: Household agents are clustered into <u>base types</u> in accordance with their <u>base states</u> (i.e., their user-set initial data, attributes, and/or methods).



Bridging the "Valley of Death" for Power System Design   Ref. [3, Ch. 18]

- Design implementation should be based on strong empirical evidence.
- Ensuring a design is ready for implementation typically requires multiple modeling efforts at different scales, and with different degrees of empirical validation.
- Moving too soon to design implementation entails major risk of unintended consequences.

Standardized **D**esign **R**eadiness **L**evels (DRLs) Ref. [3, Ch. 18]

DRL-1: Conceptual design idea

DRL-2: Analytic formulation

DRL-3: Low-fidelity model

Basic research carried out at universities...

DRL-4: Moderate-fidelity small-scale model

DRL-5: High-fidelity small-scale model

DRL-6: Prototype small-scale model

"Valley of Death"

DRL-7: Prototype large-scale model

DRL-8: Field study

DRL-9: Real-world implementation

Industry, government, regulatory agencies

Design Readiness Levels DRL4 - DRL6: “Valley of Death”

- Infrequency of design studies in the “Valley of Death” (DRLs 4-6) hinders design development

  Concept ⇒ Implementation

- ABM is well suited for bridging this valley.

  — ABM computational platforms permit design development and performance testing at DRLs 4-6.

- ABM ability to bridge the "Valley of Death" facilitates the use of Iterative Participatory **Modeling (IPM)**

— **IPM for Complex Design Problems***:* Modelers and stakeholders repeatedly cycle through the nine design readiness levels (DRLs 1-9) in an open-ended learning process.

— **Goal of IPM for Complex Design Problems:** Ongoing learning rather than attempted delivery of a "definitive" solution

Conclusion: Why ABM Platforms for Electric Power Systems? Refs. [2],[3]

— **Permit modeling of economic & physical operations** with empirical fidelity ranging from low to high, depending on purpose.

— Permit operations to be **simulated over successive days with run-time visualization** for more comprehensive performance evaluation under normal conditions and in response to **H**igh-**I**mpact **L**ow-**F**requency (**HILF**) events.

— Permit proposed novel design features to be studied **at increasing scales with increasing degrees of empirical fidelity**, thus helping to bridge the "Valley of Death" between conceptual design development and practical design implementation.

— Permit **inclusion of human/social behaviors (e.g., learning)** in two ways: **(i)** computational agents that express human/social behaviors; **(ii)** external real-world humans able to direct the run-time behavior of designated computational agents for experimental purposes.

— Permit **inclusion of data-driven agents (e.g., weather, physical devices, …)** whose actions are guided or driven by data streaming from external events.

Background References [1-3] & Code/Data Repositories [4-8]

[1] Agent-based Computational Economics (ACE): Homepage
https://www2.econ.iastate.edu/tesfatsi/ace.htm

[2] Integrated Transmission and Distribution (ITD) Project: Homepage
https://www2.econ.iastate.edu/tesfatsi/ITDProjectHome.htm

[3] L. Tesfatsion (2021), *A New Swing-Contract Design for Wholesale Power Markets*, 20 Chapters, 288pp., John Wiley & Sons, Inc. (IEEE Press Series on Power Engineering), Hoboken, New Jersey, USA. **(IEEEBookReview,pdf)**, **(FERCTalk,SlideSet,pdf)**, **(Wiley/IEEEPressBookFlyer,pdf)**.

[4] L. Tesfatsion (2021), Agent-based Modeling of Electricity Systems (AMES) Homepage (manuals, code/data links)
https://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

[5] S. Battula, L. Tesfatsion (2020), AMES V5.0 (OSS, Java/Python), *GitHub Repository*
https://github.com/ames-market/AMES-V5.0

[6] S. Battula, L. Tesfatsion, T.E. McDermott (2020), ERCOT Test System (OSS, Java/Python), *GitHub Repository*
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[8] S. Battula, L. Tesfatsion (2020), Household Module (OSS, Python/GLD), *GitHub Repository*
https://github.com/ITDProject/HouseholdFormulationRepository