State of the art in BMS and algorithms

- We approach frontier of knowledge in BMS and algorithms
  - The electronics aspects are important, but routine
  - SOC is well defined; established methods give good SOC estimates
  - Have learned good methods to estimate R_0 and Q, yielding SOH estimates
  - Cell energy calculation is straightforward, and
  - Can implement cell-balancing methods having varying complexities and speed
- Might improve any of these, but present state-of-art adequate for many applications
  - Some question re. long-term efficacy of present BMS on aged battery packs
  - Other issues regarding power calculation, as you will learn this week
- "Using current electronics and knowledge it takes about two years and $250K to build a custom BMS" [Davide Andrea]... not trivial, but very doable

The problem with power-limits computations

- Present methods compute power to constrain voltage limits
- But why? *Real issue is cell degradation!* Assumption is that:
  - If voltage limits are violated, then the cell will degrade quickly
  - If limits are maintained, cell will have a long and productive and happy life
- But, voltage limits *can* be violated briefly in some cases without accelerating aging
- And, "*normal*" voltages sometimes accelerate degradation, particularly for old cells
  - So, real issue is not cell voltage but rather rate of aging/degradation
- Cell power limits **should** really be calculated to more directly optimize a tradeoff between performance delivered by the cell and the rate of incremental degradation experienced by the cell

Aging-based power limits

- To compute power limits to optimize performance vs. aging
  1. Must be able to model degradation mathematically, and
  2. Devise model-based optimized controls to calculate best tradeoff
- Some early research results show that if this is done perfectly, we can often
  - Authorize more power for the same battery pack, or use a smaller battery pack with cells optimized more for energy than power
  - Achieve more *available* energy in HEV-type applications for same battery pack, or use smaller pack with cells optimized more for power than energy
  - Extend service life of battery pack and enhance value of aged pack for second-life application by understanding and controlling aging in first life
- This is ample incentive to make a strong attempt

Modeling cell degradation

- Much is known about cell degradation qualitatively
- How about quantitatively? That is, can we make accurate mathematical models of all the degradation mechanisms?
- Mechanisms aren't well understood, interactions between them are complex
  - So, at this point, we don't know (that's the nature of research!)
- But, we don't need to model **all** mechanisms **perfectly** to have a useful result
  - For control purposes, don't need to model any mechanism that isn't influenced by a variable over which we have some control (current, temperature, ΔSOC, etc.)
  - If we model the most severe mechanisms reasonably well, then we have a chance at designing controls that make a difference

Need for physics-based models

- None of the cell degradation mechanisms are tied directly to cell terminal voltage, but rather to internal stress factors
  - Knowledge of local concentration of lithium in electrolyte and at electrode surface can predict immanent collapse of power
  - Knowledge of local potentials internal to electrode regions can predict onset of side reactions such as SEI growth or lithium plating
  - Knowledge of mechanical stresses can predict electrode-particle or composite-electrode fracture
- None of this knowledge is available from equivalent-circuit models
- Must develop physics-based models of lithium-ion cells to predict aging directly

Controls problems leveraging degradation models

- If we can make models of degradation, how do we use them?
- There are (at least) three controls problems to consider:
  - For EV/E-REV/PHEV, battery pack is charged from an external source,
    - What is optimal charge profile for fast charging?
  - For all xEV, while car is being driven,
    - What are dis/charge power limits over next ΔT seconds?
  - Considering xEV as storage units for "smart grid" (beyond our scope this week),
    - When does it make sense to "lend" energy to the grid?
    - What should be the rental fee charged for allowing energy to be borrowed?
- Different kinds of optimized controls may be better for these problems

Summary

- Present BMS algorithms work well, but room for improvement
- Power-limits calculations show most promise for large gains
- Premise:
  - If we can model dominant degradation mechanisms, and
  - If these models have controllable inputs (current, temperature, ΔSOC, etc.)
  - Can devise controls to minimize degradation, maximize cell life, simultaneously
- Will need physics-based models of lithium-ion cell dynamics and degradation
- This week: very fast high-level overview of physics-based lithium-ion cell models, reduced-order models for practical implementation, degradation models, and optimal controls

For further study

- The content of this week is discussed in Chapter 7 of
  - Plett, Gregory L., *Battery Management Systems, Volume 2: Equivalent-Circuit Methods*
  - See also `http://mocha-java.uccs.edu/BMS2/index.html`.
- There are detailed lecture notes and lecture videos on these topics from which you can learn at `http://mocha-java.uccs.edu/ECE5720/index.html` (Topic 7)
- It is based on some foundational concepts from Chapters 3–6 of
  - Plett, Gregory L., *Battery Management Systems, Volume 1: Battery Modeling*
  - See also `http://mocha-java.uccs.edu/BMS1/index.html`.
- There are detailed lecture notes and lecture videos on these topics from which you can learn at `http://mocha-java.uccs.edu/ECE5710/index.html` (Topics 3–6)