Sandia National Laboratories

QUEST PCM: A PRODUCTION COST MODELING TOOL WITH HIGH-FIDELITY MODELS OF ENERGY STORAGE SYSTEMS

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PROJECT PROFILE

Topic: Analytics & Tools| Vertical: Analytics
Strategic Pathway: Optimize
Project start and finish: FY25-Ongoing

PROBLEM

- Production cost modeling (PCM) is critical for power system operations analysis and support national priorities for **grid reliability**, **affordability**, and **resilience**
- As the grid become more complex, PCM frameworks must evolve to accurately capture **operational dynamics** and **characteristics** of emerging technologies including **energy storage systems (ESS)**
- Existing open-source PCM tools:
  - ➢ Use *low-fidelity ESS models*, underestimating storage value and leading to suboptimal operational decisions
  - ➢ Deploy conventional unit commitment models, resulting in significant computational complexity and extended solve times

APPROACH

Goal: Develop open-source PCM tool with **advanced ESS operation** and **unit commitment models** for accurate evaluation of power system operations

- Chronological day-ahead unit-commitment (UC) and real-time economic dispatch (ED) simulation
- EGRET [1] serves as the optimization engine for UC and ED
- ESS models formed using *Pyomo* and interfaced to UC and ED frameworks
- **Key novelties:**
  - ✓ **Tech-specific ESS models** (currently supporting generic, battery, pumped hydro storage)
  - ✓ **Ancillary market participation models for ESS** (e.g., revenue evaluation, state-of-charge (SoC) withholding)
  - ✓ **SoC coordination method** for real-time ED based on day-ahead UC SoC trajectory
  - ✓ **Temporal decomposition** of UC for improved performance

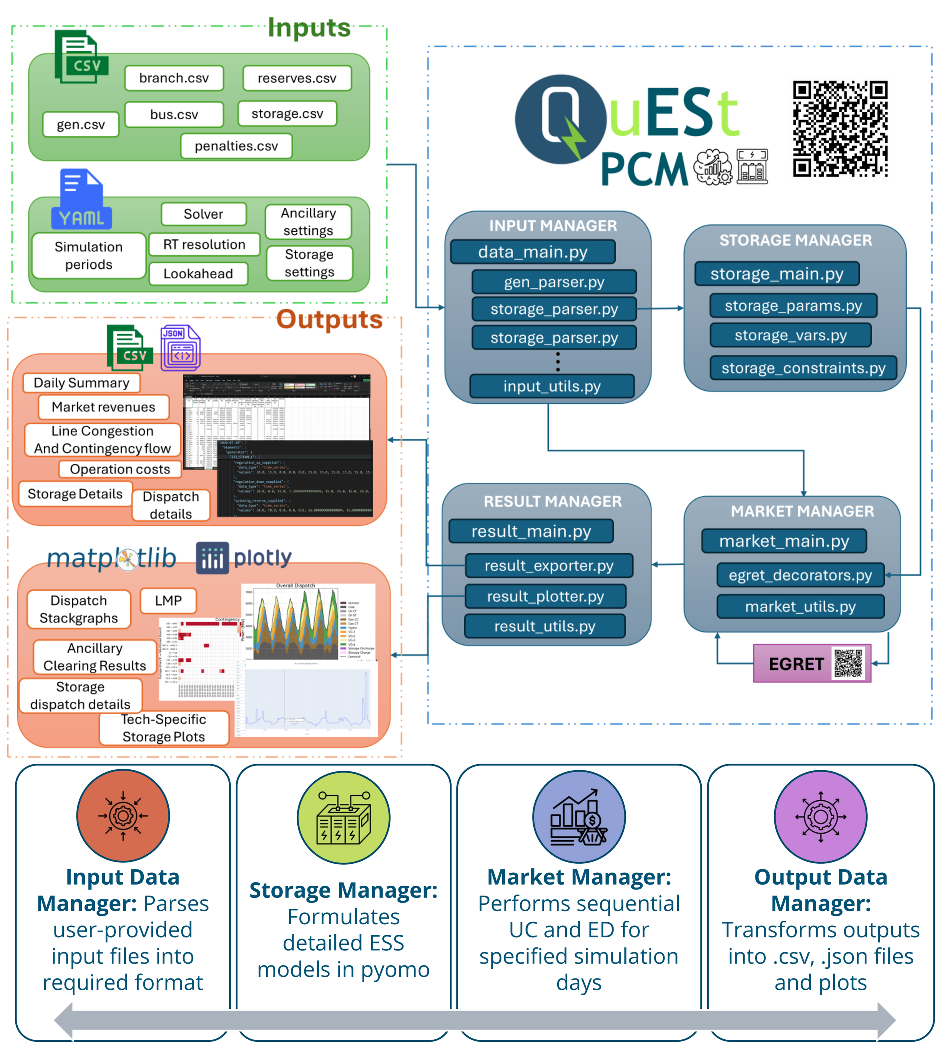


Fig. 2. Overview of the QuESt PCM tool

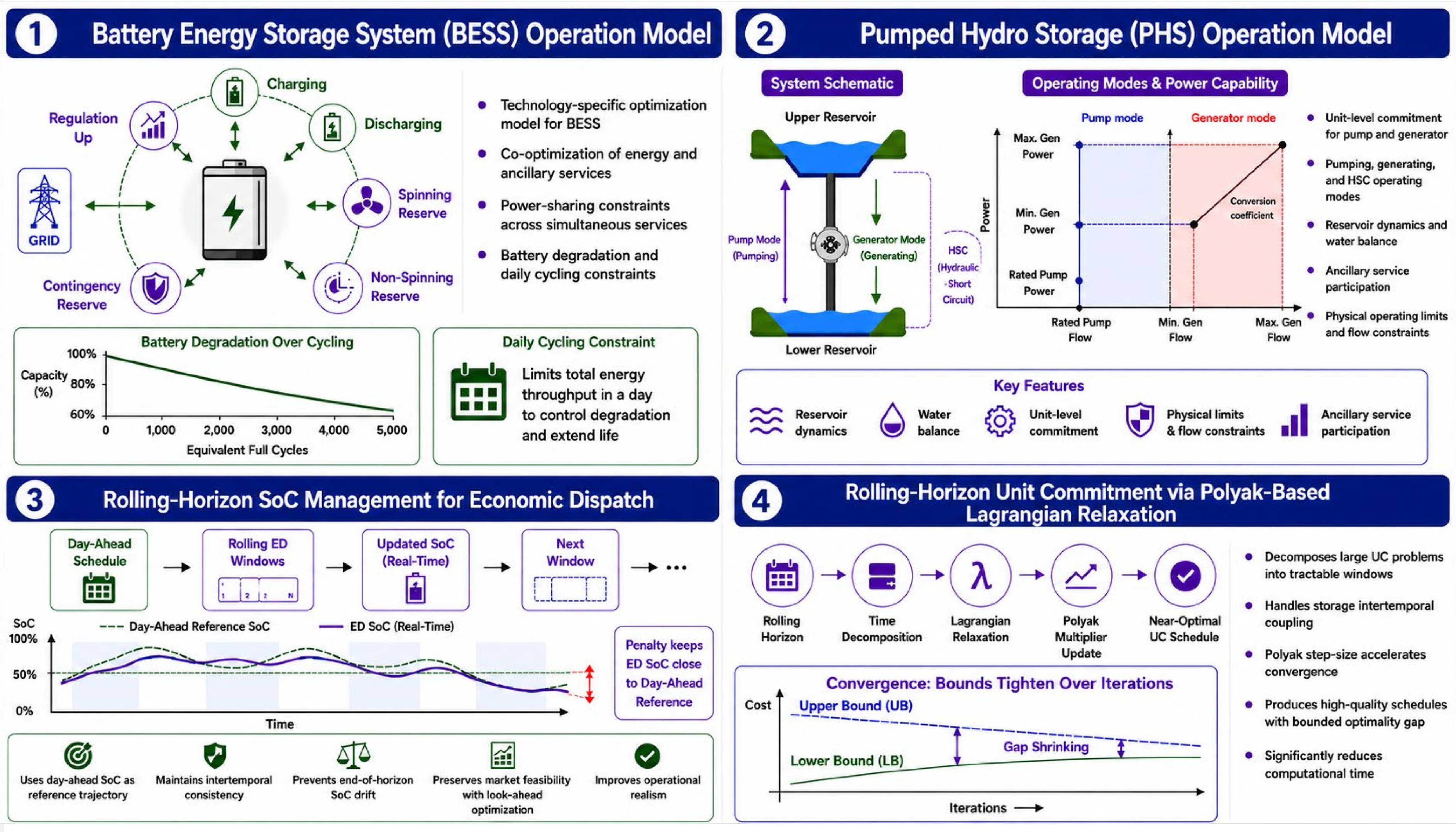
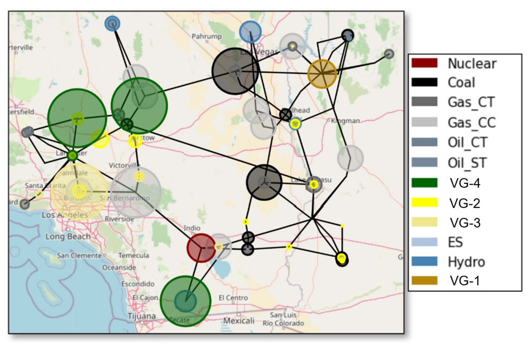


Fig. 3. Overview of the key modeling novelties in this project.

RESULTS

Case studies using QuESt PCM

- Study conducted around peak-demand week of RTS-GMLC system [2]
- ESS operated in three modes:
  - **Case I:** Generic storage (GESS)
  - **Case II:** Battery storage (BESS)
  - **Case III:** Pumped hydro storage (PHS)
- **Key takeaways:**
  - ✓ Dispatch plots show distinct ESS dispatch profiles across cases
  - ✓ SoC plot demonstrates accurate UC SoC tracking within ED despite limited lookahead horizon
  - ✓ Degradation and PHS plots emphasize the tool's tech-specific operational fidelity



Parameter	Values
Solver	CPLEX 22.1.2.0
MIP gap	0.01
Start Date	07/10/2020
End Date	07/15/2020
SCUC Lookahead	12 hours
SCED Resolution	1 hour
SCED Lookahead	1 hour
DA ancillary services	DA reserve, Reg_{Up}, Reg_{Down}, Spinning, Flex_{Up}, Flex_{Down}
RT ancillary services	Reg_{Up}, Reg_{Down}, Spinning

Fig. 3. Test system and key simulation parameters.

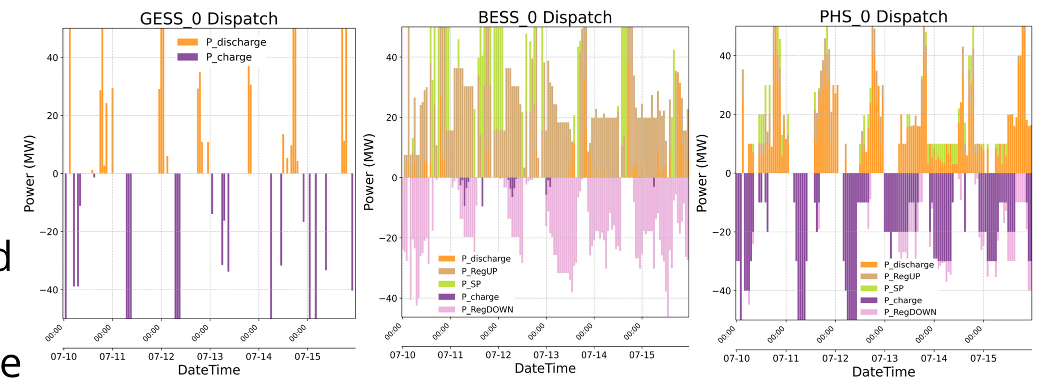


Fig. 4. Dispatch characteristics of different ESS technologies.

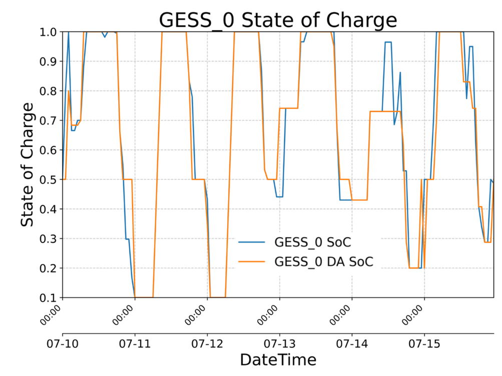


Fig. 5. Coordination between day-ahead and real-time ESS SoC.

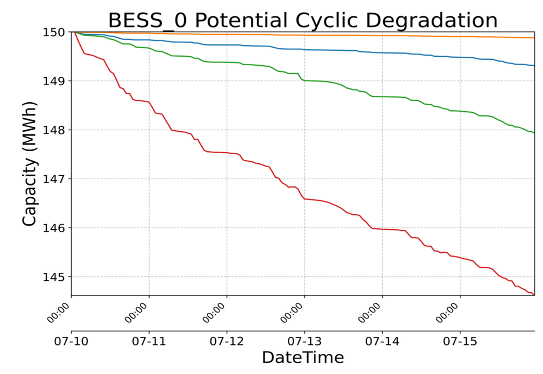


Fig. 6. Potential BESS cyclic degradation with market participation.

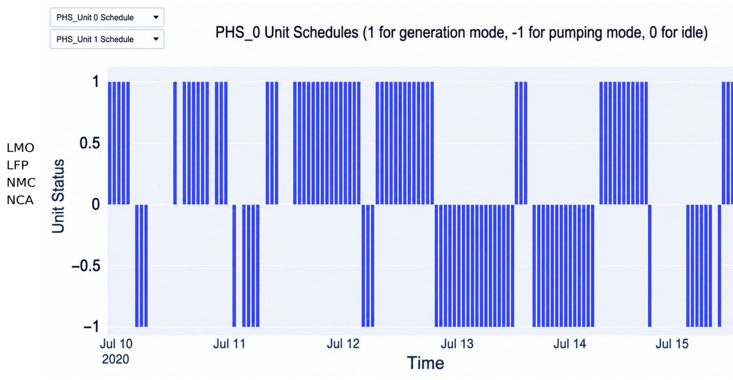


Fig. 7. Unit-level dispatch status of pumped hydro storage.

Case Studies using Rolling Horizon-based Temporal Decomposition Algorithm

- **Goal:** Test the capability of this approach to accelerate UC solve times within QuESt PCM
- Case studies performed on the North Carolina regional grid and RTS-GMLC system
- Comparison metrics: Speedup and optimality gap compared to monolithic UC
- **Key Takeaways:**
  - ✓ RH solutions certified within 0 - 3.4% of the monolithic optimum with up to 12x runtime reduction
  - ✓ Lagrangian relaxation provides valid lower-bounds that certify solution quality
  - ✓ However, ESS SoC tracking across RH windows should be improved prior to deployment within QuESt PCM

Table 1. RH Speedup and Optimality Gap (F = freeze window, L = Look-ahead window length)

System	Horizon	Speedup $Worst_{F,L}$	Speedup $Best_{F,L}$	Diff. to mono (%) $Min_{F,L}$	Diff. to mono (%) $Max_{F,L}$
Regional	72	$0.74_{6,12}$	$1.61_{24,6}$	$\mathbf{0.00_{48,24}}$	$1.51_{6,12}$
	168	$1.47_{12,24}$	$3.05_{12,6}$	$0.03_{48,24}$	$1.61_{12,24}$
	336	$1.92_{12,24}$	$\mathbf{4.42_{48,6}}$	$0.00_{24,24}$	$1.59_{12,24}$
RTS-GMLC	24	$0.54_{48,24}$	$1.17_{48,12}$	$\mathbf{0.03_{24,6}}$	$3.36_{48,24}$
	168	$2.13_{48,6}$	$5.46_{24,6}$	$\mathbf{0.03_{24,12}}$	$1.70_{48,6}$
	336	$4.39_{48,6}$	$\mathbf{12.1_{24,6}}$	$0.09_{24,12}$	$0.00_{48,6}$

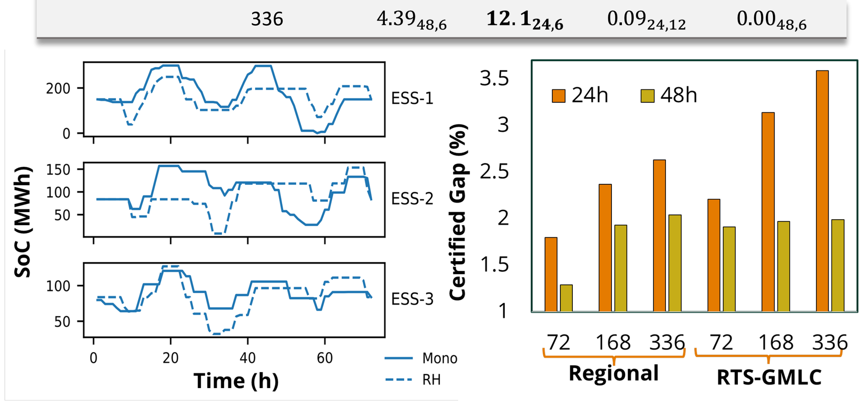


Fig. 9. SoC tracking performance and certified optimality gap

CONCLUSIONS & IMPACT

- **Results highlight that:**
  - ✓ QuESt PCM ESS models capture **detailed ESS operations and market interactions**
  - ✓ RH-based algorithm shows strong potential to **significantly reduce UC solve times**
- **Key accomplishments:**
  - ✓ GitHub **release of QuESt PCM** v1.0.0 and v1.1.0, integration with the *QuESt* platform
  - ✓ Paper on temporal decomposition method accepted for the *IEEE PESGM 2026*
  - ✓ Submitted articles based on this work to the *EESAT* conference and *SoftwareX* journal
- **Expected impacts of this work:**
  - ✓ *Enhance power system reliability and cost-effectiveness* through scalable assessment of ESS operations and grid services
  - ✓ *Accelerate energy storage innovation and validation* using an open-source platform for testing next-generation ESS technologies
  - ✓ *Enable informed investment and deployment decisions* that strengthen energy security and storage market competitiveness

FUTURE DIRECTIONS

- Improve the SoC tracking model of RH algorithm and include it in *QuESt PCM*
- Develop large-load models and expand ESS technologies within the tool
- Work with utility partners to perform case studies on real-world systems
- Improve integration via *SNL QuESt planning* (expansion planning) and *ProGRESS* (resource adequacy) pipelines, *QuESt workspace*, and *AI-agent* workflows.

References

[1] Knueven, Bernard, James Ostrowski, and Jean-Paul Watson. "On mixed-integer programming formulations for the unit commitment problem." INFORMS Journal on Computing 32.4 (2020): 857-876.
[2] Barrows, Clayton, et al. "The IEEE reliability test system: A proposed 2019 update." IEEE Transactions on Power Systems 35.1 (2019): 119-127.

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