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

- Original Task/Milestone Schedule: M1-M3
- Updated Task/Milestone Schedule: M1-M3
- M3.2: Summary of AMES V5.0 Work to Date
- M3.2: Summary of AMES V5.0 Work in Progress
- M3.2: Report on AMES V5.0 Verification Test Cases & Specific PNNL Requests (AMES-PSST sequencing, stopping rules, modeling of total production costs)
- M3.2: Latest AMES V5.0 Work:
  - Completed coding of system-wide and zonal reserve requirement constraints
  - Clarification of AMES V5.0 naming conventions for transmission grid configuration
  - ERCOT 200-bus test case input modified to be in conformity with AMES V5.0 transmission grid naming conventions
  - AMES V5.0 code modified to permit solutions with non-zero power balance slack variables in cases where load cannot be balanced at one or more buses due to insufficient generation capacity and/or transmission grid congestion.
  - ERCOT 200-Bus Test Case (1-day) now runs with no compilation or run-time errors

# 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**

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

- **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.

# M3.2: Summary of AMES V5.0 Work to Date … 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 Test Cases**

- 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

# Verification Test Cases: 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.

# Verification Test Cases: Summary Listing

- 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

# Verification Test Cases: Summary Listing … Continued

- 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

# 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 'NS' - Done
    - ✓ In the psst folder, the value of 'NS' in 'cli.py' needs to be set in order to specify the number of power segments for the total cost function approximations
  - 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)

# 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.
```

# 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: GenCo Action Probability (stabilization of action choices)
- Stopping Rule 4: GenCo 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 Generating Company (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.

# Notes on Stopping Rules … Continued

## Maximum Day Stopping Rule

- The Maximum Day stopping rule requires a user to set an integer-valued parameter named MaxDay, where MaxDay = total number of simulated days the simulation will run.
- Example: MaxDay = 10
  - If no other stopping rules are set, the simulation will run for exactly 10 successive simulated days.
  - If other stopping rules are set, the simulation will run for at most 10 days. However, other stopping rules could cause earlier stoppage.
- Notes: In earlier AMES versions, this parameter is named Max_Day; this parameter name has been changed to MaxDay in AMES V5.0.
- The 'MaxDay' value 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
```

# 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.

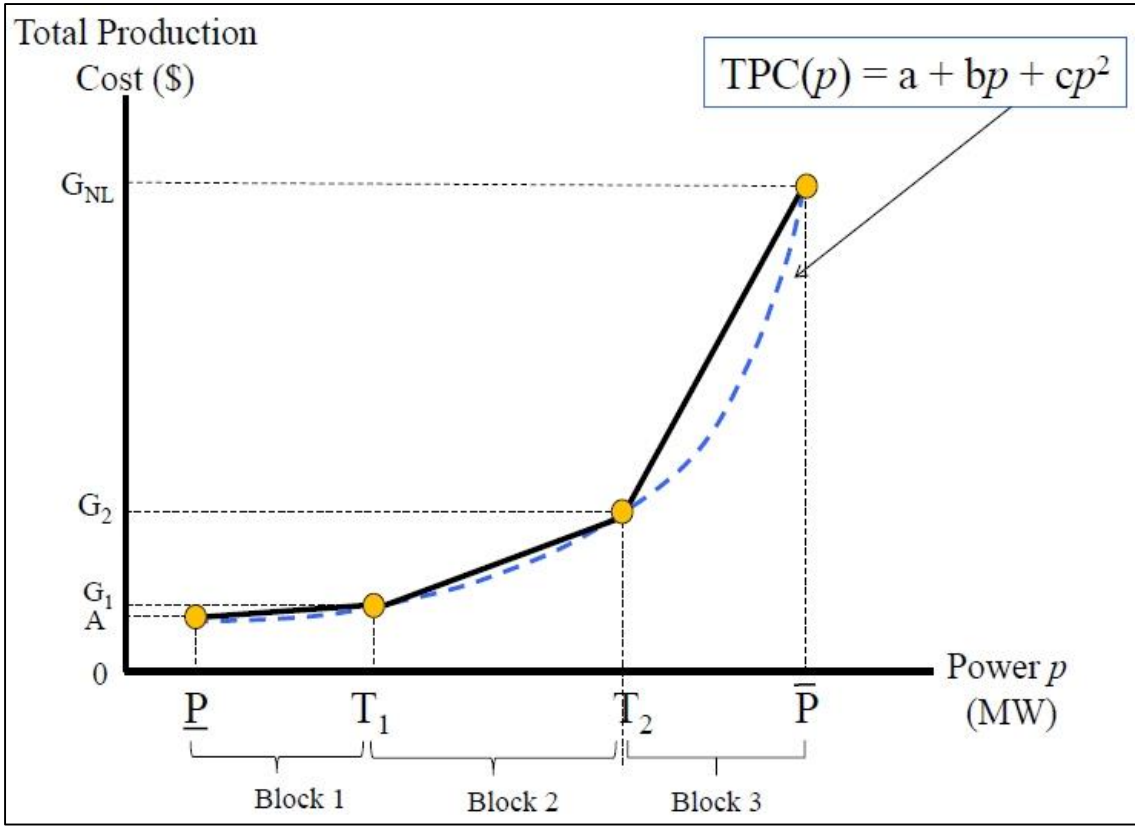


Fig 1. Linearized approximation for the total production cost function TPC(p) of a generator j, used for each operating period k (e.g., each hour).

**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

# Latest AMES V5.0 Work: 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.

# Latest AMES V5.0 Work: Naming Conventions for Grid Configuration

- AMES V5.0 uses “bus” and “line” for the physical configuration of grids
- For a grid with ‘NB’ buses, the buses must be named ***in sequence*** as 1, 2, 3,… NB
- Any two distinct buses can have at most one line connecting them.
- The following line-naming convention must be used: If a line connects two distinct buses, first order the buses in sequence so that the lower-numbered bus comes first: e.g., i < j . The line connecting bus i and bus j is then denoted by (i,j).

- **5-Bus Grid Example:** Buses must be named in sequence (no gaps) as 1, 2, 3, 4, 5
  - All possible lines are (1,2), (1,3), (1,4), (1,5), (2,3), (2,4), (2,5), (3,4), (3,5) and (4,5).
  - Lines for 5-Bus Grid Example: Note that this example grid is not completely connected, i.e., some distinct bus pairs have no direct line connection. Also, the user can insert whatever “Name” is desired for the line names.

| Name | From Bus: | To Bus: |
|---|---|---|
| Line (1,2) | 1 | 2 |
| Line (1,4) | 1 | 4 |
| Line (1,5) | 1 | 5 |
| Line (2,3) | 2 | 3 |
| Line (3,4) | 3 | 4 |
| Line (4,5) | 4 | 5 |

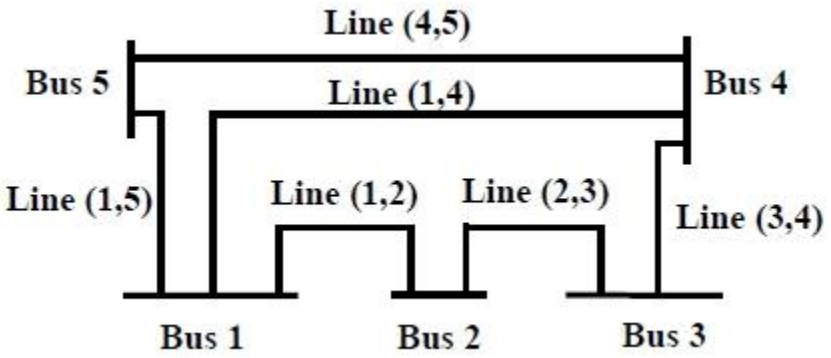


Fig: Depiction of lines & buses for 5-Bus Grid Example

# Latest AMES V5.0 Work …. Continued

- Modified AMES V5.0 code to remove the need to input
  - Zonal data
  - Price-sensitive demand data
  - Hybrid flag data
- Removed 'data verification check' for cases handled by slack variables – e.g. when sum of GenCos Min Capacity > sum of fixed load (for any hour), this no longer produces an error. This scenario is handled by power-balance slack variables in the SCUC/SCED optimization.
- Modified 'AMES_ercot_200bus.dat' file data to follow the afore-stated naming convention.
- With the modifications specified on previous slide, now AMES V5.0 is able to run test case 'AMES_ercot_200bus.dat' without run-time errors for a single day.
- Uploaded the modified 'AMES_ercot_200bus.dat' file at https://github.com/ITDProject/ERCOTTestSystem/tree/dev-source-code/AMES-V5.0/DATA/ERCOT
- Uploaded the latest code at https://github.com/ITDProject/ERCOTTestSystem/tree/dev-source-code/AMES-V5.0