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

# Report on:

## ERCOT PNNL Contract 401882: *Start Date* 3/19/2018

# Development of an Integrated Transmission and Distribution Test System to Evaluate Transactive Energy Systems

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# ERCOT Contract: Presentation Outline

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- **Updated Task/Milestone Schedule: M1-M3**
- **M3.2 Work to Date:** Summary of AMES V5.0 Work to Date for Milestone M3.2
- **M3.2 Work in Progress:** Summary of AMES V5.0 Work in Progress for Milestone M3.2
- **M3.2: Report on AMES V5.0 Verification Test Cases**
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- **Latest Work: Revised Modeling of AMES V5.0 Reserve Requirement Constraints**
- **Four-Stage GLD Improvement Proposal (emailed to PNNL GLD developers on 3/1/2019)**

# Original Task & Milestone Schedule

| Milestone | Date Due | Original Description |
|---|---|---|
| M1 | May 31, 2018 | 5-zone model of the old ERCOT system, posted to a web repository. |
| M2 | Sep 30, 2018 | Nodal model of the new ERCOT system, posted to a web repository. |
| M3 | Sep 30, 2018 | Submitted conference or journal paper on this work. |

# Updated Task & Milestone Schedule

| Milestone | Date Due | Date Delivered | Fuller Descriptions of Actual Work |
|---|---|---|---|
| M1* DONE | May 31, 2018 | June 5, 2018 | Development of 8-Bus ERCOT model (with nodal locational marginal pricing); grid/load/gen data posted at PNNL repository |
| M2.1 DONE | Sept 30, 2018 | August 1, 2018 | Basic 8-Bus ERCOT Test System, implemented via AMES V3.1, posted at https://github.com/ITDProject/ERCOTTestSystem |
| M2.2 DONE | Sept 30, 2018 | August 24, 2018 | 8-Bus ERCOT Test System (with wind power), implemented via AMES V3.2, posted at https://github.com/ITDProject/ERCOTTestSystem |
| M3.1 DONE | Sept 30, 2018 | August 31, 2018 | 200-Bus ERCOT Test System (with wind power), implemented via AMES V3.2, posted at https://github.com/ITDProject/ERCOTTestSystem/tree/master/ERCOT_Test_Systems/The_200Bus_ERCOT_Test_System |
| M3.2** | July 31, 2019 | | 200-Bus ERCOT Test System (with wind power), implemented via AMES V5.0, to be posted at PNNL/ISU repositories. |
| M3.3** | July 31, 2019 | | Paper to be submitted that focuses on the development of the ERCOT Test Systems |

- * **M1 Modification (Ok'd by PNNL):** For M1 we have skipped the modeling of the old (zonal) ERCOT system and instead directly worked to develop an 8-bus model of the new (nodal) ERCOT system.
- ** **M3 Modification: Contract extension through July 31, 2019 received from PNNL on March 4, 2019, for completion of task M3**

# Summary of AMES V5.0 Work to Date for M3.2

- **Extension of AMES V5.0 Capabilities for Milestone M3.2**
  - [DONE] Coding for Daily DAM SCUC optimization
  - [DONE] Coding for RTM SCED optimization every M minutes (M user specified).
  - [DONE] Coding for FNCS integration to enable network co-simulation.
  - [DONE] Detailed documentation for analytical DAM SCUC/SCED optimization in AMES V5.0
  - [DONE] Basic documentation for AMES V5.0, including a detailed list for all parameters/flags and initial state variables that need user configuration.

# Summary of AMES V5.0 Work to Date for M3.2 … Continued

- **[ DONE ]**

— **Modified `PSST' Code**

- To ensure correct refreshing of initial DAM/RTM conditions for multiple-day runs.
- To report DAM LMPs and GenCo Commitments back to the user.
- To read 'startup' and 'shutdown' cost components from AMES
- To produce output messages related to solver, e.g. status of the solver, termination condition of the solver
- To include the parameter 'Maximum Time Limit' – to allow the solver to terminate after the prescribed time has elapsed

— **Verification Tests Done**

- Verified 'DAM SCUC' outcomes for their correctness for simple test cases
- Verified 'RTM SCED' outcomes for their correctness for simple test cases with RTM running every five minutes (i.e., M=5)
- Verified that AMES V5.0 runs for multiple days
- Verified that all the cost components from AMES are read correctly into the SCUC formulation

# Summary of Work in Progress for Milestone M3.2

- **[IN PROGRESS] Additional Verification Checks for AMES V5.0 Code**
  - Additional DAM/RTM verification test cases are being formulated and conducted.
    - *Example:* Formulation of test cases with varied generator production cost coefficients and minimum generating capacity that permit validation of production cost component modeling for the SCUC optimization
  - Need to ensure outcomes are reported properly back to the user. Additional data that need to be written to '.out' file are: RTM LMPs, RTM GenCo commitment data, DAM/RTM power flow data, LMP true costs, and generator profit/propensity data.
  - Detailed verification of PSST code for validating SCUC optimization formulation, including both objective function and constraints.

- **[IN PROGRESS] Further Cleaning Up of AMES V5.0 Code**
  - Current code includes unused functions that need to be removed.

# Report on AMES V5.0 Verification Test Cases

# Notes on AMES V5.0 Test-Case Data Files

- Input data files for verification test cases are located in the following GitHub website directory: AMES-V5.0\DATA\VerificationTestCases\
- Intermediary output files:
  - Data files written by AMES V5.0
    - ✓ ReferenceModel.dat : This is an input file for PSST that contains input data required to solve SCUC.
    - ✓ RTReferenceModel.dat : This is an input file for PSST that contains input data required to solve SCUC.
    - ✓ rt-unitcommitments.dat: : This is an input file for PSST that contains the unit commitment status of each generator for each M-minute period.
  - SCUC output data files generated by PSST for Day-Ahead Market (DAM)
    - ✓ xfertoames.dat : Contains DAM unit commitment status and dispatch schedule for each generator along with generator ID.
    - ✓ DAMLMP.dat : Contains DAM LMP at each bus for each hour of a 24-hour period
  - SCED output data files generated by PSST for the Real-Time Market (RTM)
    - ✓ RTSCED.dat : Contains RTM LMP at each bus for each M-minute period, power dispatch scheduled for each generator for the next M-minute period, and start-up and shut-down cost details for each minute of each M-minute period.

# AMES – PSST : Sequence of Events

Step 0: Initialize D = 0, H = 0, I = 0;

Step 1: AMES starts DAM operation on day ‘D’ for day ‘D+1’.

Step 2: AMES writes ‘ReferenceModel.dat’ file and makes an external call to PSST to solve SCUC.

Step 3: PSST reads the input file ‘ReferenceModel.dat’ and performs SCUC.

Step 4: PSST writes SCUC outcomes into ‘DAMLMP.dat’ and ‘xfertoames.dat’ files.

Step 5: AMES reads ‘DAMLMP.dat’ and ‘xfertoames.dat’ and updates its DAM outcomes.

Step 6: AMES starts RTM operations for interval ‘I’ (duration of each interval = ‘M’ min).

Step 7: AMES writes ‘rt-unitcommitments.dat’ (contains generator unit commitments of day ‘D’ and ‘RTReferenceModel.dat’ and makes an external call to PSST to solve SCED.

Step 8: PSST reads the input files ‘rt-unitcommitments.dat’, ‘RTReferenceModel.dat’ and performs SCED.

# AMES – PSST : Sequence of Events … Continued

Step 9: PSST writes SCED outcomes into ‘RTSCED.dat’.

Step 10: AMES reads ‘RTSCED.dat’ and updates RTM outcomes.

Step 11: Increment I;

```
If (I*M % 60 == 0) {
        H++;
}
If (H% 24 == 0) {
        increment D;
        goto Step 0;
}
Else goto Step 6.
```

# Summary of Completed AMES V5.0 Verification Test Cases

- VerTestCaseBaseCase
  - This test case produces SCUC/SCED outcomes under the following conditions:
    - ✓ Transmission congestion is absent
    - ✓ Minimum power generation limits are taken to be zero
    - ✓ Start up, shut down and no-load costs are taken to be zero
    - ✓ Minimum up-time and down-time values are taken to be 0 (hr)
    - ✓ No ramping limits
    - ✓ Day-ahead and real-time load forecasts are set equal
  - This test case provides a base case for later comparison purposes.
- VerTestCaseGenMinPowerLevel
  - This test case verifies a generator's minimum power level is maintained when it is committed, given the above-stated conditions (i) and (iii)-(vi).
- VerTestCaseUpTimeDownTime
  - This test case verifies a generator's minimum up time and down time are maintained when it is committed, given the above-stated conditions (i) and (iii)-(vi).
- VerTestCaseMultiDayRun
  - This test case verifies DAM/RTM initial conditions are refreshed appropriately when AMES V5.0 is run for multiple successive days.

Note: Files for the above test cases are uploaded at https://github.com/ITDProject/ERCOTTestSystem/tree/dev-source-code/AMES-V5.0/DATA/VerificationTestCases

# Summary of Additional Completed and Ongoing AMES V5.0 Verification Test Cases

- VerTestCaseCostComponents

The purpose of this test case is to verify cost component aspects of the SCUC formulation under the above-stated conditions (i)-(ii) and (iv)-(vi) – i.e., to verify that the SCUC formulation correctly includes no load, start-up, dispatch, and shut-down cost components.

✓ Completed

- VerTestCaseCostComponentsNoLoad

  This test case verifies that no load cost is appropriately taken into account in SCUC/SCED formulation given the above-stated conditions (i), (ii) and (iv)-(vi).

✓ To be completed

- VerTestCaseCostComponentsStartUP
- VerTestCaseCostComponentsShutDown

# Total Production Cost Modeling in AMES V5.0 for SCUC/SCED Operations

1. For any given generator j, the user specifies a convex total production cost function

   $TPC(p) = a + bp + cp^2$ ,

   $p \in [\underline{P}, \overline{P}]$, applicable for each operating period k (e.g., hourly).

2. User then sets the number NL of power blocks ("segments"), and either

i. specifies the length of each of the NL power blocks, starting at $\underline{P}$ and ending at $\overline{P}$ , OR

ii. chooses "Automated Approximation Option" in which the power output range $[\underline{P}, \overline{P}]$ is simply divided into NL equal-length blocks.

3. A piecewise-linear approximation for TPC(p) is then constructed; see Fig. 1.

4. A point (p,TPC(p)) approximates gen j's TPC for period k if gen j maintains power injection level p during entire period k.

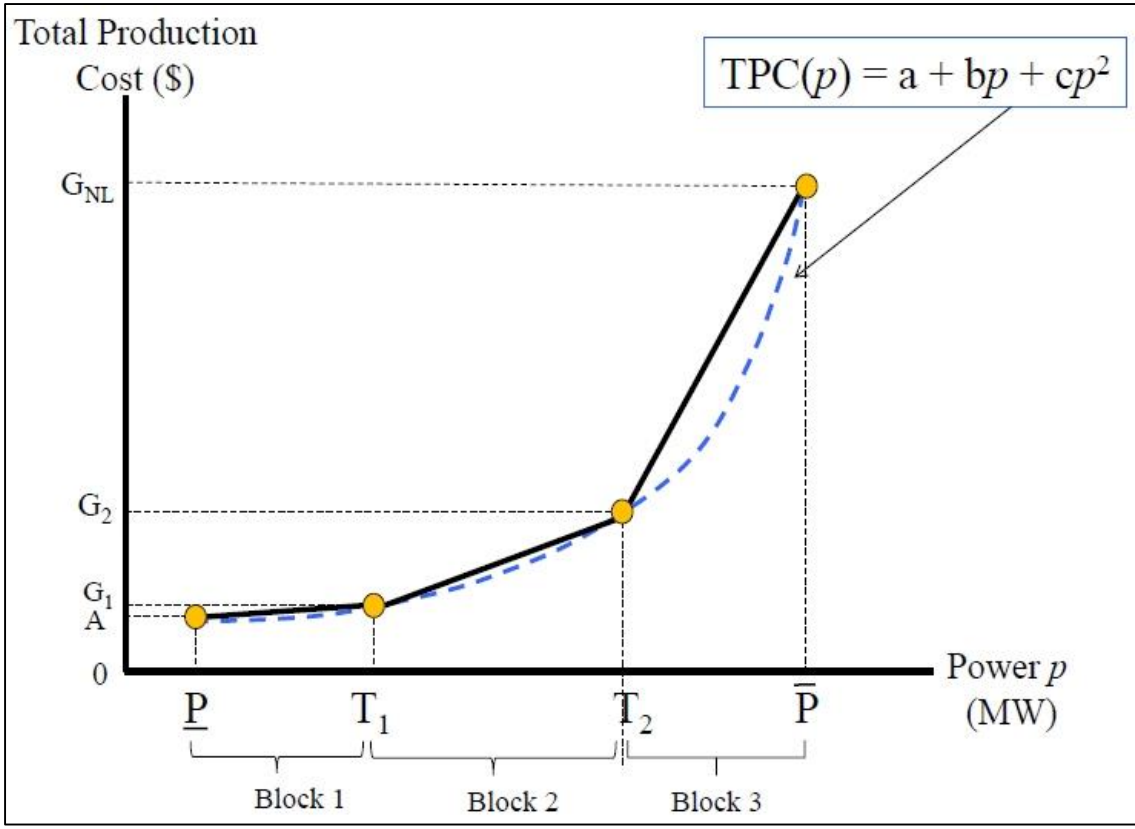


Fig 1. Linearized approximation for the total production cost function TPC(p) of a generator j, used for each operating period k (e.g., each hour).

**NOTE:** For a detailed explanation of construction 1.-3., please refer to Section 5 of "Analytical Formulation and Python Implementation for an Extended Carrion/Arroyo SCUC/SCED Optimization Formulation" at http://www2.econ.iastate.edu/tesfatsi/ECAModelAndPyomoCodeDoc.LTesfatsion.pdf

# Brief Summary of Planned Future AMES V5.0 Verification Test Cases

- VerTestCaseRampUpRampDown

  The purpose of this test case is to verify that ramping constraints are correctly modeled in the SCUC/SCED formulation.

- VerTestCaseNonDispatchableGeneration

  The purpose of this test case is to verify if non-dispatchable generation is correctly taken into account in the SCUC/SCED formulation.

# Progress on Specific AMES V5.0 Requests Received from PNNL

- List of tasks
  - LMP results for SCED - Done
    - ✓ AMES V5.0 has been modified to fix some bugs – the latest files will be uploaded on GitHub
    - ✓ Currently maintained assumptions for SCUC/SCED operations:
      - For now, the net load for day D+1 RTM operations is assumed to be the same as forecasted in the day-D DAM.
      - For now, commitment status of generators in day D+1 RTM operations is assumed to be the same as determined in the day-D DAM.
  - Specification of 'NL' - Done
    - ✓ In the psst folder, the value of 'NL' in 'cli.py' needs to be set in order to specify the number of power blocks (segments)
  - Testing of SCED separately from SCUC
    - ✓ Can be done by pre-setting 0/1 unit commitment variables to any desired values
  - Notes on AMES V5.0 Stopping Rules – In progress (see partial descriptions below)

# Notes on Stopping Rules

- Stopping Rules = Rules determining the termination of a simulation run

- Stopping Rule 1 : Maximum Day (total number of days to be simulated)
- Stopping Rule 2: Threshold Probability (stabilization of action choice probabilities)
- Stopping Rule 3: Generator Action Probability (stabilization of action choices)
- Stopping Rule 4: Generator Learning Results (stabilization of all learning outcomes)
- Stopping Rule 5: Daily Net Earning (stabilization of GenCo daily net earning outcomes)

***NOTE:*** Stopping Rules 2-4 are only relevant for test cases in which at least one AMES GenCo has "learning capabilities" turned on, enabling it to adaptively update its DAM supply offers from one day to the next in an attempt to increase its daily net earnings. AMES V5.0 learning settings will be discussed in a later slideset.

## Maximum Day Stopping Rule

- The Maximum Day stopping rule requires user to set a MaxDay integer-valued parameter,
  - where MaxDay denotes the total number of simulated days the simulation will run.
  - If MaxDay =10, for example, the simulation will run for 10 successive simulated days.
- Notes: In earlier versions of AMES, the parameter is Max_Day which has been changed to MaxDay in the latest version.
- The 'MaxDay' can be set as follows, where the code snippet has been taken from an input test case

```
// Simulation Parameters
MaxDay          1
RandomSeed 695672061
ThresholdProbability 0.999
```

# Latest Work: Modeling Reserve Requirement Constraints

- The SCUC/SCED formulation for AMES V5.0 has been modified as follows. For details, see the latest ECA/Pyomo Model notes available at:

https://github.com/ITDProject/ERCOTTestSystem/blob/master/Documentation/ECAModelAndPyomoCodeDoc.LTesfatsion.20Feb2019.pdf

  - ✓ Introduced run-time variables \underline{p}_g(k) into the SCUC/SCED optimization that give the minimum possible power output (MW) for each dispatchable generator g in each time-period k.
  - ✓ Modified constraints (14)-(16) and (19) in the SCUC/SCED optimization to include these run-time minimum possible power outputs.
  - ✓ Modified constraints (41) – (44) in the SCUC/SCED optimization, which give the system-wide and zonal spinning reserve requirement constraints for this optimization.

- Completed AMES V5.0 coding of system-wide spinning reserve requirement constraints in accordance with the latest ECA/Pyomo Model notes.

# Four-Stage GLD Improvement Proposal (Emailed to PNNL GLD developers on March 1, 2019)

- STAGE ONE: Improve current GLD documentation
  - Provision of clear variable/parameter definitions and consolidated documentation for GLD as it currently exists.
- STAGE TWO: Develop additional user cases
  - Provision of additional relatively-simple user cases for GLD to reduce the GLD learning curve. These GLD user cases should be accompanied by step-by-step instructions (perhaps even YouTube videos).
- THIRD STAGE: Develop an "Agent-Based" GLD
  - This Agent-Based GLD should be a "macro" version of the current GLD code, much as LaTeX provides a macro version of TeX.
  - More precisely, this Agent-Based GLD should provide clear and comprehensive documentation for a collection of "representative" Distribution System (DS) agent types that can be modeled and implemented via GLD.
- FOURTH STAGE: Incorporate the Agent-Based GLD as the DS component of an open-source agent-based computational platform modeling integrated T & D system operations.