SOUTHWEST RESEARCH INSTITUTE

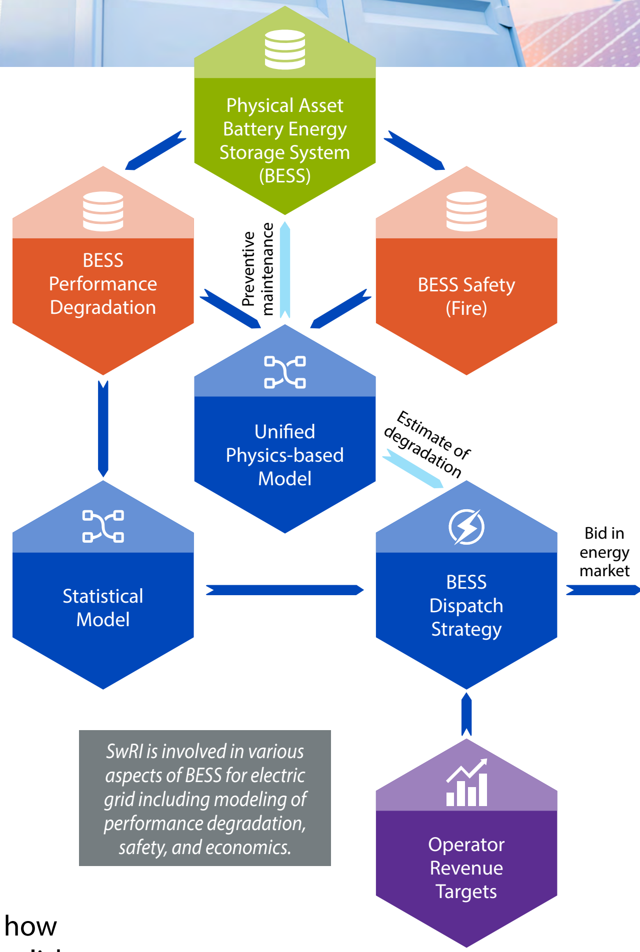
Grid-connected Battery Energy Storage Systems

Lithium-ion batteries routinely undergo charge-discharge cycles and their performance degrades with use. Storage and cycling are the main causes of performance degradation.

The main indicators of battery performance are charge capacity and resistance. For lithium-ion batteries, performance decline can be attributed to loss of cyclable lithium, electrode fracture, and degradation of electrolyte.

Southwest Research Institute® (SwRI®) has launched the Battery Energy Storage System (BESS) for Electric Grid Joint Industry Program (JIP). Our investigations will include:

- Developing new test cycles for batteries used in grid applications
- Estimating the life span of batteries and their potential for failure
- Reducing the likelihood of battery fires



SwRI is involved in various aspects of BESS for electric grid including modeling of performance degradation, safety, and economics.

JIP Goal

The main goal of the Joint Industry Program is to discover more about how a battery degrades and the likelihood of its failure. SwRI plans to accomplish this by developing a physical model-based method to estimate performance degradation in grid-connected batteries and establish a correlation with battery fires. Program outcomes could be used in a revenue maximization model and for preventive maintenance to reduce occurrence of battery fires.

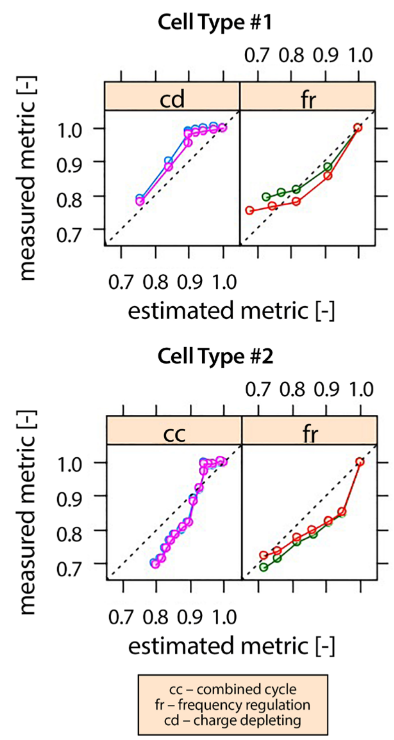
Statistical Model of Battery Degradation

As an alternative or redundancy to the physical model-based method above, battery performance degradation could be estimated by statistical means. SwRI has developed and verified a hierarchical method that uses characteristic timescales of a battery and a representation of any arbitrary duty as a composition of "simple" cycles.

The main uses of this model are:

- Off-line calculation to meet expected battery life
- Estimation of warranty costs using uncertainty bounds on battery life
- Real-time estimation of degradation

The degradation from the fundamental components was determined using SwRI's proprietary hierarchical cyclic degradation model. The charts show good agreement between the estimated and measured degradation.

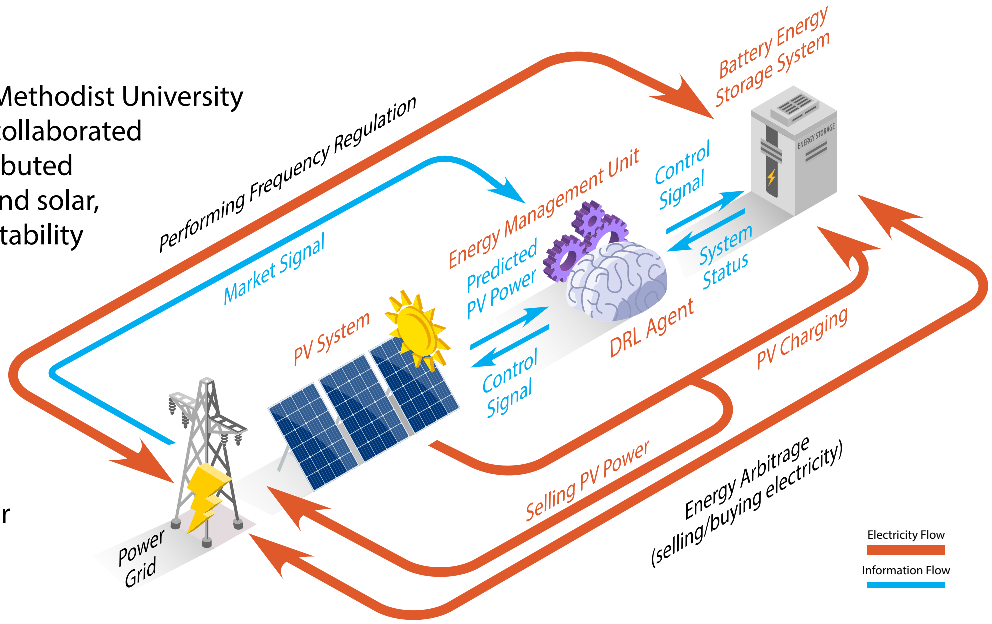


Energy Management Unit

Through the SPARKS program, Southern Methodist University (SMU) and Southwest Research Institute collaborated on research to manage variability of distributed renewable energy sources such as wind and solar, with simultaneous consideration of grid stability and operator revenue.

We focused on how to maximize long-term revenue generation of a typical solar farm and its connected battery energy storage providing stacked services including:

- Direct power sale to the grid from solar generation
- Fast frequency regulation (quickly responding to deviation in the grid frequency) from the battery
- Energy arbitrage (buy low and sell high) using the battery as intermediate storage



Agent-based machine learning is made to maximize revenue from grid service provided by a BESS.

SMU and SwRI built a machine learning model with a PPO (proximal policy optimization)-based agent, a cutting-edge method in deep reinforcement learning (DRL agent).

Using data from SwRI's Energy Storage Technology Center and public sources, we demonstrated that our model is flexible, quick to learn, and beats comparative models at maximizing profit by more than 20%. The BESS life-cycle cost needed for this model could be obtained from our physically- and statistically-based degradation methods.

Benefits of JIP Membership

Participants can guide the research to keep it true to industry needs. They also can license the IP before SwRI offers it to JIP non-participants, which may provide a competitive advantage by reducing life-cycle costs.

This new JIP will utilize grid-connected energy storage at SwRI's San Antonio location.

We welcome your inquiries.
For more information, please contact:

Jayant V. Sarlashkar
Institute Engineer
210.522.5506
jsarlashkar@swri.org

Powertrain Engineering Division
energystorage.swri.org