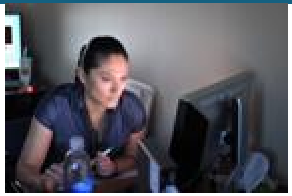
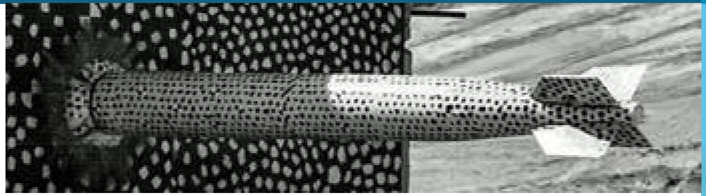
SAND2021-13817C

SAND #: 1381582

Sandia National Laboratories

LONG DURATION STORAGE FOR DISPATCHABLE RENEWABLE GENERATION AND QUEST UPDATES





PRESENTED BY

Tu A. Nguyen

2021 DOE OE Energy Storage Peer Review

U.S. DEPARTMENT OF ENERGY NNSA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

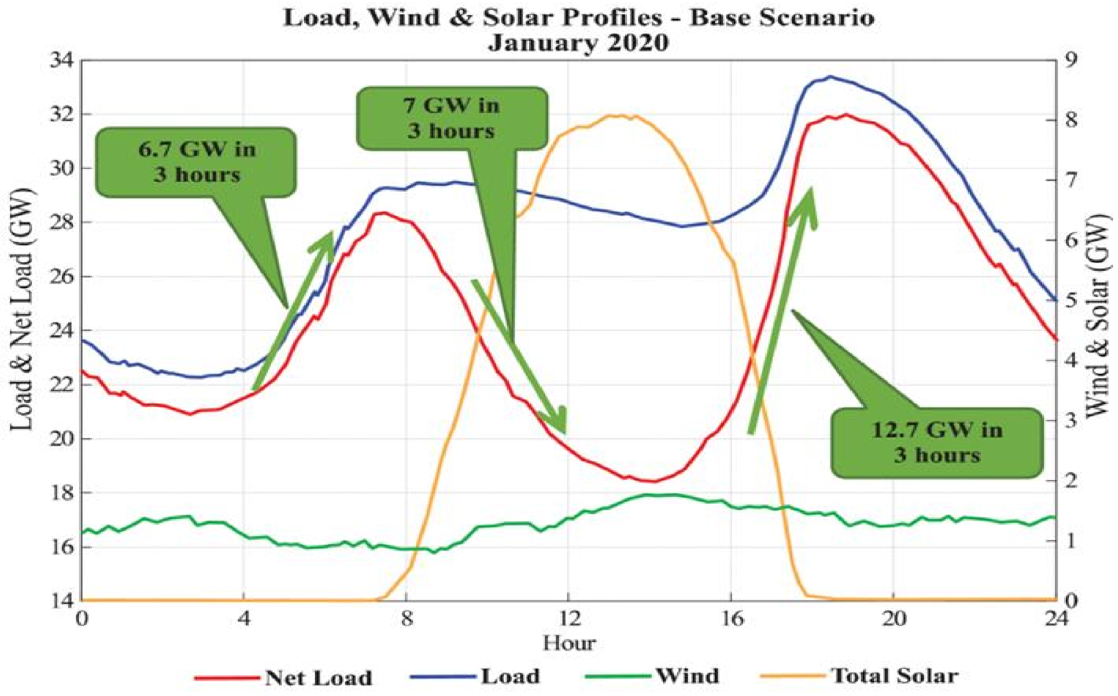
PROJECT OBJECTIVE

Objective: *to investigate how long-duration energy storage can be used to make renewable power plants (REP) dispatchable.*
Methodology: *we propose 2-storage configuration to fully mitigate the intermittency and uncertainty of REPs and make them dispatchable (d-REP). We have developed an optimization framework to dispatch multiple d-REPs.*

Outlines:

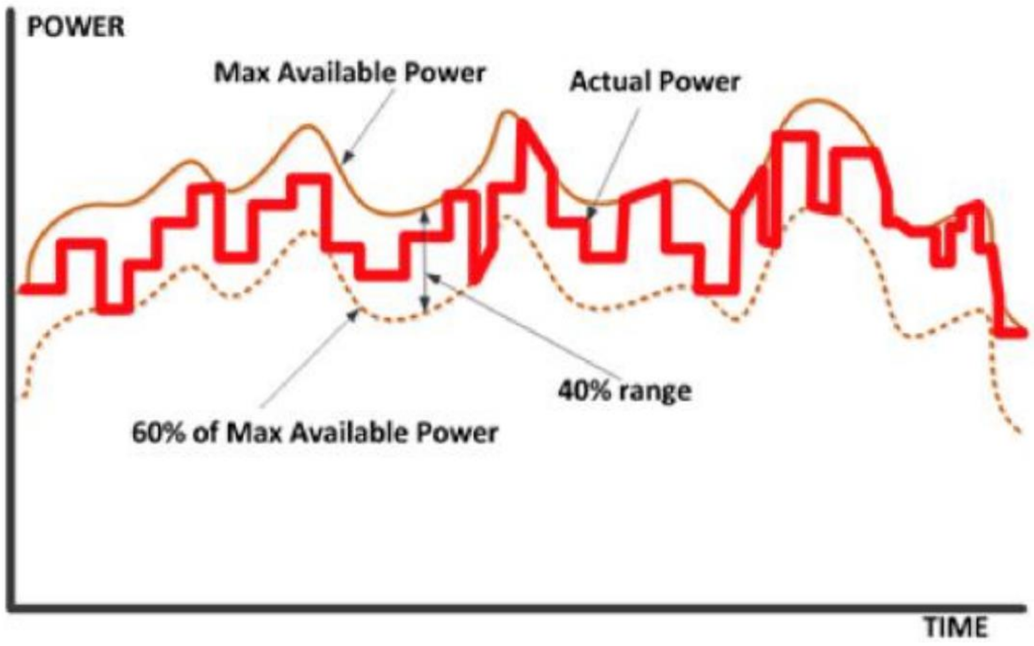
- Current challenges for dispatchable REPs.
- The need of long duration storage.
- 2-storage configuration: concept, pros and cons.
- Economic dispatch of d-REPs.
- Case study
- QuESt Updates.

CURRENT CHALLENGES FOR DISPATCHABLE REPS



High Variability and Uncertainty

- Solar PV creates larger ramps since large amount of energy is produced only during daytime, which is not coincident with the peak load.
- Wind generation tends to be larger during nighttime, which also create ramps.



Dispatching Renewable Power Plants

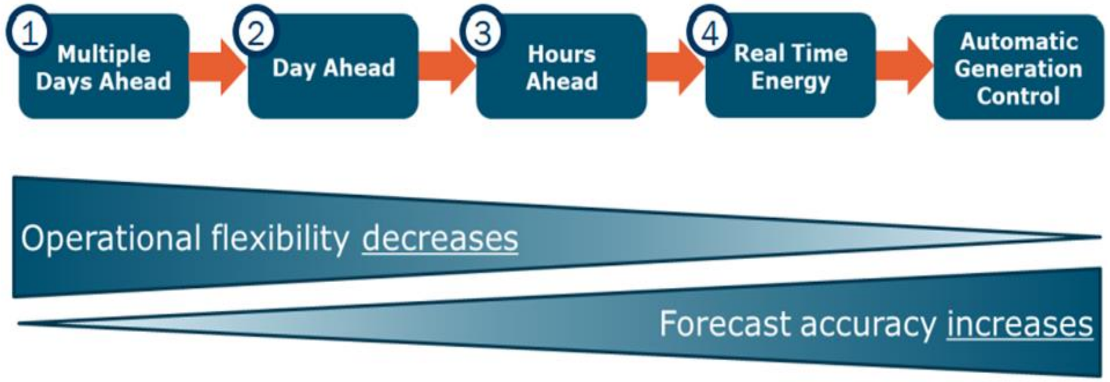


Image Credit: First Solar

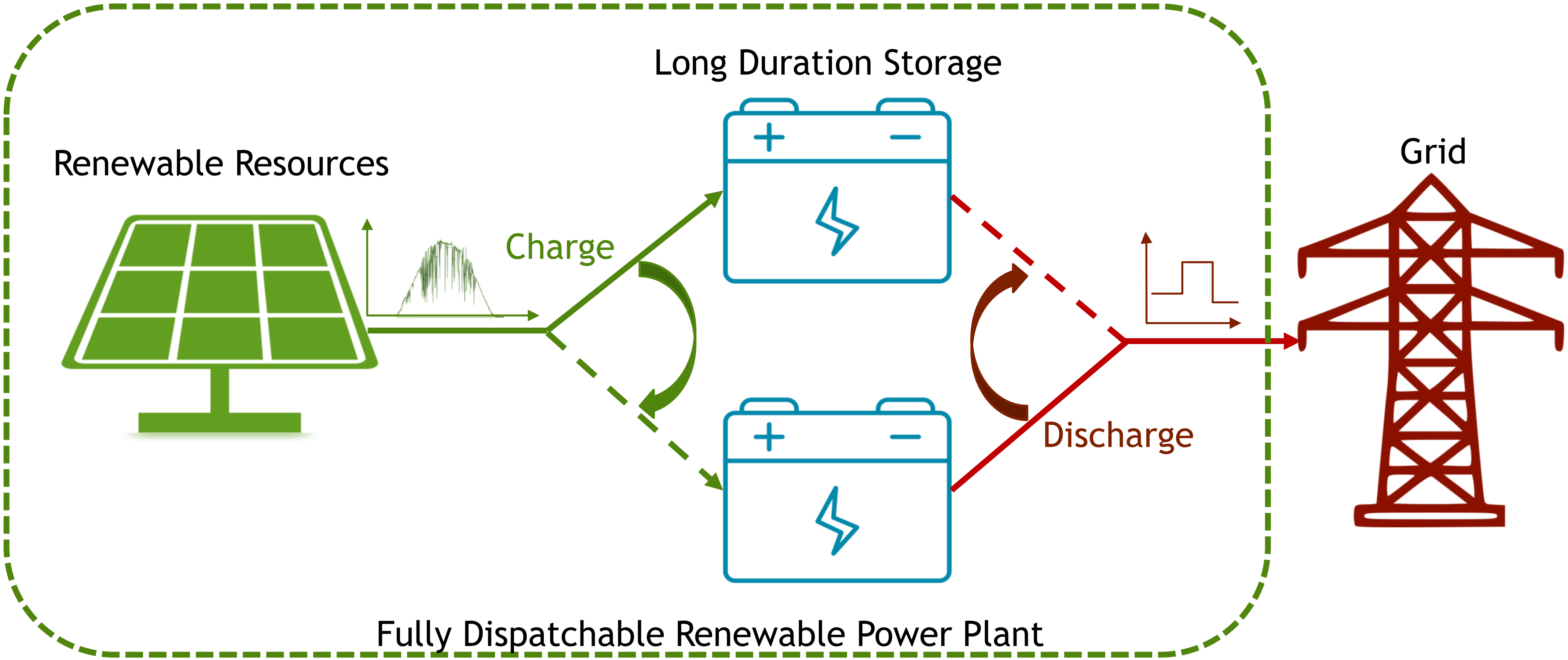
THE NEED OF LONG DURATION STORAGE

Image Credit: Form Energy

Image Credit: Energy Vault

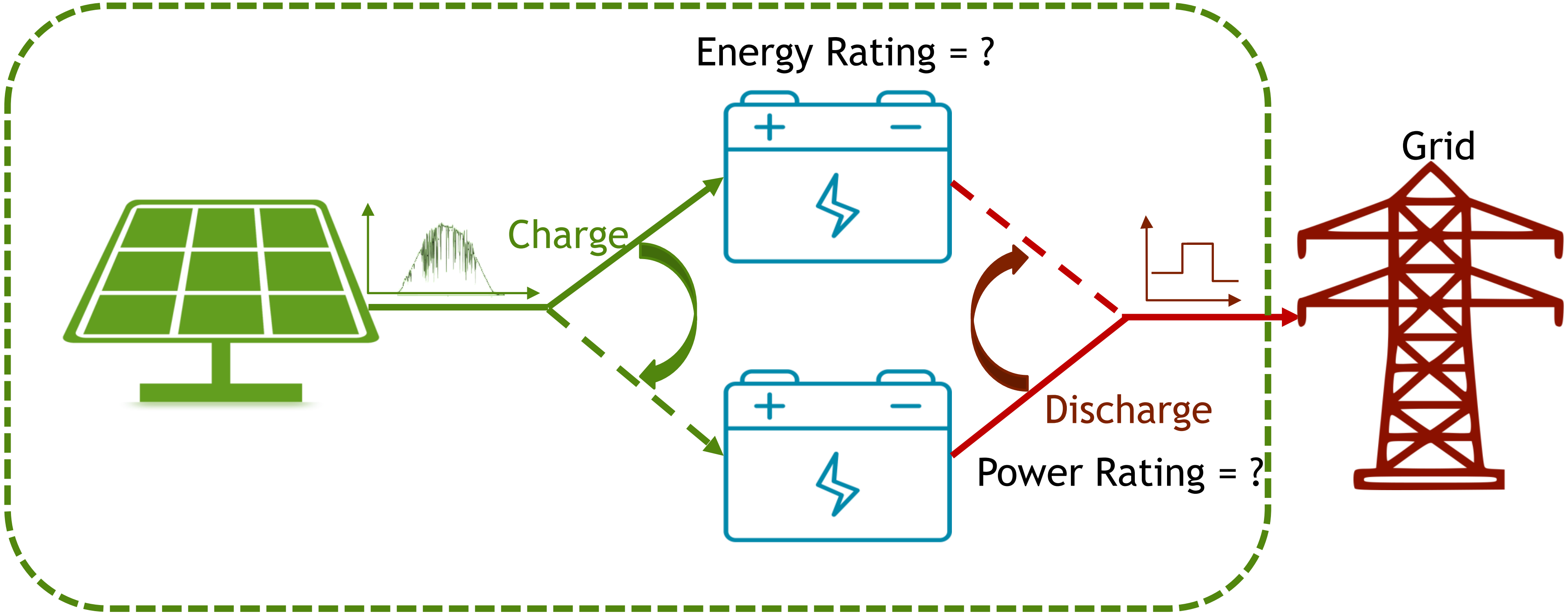
Image Credit: U.S. DOE

2-STORAGE CONFIGURATION



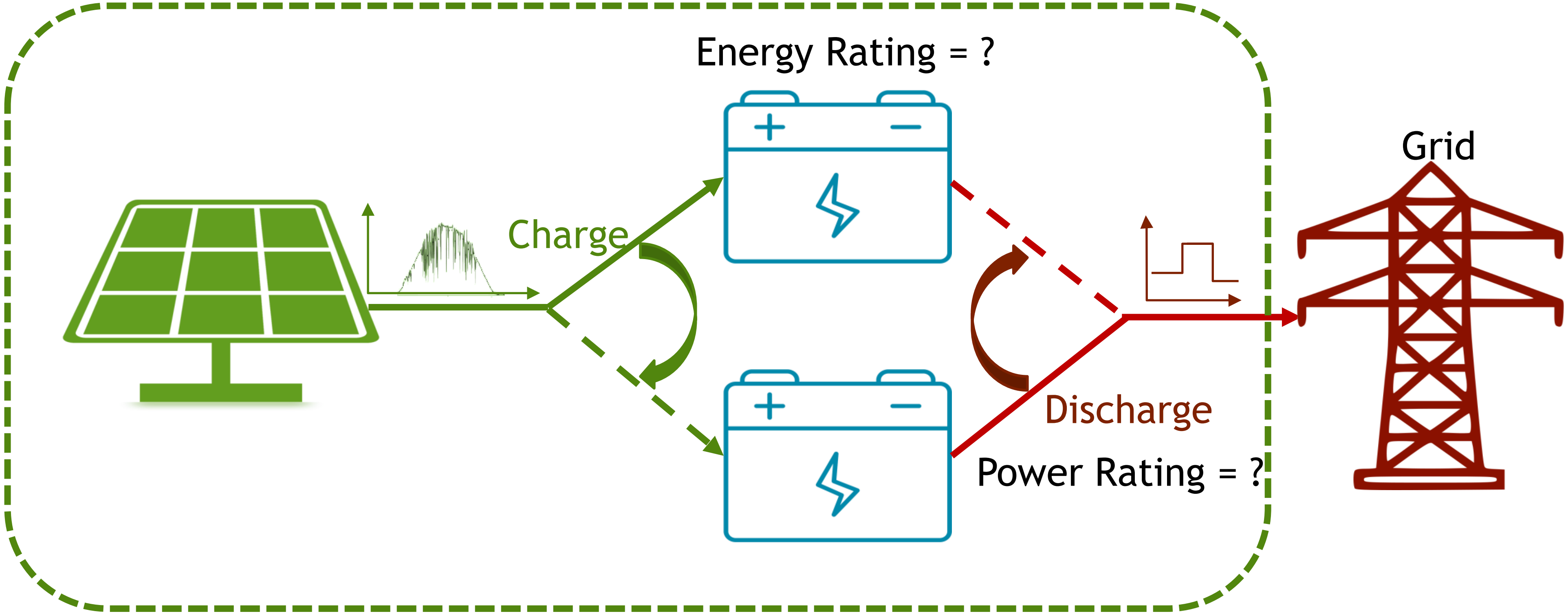
- How much energy storage capacity we need in order for this to work?
- What should be the power rating of a d-REP?
- How to optimally dispatch multiple power plants like this?

2-STORAGE CONFIGURATION – SIZING



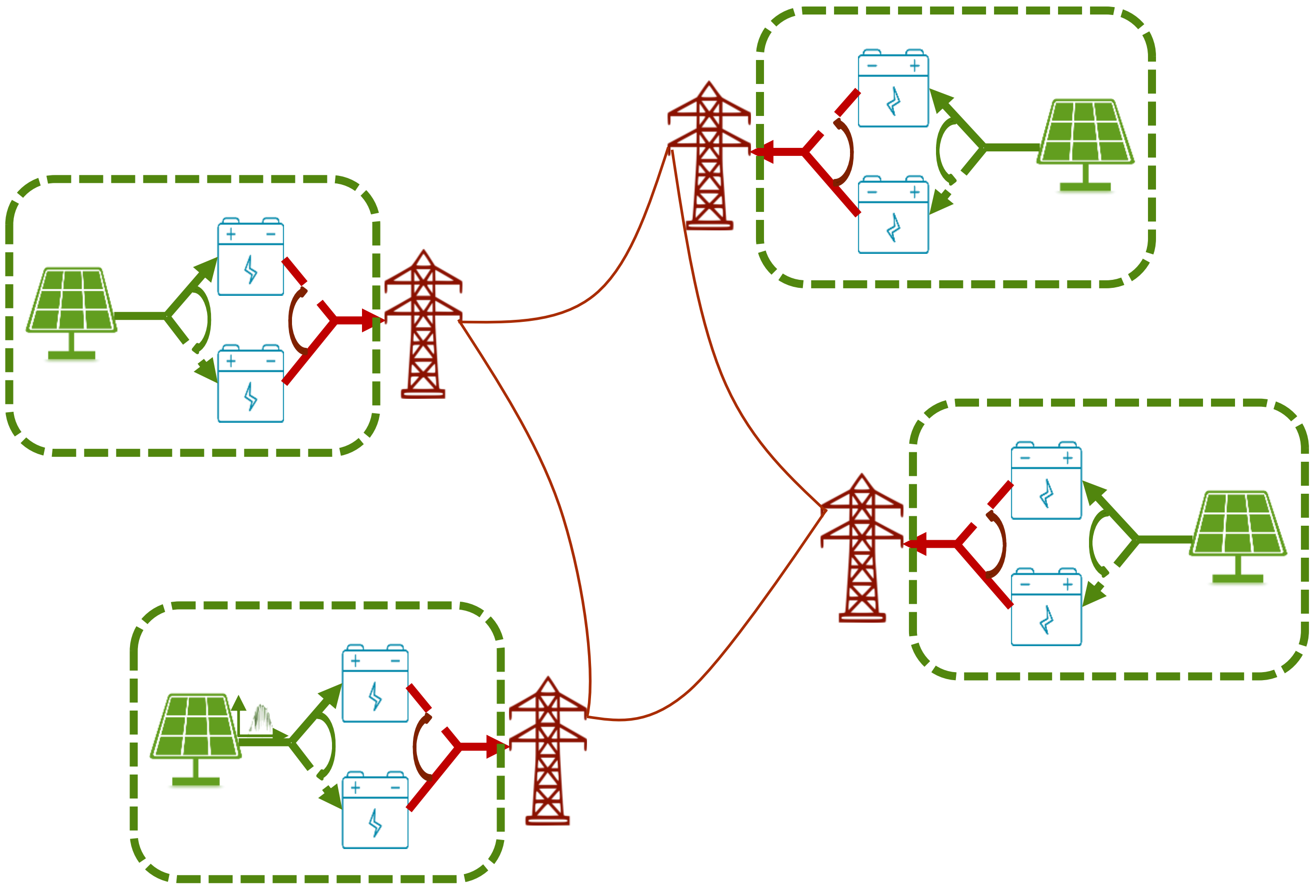
- Given a PV or wind system, find the capacity rating of ESSs and the power rating of the plant:
  - Energy rating of each ESS will depend on how much renewable energy is available over a predefined observe/operation period (op).
  - Power rating of the plant will depend on what it is used for: base load vs peak load.

2-STORAGE CONFIGURATION - EXAMPLE



- Given a 100MW PV at a location with 5 peak sun hours, each ESS ~ 500MWh if observation period is 24hr and 250 MWh if observation period is 12 hr.
- Given that the plant is intended to cover the base load, the power rating of the plant can be 500MWh/24h~ 20MW.

ECONOMIC DISPATCH OF MULTIPLE d-REPs



- Economic dispatch can be used to operate this system at minimum cost.
  - Since there is no fuel cost in this system, energy lost characteristics of the storage systems are used as production cost functions.
  - No integer variables since all grid-connected ESSs are discharging.
  - At the beginning of each op, the grid operators know: the SOC of all ESSs, the power ratings of all plants and the network parameters
- Different models of energy storage can be used:
  - Linear energy flow model using constant round trip efficiency.
  - Non-linear energy flow model capturing non-linear discharge lost characteristics

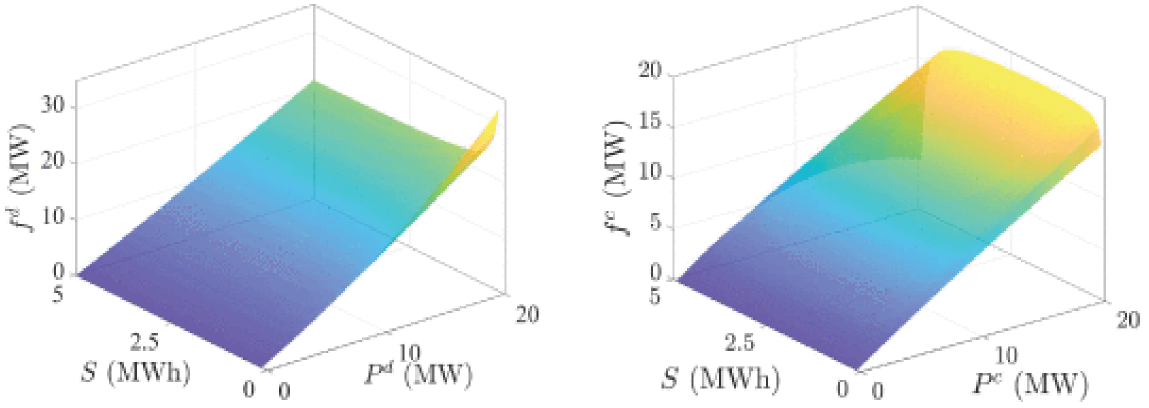
ECONOMIC DISPATCH OF MULTIPLE d-REPs – NONLINEAR STORAGE MODEL

$$S_i = \eta_s S_{i-1} + \underbrace{f^c(P_i^c, S_{i-1})}_{\text{Total charged power}}\tau - \underbrace{f^d(P_i^d, S_{i-1})}_{\text{Total discharged power}}\tau$$

- Electrochemical batteries:

$$f^d = P^d/\eta_p + P^{ld}$$

$$P^{ld} \approx \frac{\bar{q}}{\bar{v}\bar{S}}\left[\left(r + \frac{k\bar{S}}{S}\right)\left(\frac{P^d}{\eta_p}\right)^2 + \frac{k\bar{S}\left(\bar{S}-S\right)}{S}\frac{P^d}{\eta_p}\right]$$



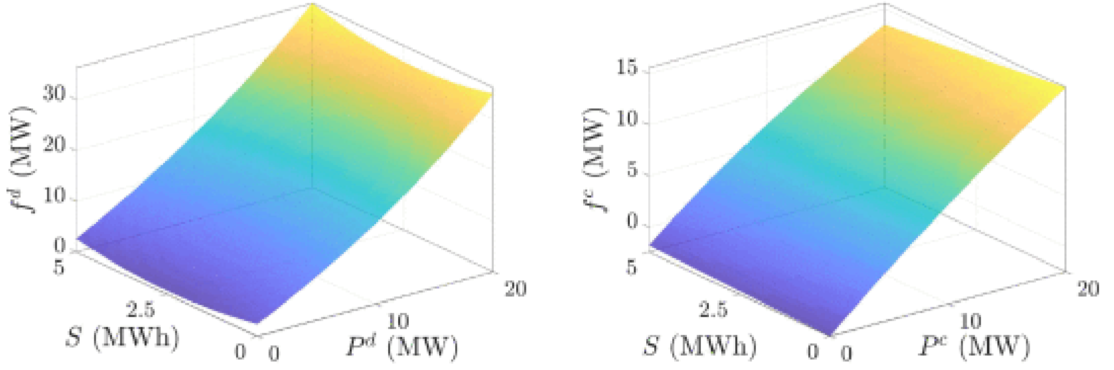
(a) (b)

- Vanadium Redox batteries:

$$f^d = \frac{P^{stackd}}{\eta_d}$$

$$P^{stackd} = a_p^d P^d/\eta_p + b_p^d S(S-\bar{S}) + c_p^d$$

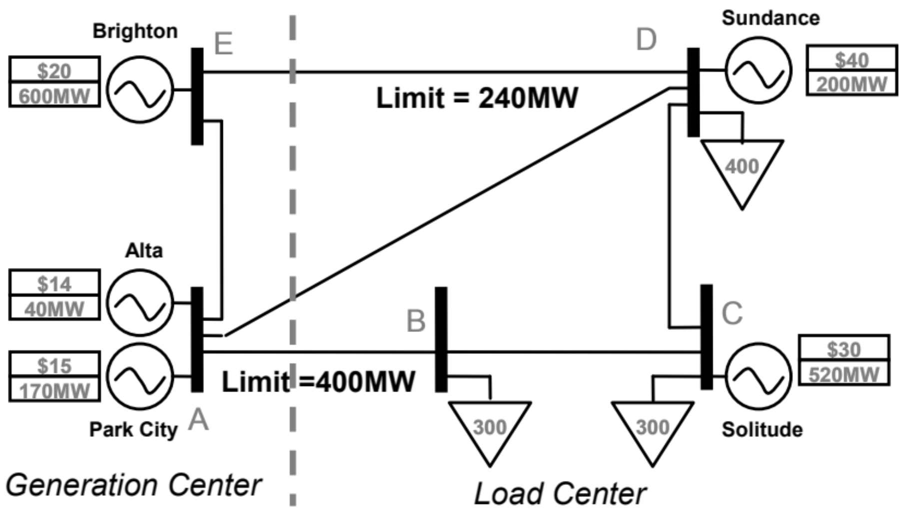
$$\eta_d = \frac{a_v^d P^d/\eta_p + b_v^d S + c_v^d}{a_v^o S + b_v^o}$$



(a) (b)

Reference: T. A. Nguyen, D. A. Copp, R. H. Byrne, B. R. Chalamala, "Market Evaluation of Energy Storage Systems Incorporating Technology-specific Nonlinear Models," in IEEE Transactions on Power Systems, vol. 34, no. 5, pp. 3706 – 3715, April 2019.

CASE STUDY - Results



The PJM 5-bus system.

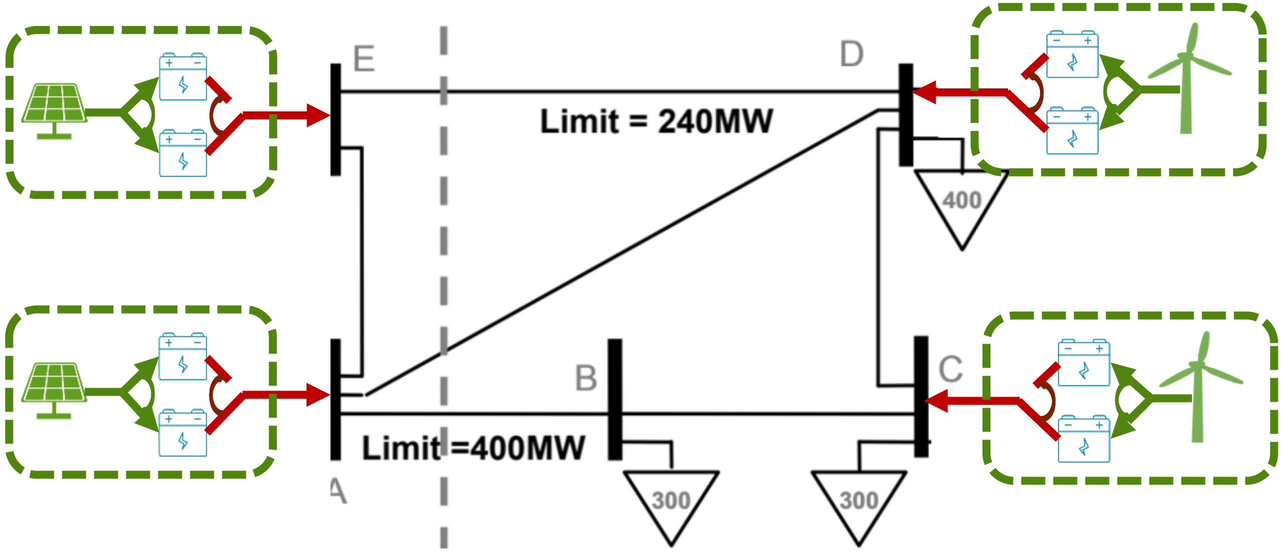


Table 1. Generation Parameters

Gen. Name	Alta	Park City	Solitude	Sundance	Brighton
Bus	A	A	C	D	E
Cost ($/MWh)	14	15	30	40	10
MW Limit	40	170	520	200	600
MVar Limit	±30	±127.5	±390	±150	±450

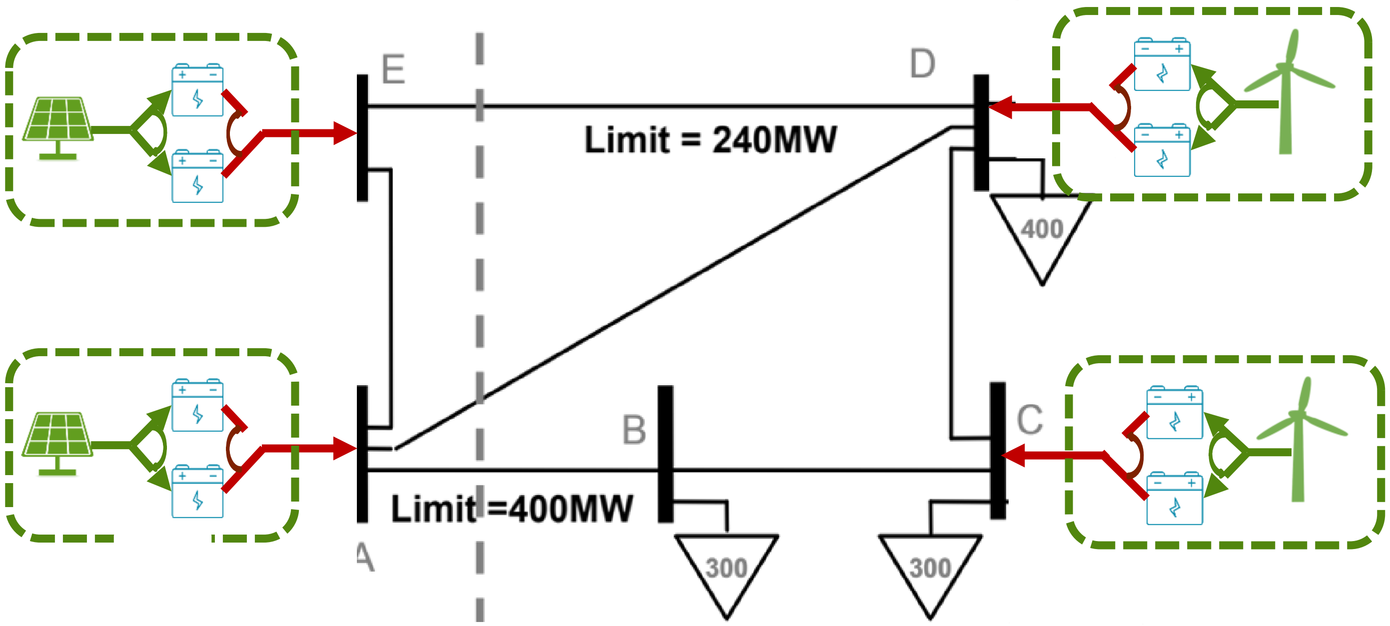
Table 2. Load data

Bus	A	B	C	D	E
MW	0	300	300	400	0
MVar	0	98.61	98.61	131.47	0

Gen. Name	Alta	Park City	Solitude	Sundance	Brighton
Bus	A	A	C	D	E
Type	PV+2ES	PV+2ES	Wind+2ES	Wind+2ES	PV+2ES
Plant MW	50	200	400	100	600
RE size MW	200	800	1600	400	2400
ES size MWh	1200	4,800	13,500	3,400	14,400
ES eff. %	90	90	70	80	70
Cost $/MWh	30	40	20	25	20

Reference: F. Li and R. Bo, "Small test systems for power system economic studies," IEEE PES General Meeting, 2010, pp. 1-4.

CASE STUDY – RESULTS



Gen. Name	Alta	Park City	Solitude	Sundance	Brighton
Bus	A	A	C	D	E
Type	PV+2ES	PV+2ES	Wind+2ES	Wind+2ES	PV+2ES
Plant MW	50	200	400	100	600
Dispatch MW	50	0	300	100	550
LMP $/MWh	30	40	20	28	20

- DCOPF is used, LMPs don't include loss component.
- There's a trade off between round trip efficiency and input energy cost.
  - Park city is not dispatched since energy cost is high even though efficiency is high.
  - Brighton and solitude are dispatched not at their maximum even though input energy costs are lowest due to low round trip eff.

QuESt UPDATES

Current:

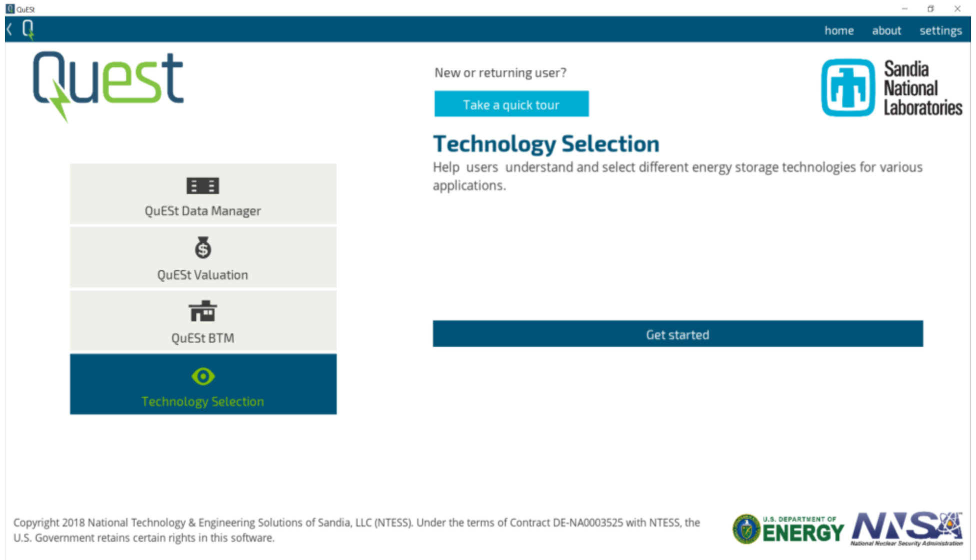
- QuESt Data Manager
- QuESt Valuation
- QuESt BTM

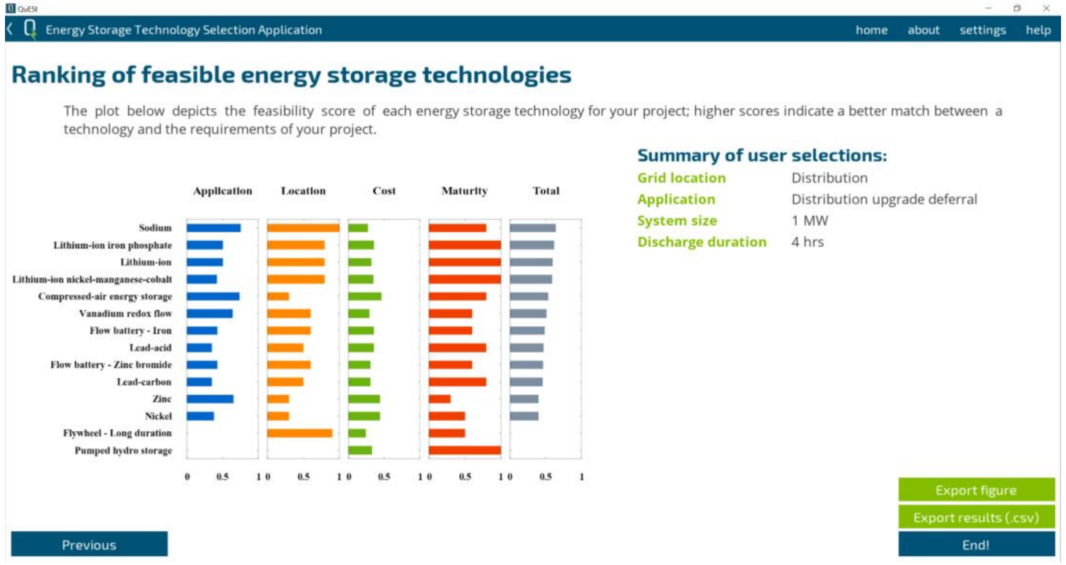
Updates:

- QuESt Technology Selection (under testing)
- QuESt Equity (completed back-end)
- QuESt Performance (completed back-end)

Given a Peaker loading profile, what are the optimal sizes of PV and storage for 1-to-1 replacement of that plant? What are the benefits for the environment?

Given a charge/discharge profile of a BESS, how much energy is needed to run the HVAC that maintain system temperature within its operating range? What is the optimal size of the BESS considering the HVAC load?





ACCOMPLISHMENTS

Accomplishments of FY21 :

- 2 book chapters.
- 4 journal papers, 3 conference papers.
- 6 presentations.
- Chaired 3 technical and panel sessions at ECCE, PEC and ISGT.

Next steps:

- A conference paper for 2022 IEEE PES General Meeting.
- Next release of QuESt in Dec 2021.

PUBLICATIONS AND PRESENTATIONS

BOOK CHAPTERS:

1. T. A. Nguyen et al., “Energy Storage Applications” in the 2020 DOE’s Energy Storage Handbook
2. T. A. Nguyen et al., “Energy Storage Management Systems” in the 2020 DOE’s Energy Storage Handbook
3. J. Johnson et al., “Physical Security and Cybersecurity of Energy Storage Systems” in the 2020 DOE’s Energy Storage Handbook

JOUNRAL PAPERS:

1. T. A. Nguyen, R.H. Byrne, “Software Tools for Energy Storage Valuation and Design,” in Current Sustainable Renewable Energy Reports, vol. 8, pp. 156–163, 2021, doi: 10.1007/s40518-021-00186-4.
2. D. A. Copp, T. A. Nguyen, R. H. Byrne, and B. R. Chalamala “Optimal Sizing of Distributed Energy Resources for Planning 100% Renewable Electric Power Systems”, accepted to Energy, 10/2021.
3. U. Tamrakar, D. A. Copp, T. A. Nguyen, T. M. Hansen and R. Tonkoski, "Real-Time Estimation of Microgrid Inertia and Damping Constant," in IEEE Access, vol. 9, pp. 114523-114534, 2021, doi: 10.1109/ACCESS.2021.3104516.
4. U. Tamrakar, D. A. Copp, T. A. Nguyen, T. M. Hansen and R. Tonkoski, "Optimization-Based Fast-Frequency Estimation and Control of Low-Inertia Microgrids," in IEEE Transactions on Energy Conversion, vol. 36, no. 2, pp. 1459-1468, June 2021, doi: 10.1109/TEC.2020.3040107.

CONFERENCE PAPERS:

4. 5. U. Tamrakar, T. A. Nguyen, R. H. Byrne, “Model Predictive Dispatch of Energy Storage for Voltage Regulation in Active Distribution Systems” in the proceeding of the 30th IEEE International Symposium on Industrial Electronics (ISIE), May 2021.
5. 6. A. Bastos, T. A. Nguyen, R. H. Byrne, ”Optimal Dispatch of Energy Storage Systems for Harmonic Mitigation and Power Factor Correction” the 30th IEEE International Symposium on Industrial Electronics (ISIE), May 2021.
6. 7. T. A. Nguyen, R. H. Byrne, “Evaluation of Energy Storage Providing Virtual Transmission Capacity,” in the proceeding of the 2021 IEEE Power & Energy Society General Meeting (PESGM), July 2021.

PRESENTATIONS:

1. “Evaluation of Energy Storage as Transmission Assets,” at the 2020 DOE Energy Storage Peer Review, Sep 2020.
2. “Maximizing the savings for utility customers using behind the meter energy storage” at Sigma Xi - Science & Society Distinguished Public Talks, University of New Mexico, October 2020.
3. “Energy Storage Technologies and Grid Services,” at Current Status and Development Perspectives of Solar Photovoltaic Power Technology in Vietnam, June 2021.
4. “Evaluation of Energy Storage Providing Virtual Transmission Capacity,” at the 2021 IEEE Power & Energy Society General Meeting (PESGM), July 2021.
5. “Energy Storage Management System and Valuation,” at the IEEE Smart Grid R&D Committee Meeting, August 2021.
6. “QuESt – An Open-source Software Application Suite for Energy Storage Evaluation,” at the DOE Energy Storage Financing Summit, September 2021.

ACKNOWLEDGEMENTS

Funding provided by US DOE Energy Storage Program managed by Dr. Imre Gyuk of the DOE Office of Electricity.

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Contact: Tu Nguyen, tunguy@sandia.gov