



Battery / Inverter Device Model and Characterization Protocol

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Battery / Inverter Devices and Control

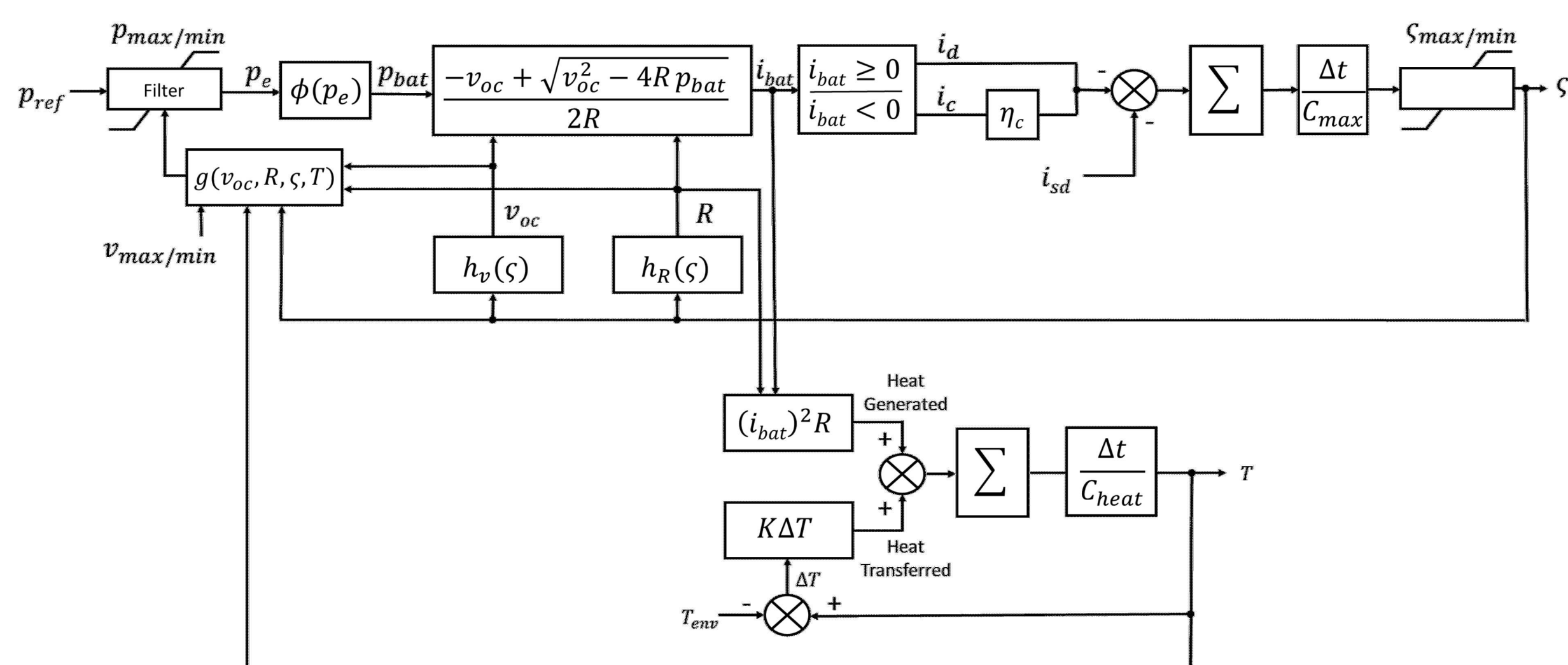
Batteries are designed to store electrical energy and the most prevalent application of stationary batteries has been as backup power for critical processes. More recently, the increasing variation in time value of energy has driven the use of batteries as controllable distributed energy resources (DER). One control mode for batteries, through inverters, is using an AC power setpoint with limits imposed for the batteries safety and life.

AC – power control – Battery limits

- This control mode sets limits for battery/inverter parameters (current, voltage, temperature), and then attempts to achieve an AC power set point. If battery/inverter limits are reached the power set point is reduced through feedback control until equilibrium is achieved at the battery/inverter limit. Otherwise, the AC power set point is maintained until another command is give or a limit is reached.

Linked Electrical and Thermal Battery / Inverter Device Model

Battery performance is a nonlinear function of both electrical physics, movement of electrons, and thermal physics. Hence a linked model is the most appropriate method for approximating the underlying limits that restrict performance.



Flow Diagram for Linked Electrical and Thermal Battery / Inverter Models

Model Accuracy Assessment

A duty cycle should be applied to the battery/inverter system under test. From these data, the following metrics should be computed based on the difference between the calculated state of charge / temperature and the values that the model would predict.

Equipment Impact Metrics

As batteries age, one aging mechanism is a growth in internal resistance. This reduces the instantaneous available power, reduces energy capacity, and increases heat generation. Not having a calibrated model for resistance growth, the following can be used.

Calendar Life Acceleration Factor [4] (parameters derived from test data)

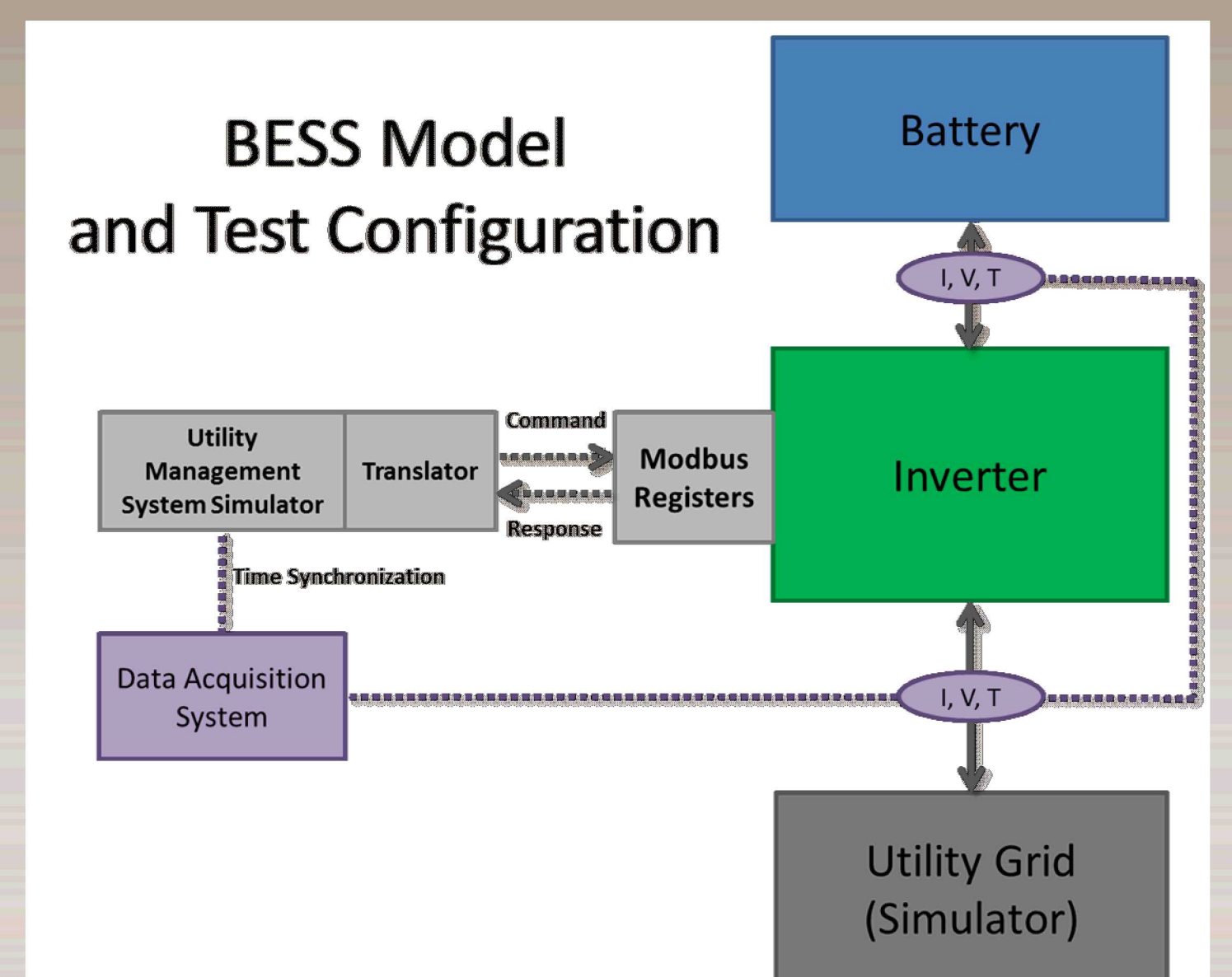
$$F_{CAL} = e^{T_{ACT} \left[\frac{1}{T_{REF}} - \frac{1}{T} \right]}$$

Cycle Life Acceleration Factor [4] (parameters derived from test data)

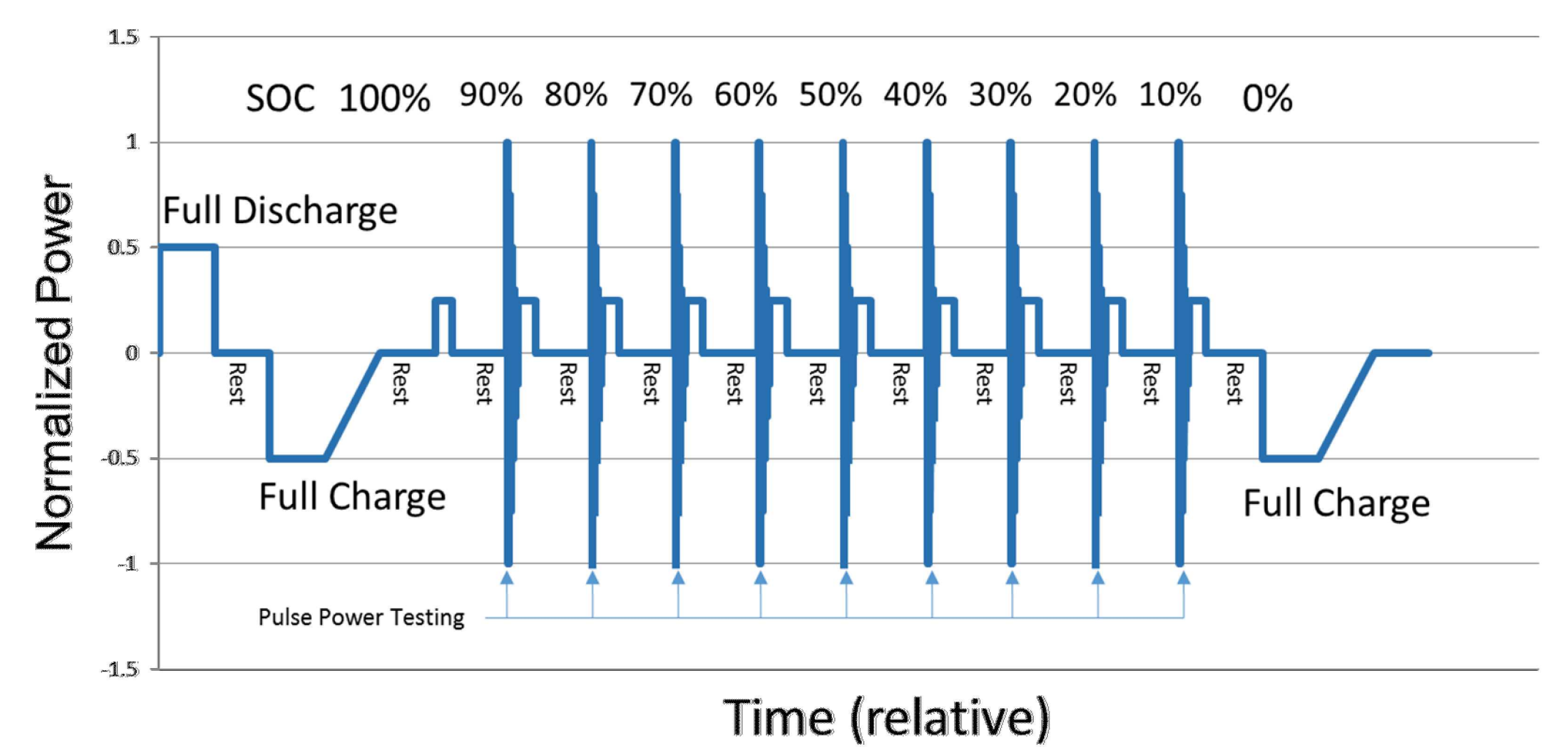
$$F_{CYC} = 1 + (K_P) \left(\frac{P}{P_{Rated}} \right)^\omega [1 + (K_T)(T - T_{REF})]$$

Model parameters can be derived using tests from existing standards and protocols. No additional testing is required.

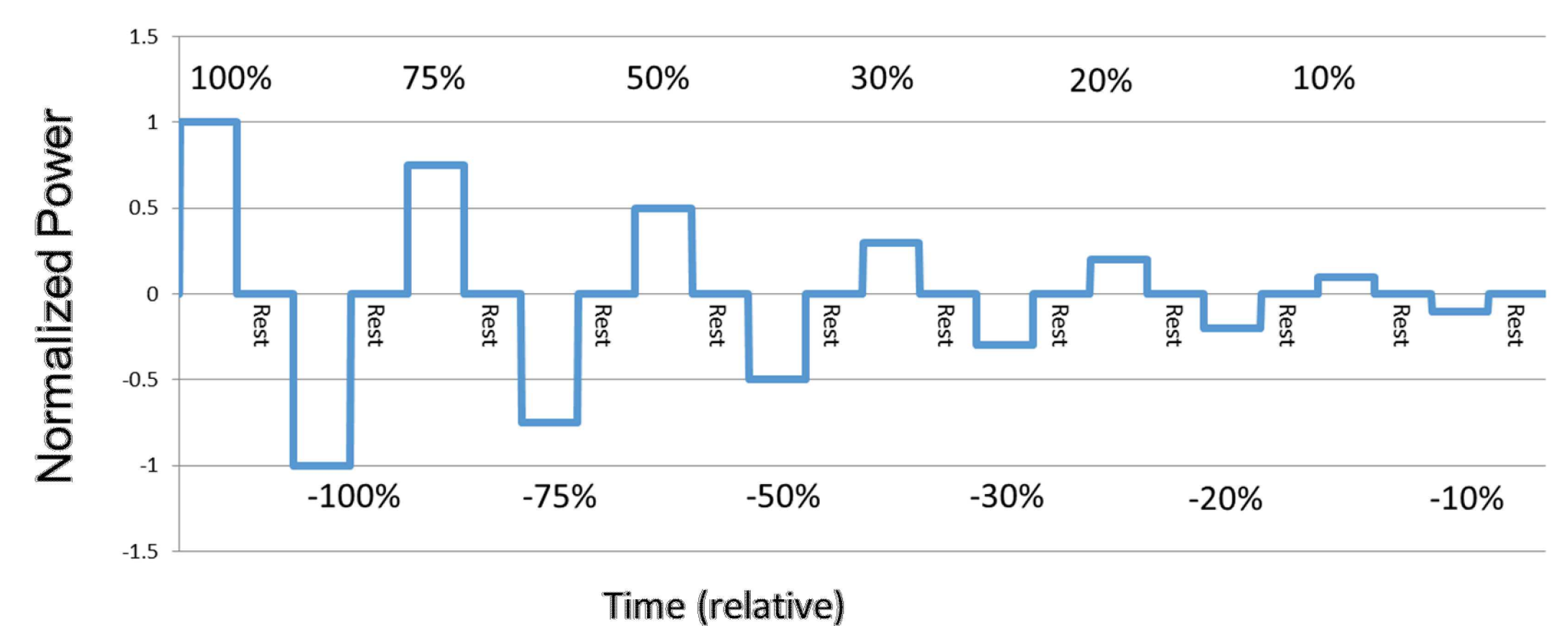
- Tests for capacity, efficiency, response rate can be found in [1,5]
- Tests for DC battery performance and life can be found in [3,4]
- Tests for advanced functionality (e.g. frequency/watt) can be found in [2]



If the full set of tests have not been completed, or if model validation is desired in the resulting model, an additional test optimized for model parameterization can be performed. The Energy Storage Pulsed Power Characterization (ESPPC) test, based on a combination of tests from [1], [3] and [5], offers an efficient procedure for deriving most battery model parameters.



Energy Storage Pulsed Power Characterization (ESPPC) Test



Pulsed Power Testing Performed at Each State-of-Charge

References

- DR Conover et al, "Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems" Sandia National Laboratories, SAND2016-3078R, <http://www.sandia.gov/ess/publications/SAND2016-3078R.pdf>
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- Battery Test Manual For Plug-In Hybrid Electric Vehicles, U.S. Department of Energy Vehicle Technologies Program, rev 3, September 2014 <https://infdigitalibrary.inl.gov/sti/6308373.pdf>
- Haskins H. et al "Battery Technology Life Verification Test Manual" Advanced Technology Development Program For Lithium-Ion Batteries, Idaho National Laboratory, February 2005, INEEL/EXT-04-01986
- David L. King, Sigifredo Gonzalez, Gary M. Galbraith, and William E. Boyson "Performance Model for Grid-Connected Photovoltaic Inverters" Sandia National Laboratories, SAND2007-5036 <http://energy.sandia.gov/wp-content/gallery/uploads/Performance-Model-for-Grid-Connected-Photovoltaic-Inverters.pdf>