Improvements in Battery Life Estimation for Use in Hybrid2 and Other Simulation Models

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Overview

- Impetus for Improvements to Battery Lifetime Estimation
- The Hybrid2 Computer Code
- The Kinetic Battery Model
- Battery Life Calculations
- Modifications to Battery Life Estimation Code

Impetus for Improved Battery Lifetime Estimates

- Many Hybrid (inc. Wind/Diesel) Systems Use Batteries
- Economics of Hybrid Systems Affected by Frequency of Battery Replacement
- Operating Characteristics of Hybrid Systems Significantly Affects Battery Life
- Accurate Prediction of Battery Life has Proven to be Very Difficult

Battery Aging Mechanisms
(Lead Acid)

- Corrosion
- Shedding
- Sulphation
- Water Loss
- Stratification of Electrolyte
- Degradation of Active Mass

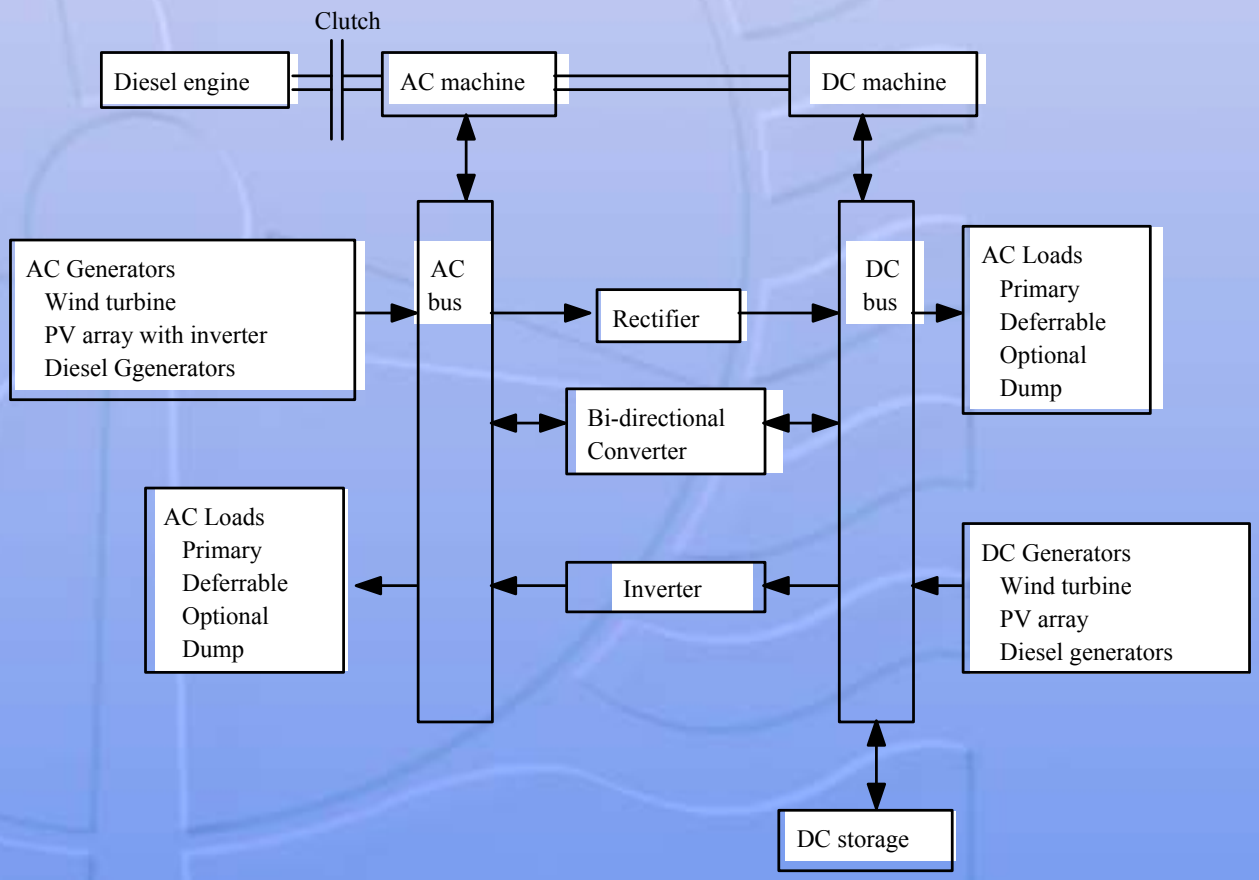
Factors Affecting Battery Life

- Total Amp-hr Throughput
- Charge/Discharge Cycling
- Mean State-of-Charge Levels
- Time Between Full Charge
- Discharge Rate
- Temperature

Hybrid2

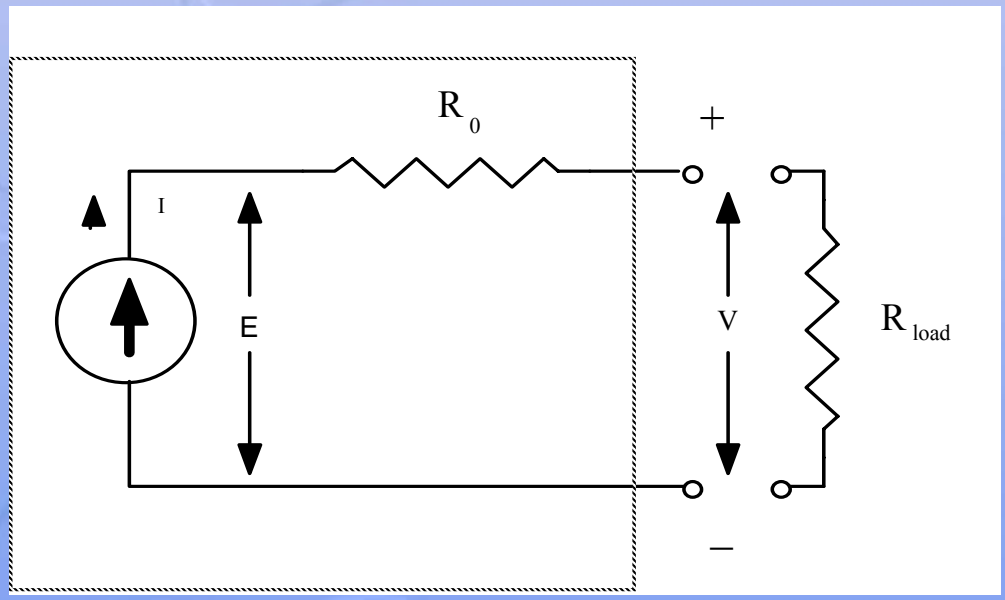
- Engineering Model to Estimate Performance and Economics of Hybrid Power System
- Developed by the University of Massachusetts and the National Renewable Energy Laboratory
- Wide Range of Systems Modeled

Hybrid2 Systems



Kinetic Battery Model

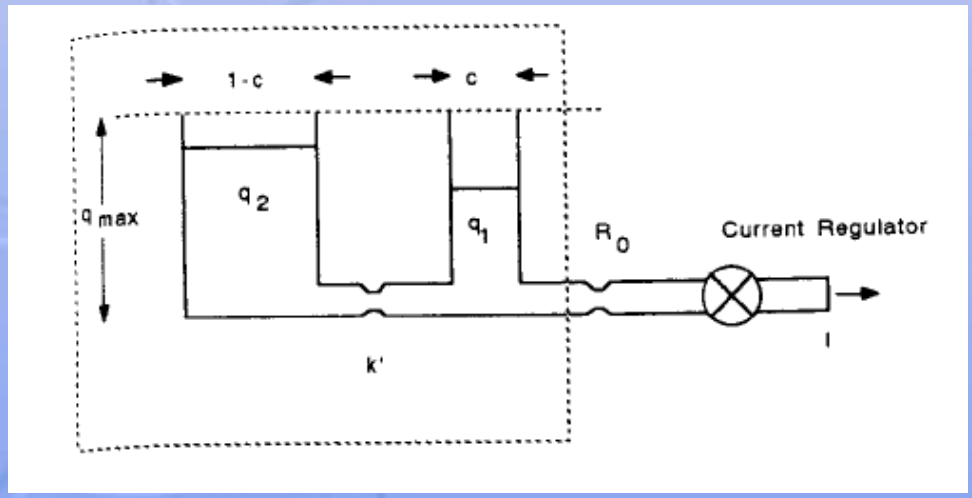
- Capacity Model
- Voltage Model
- Charge Transfer Model
- Battery Energy Losses Model
- Battery Life Model



Kinetic Battery Model:

Capacity and Rates

- Four parameters, derived from tests:
  - Maximum capacity, Q_{max}
  - Relative amount of "free charge", c
  - Rate constant, k
  - Internal resistance, R_0



Kinetic Battery Model:
Voltage

- Terminal voltage, V = f(E, I, R)

$$V = E - IR_0$$

- Internal voltage, E = f(state of charge)

$$E = E_0 + AX + CX/(D - X)$$

Kinetic Battery Model:
Voltage Details

- Charging:

$$X = q / q_{\max}(I)$$

- Discharging:

$$X = \left(q_{\max}(I) - q\right) / q_{\max}(I)$$

Battery Life Model

- Used for Economic Assessment in Hybrid2
  - Number of times batteries are replaced over system lifetime
- Effect of capacity reduction on system performance not considered

Battery Life Model

- Miner's Rule for Batteries
  - Based on material fatigue damage
  - First proposed by Facinelli (1983)
  - Extended for random cycles

Original Battery Life Model

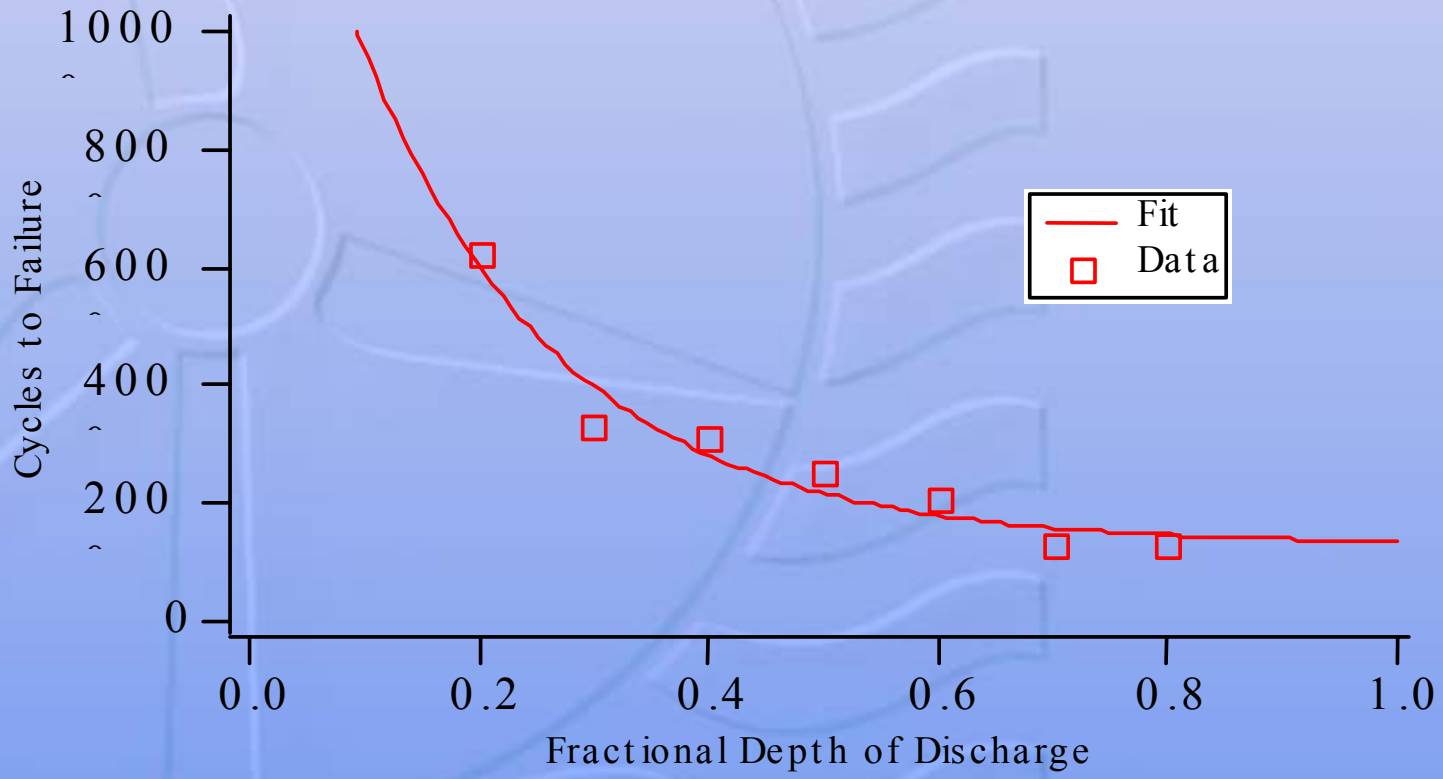
- Damage from cycles to failure and number of cycles
- Only cycle depth considered, not mean value
- Number of cycles from Hybrid2 Simulation

Battery Cycles to Failure

- Cycles to Failure from Test Data
  - Expressed in terms of fractional depth of discharge, R
  - Modeled by double exponential in Hybrid2

$$C_F = a_1 + a_2 e^{-a_3 R} + a_4 e^{-a_5 R}$$

Typical Cycles to Failure Curve



Damage

- Damage from N_i cycles of fractional discharge corresponding to $C_{F,i}$ cycles to failure

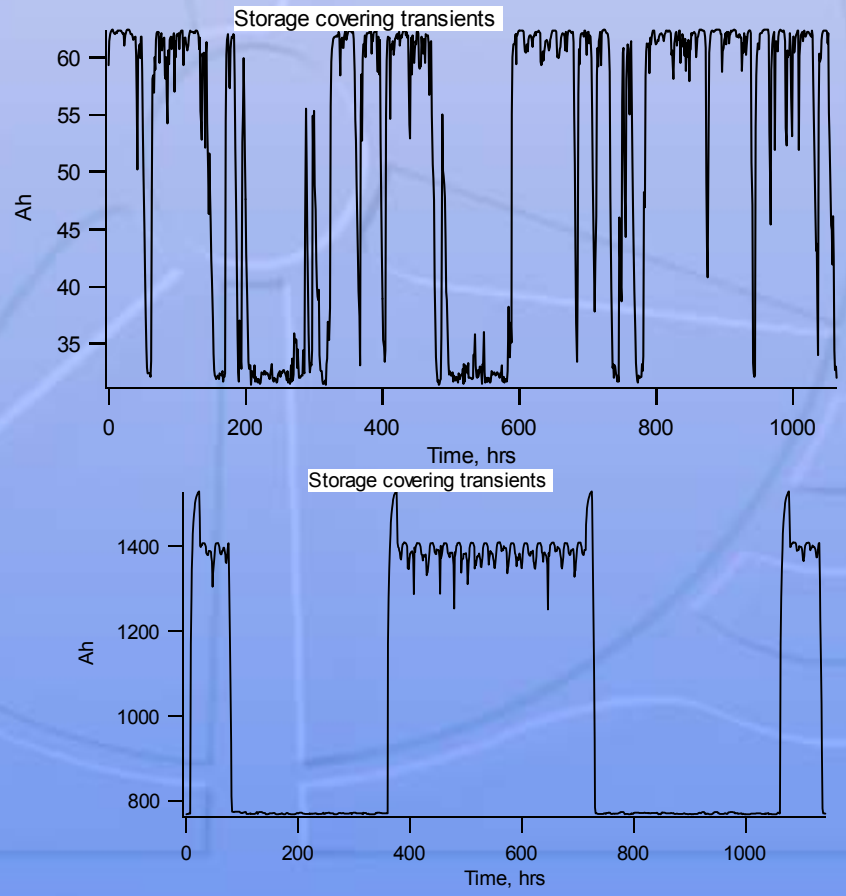
$$N_i \frac{1}{C_{F,i}}$$

- Total damage from all N_T cycle depths:

$$D = \sum_{i=1}^{N_T} N_i \frac{1}{C_{F,i}}$$

- Failure when D = 1

Typical Battery Cycles in Wind/Diesel System



Not Regular!

Case 1: Deering, AK

Case 2: Cuttyhunk, MA

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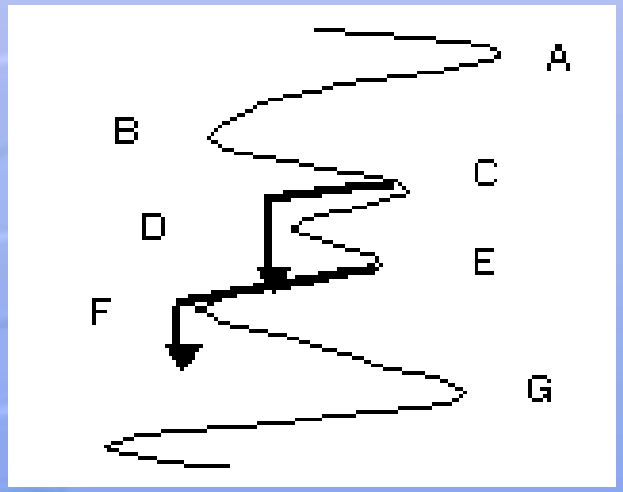
Damage from Random Cycles

- Rainflow Cycle Counting Used to Find Number of Cycles with Various DOD
- Same Damage Calculation Method as Before

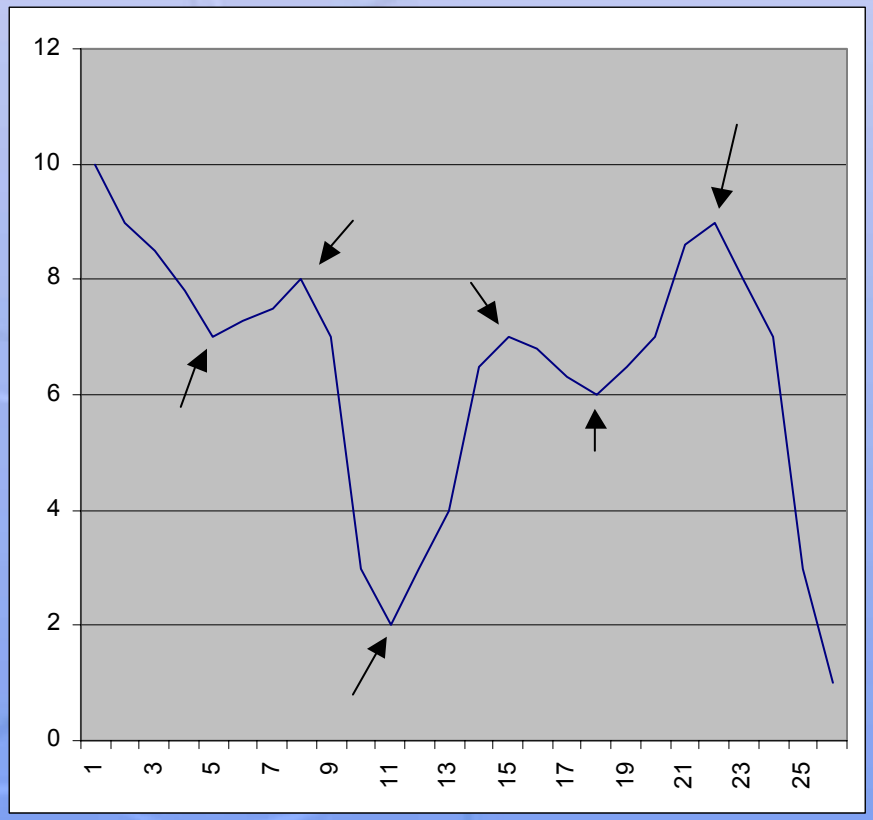
Rainflow Cycle Counting

- Time series turned on side
- “Roofs” located
- Cycle ends when rain running from one “roof” meets rain from lower “roof”
- Cycle counted and removed from further consideration



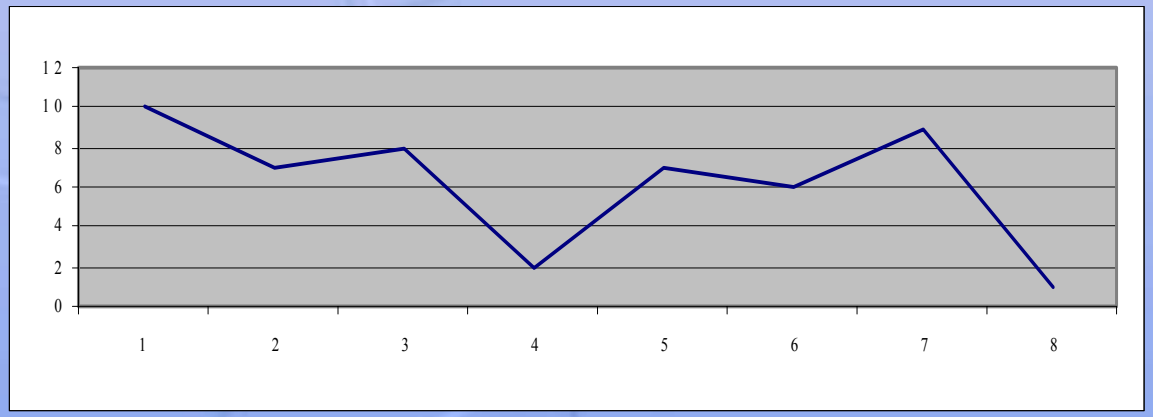
Rainflow Algorithm

- Identify peaks/ valleys



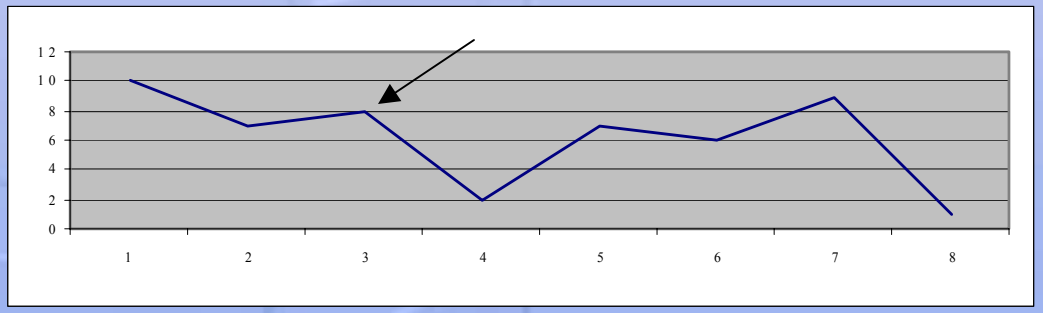
Rainflow Algorithm (2)

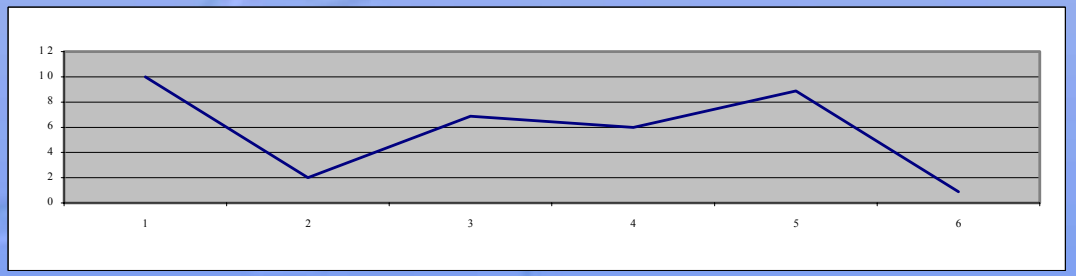
- Eliminate other points



Rainflow Algorithm (3)

- Sequentially find cycle and eliminate
- First there is one at 7-8-2, range = 1, mean = 7.5
- And so on…





Extensions to Battery Model

- New Code for Obtaining Parameters
- Hy2 Battery Model Extracted into Free-Standing Code
- Mean of Charge/Discharge Cycles Now Considered
- Comparisons with EU/NREL “Benchmarking” Battery Tests Have Been Made
- Provision for Consideration of Discharge Rates Being Added

Next Steps

- Complete Consideration of Rates
- Add Consideration of “Time at Level”
- Prepare Free-Standing Battery Code for General Release
- Incorporate Improved Battery Code Back into Hybrid2