## Meeting energy and power specifications

- High-power batteries deliver high voltage, high current, or both
  - Chemistry of individual cells fixes their voltage range, so for high-voltage packs, we must stack cells in series: $v_{\text{pack}} = n_s \cdot v_{\text{cell}}$
  - Cell construction places limits on cell current, so for high-current packs, we must wire cells in parallel: $i_{\text{pack}} = n_p \cdot i_{\text{cell}}$
  - Similarly, capacity in ampere hours scales as: $Q_{\text{pack}} = n_p \cdot Q_{\text{cell}}$
- Therefore, total pack energy and power can be computed as

$$E_{\text{pack}} = n_s \cdot n_p \cdot Q_{\text{cell}} \cdot v_{\text{cell}} \quad \text{and} \quad P_{\text{pack}} = n_s \cdot n_p \cdot i_{\text{cell}} \cdot v_{\text{cell}}$$

- Conclusion: to meet energy/power specifications, the product of $n_s$ and $n_p$ must meet some criteria, but the individual values of $n_s$ and $n_p$ are flexible





## Series and parallel cells

- Design of $n_s$, $n_p$ determined by economic, safety factors
  - For safety, want voltage $\lesssim$ 100 V (sometimes $\lesssim$ 50 V)
  - To minimize power-electronics cost want voltage $\lesssim$ 600 V
    - These considerations limit $n_s$
  - For efficiency, want to minimize current to reduce $i^2R$ losses (and want to use thin higher-$R$ wire to reduce copper costs)
    - This consideration limits $n_p$
- So, packs often designed using modules having voltage $\lesssim$ 100 V, which are then wired in series for a high-voltage pack
  - But, there are also reasons for wiring modules in parallel
- e.g., "2P3S" module has 2 parallel, 3 series cells





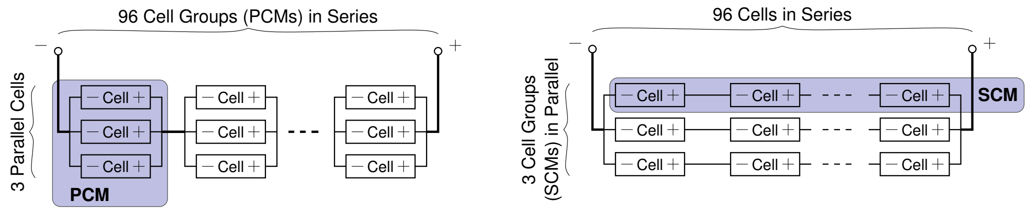
## Example of Nissan Leaf

- Most automotive battery packs manufactured from identical modules (e.g., Leaf pack comprises 48 "2S2P" modules)

- Smaller modules are easier to handle
- Modules can be tested before integrating them into the pack
- Ideally, same modules can be used in a range of different packs, reduces NRE costs

## Design of modules

- Design extreme 1: Parallel-cell modules (PCM)
- Design extreme 2: Series-cell modules (SCM)



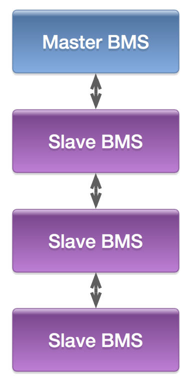

- Can design battery packs and BMS for either—usually use something in-between
- *e.g.*, consider an 18-cell "3P6S" module: Module power and energy both approximately $18\times$ that of a single cell (but not quite, in practice, as we shall find)





## BMS architecture

- A modular battery pack suggests a hierarchical master–slave BMS design as well
- One "slave" BMS unit is associated with each module
  - Module's cells welded/bolted to slave PCB, minimizing wiring and wiring losses
  - Slave has electronics for voltage measurement, cell balancing
- There is then normally a single "master" unit for each pack
  - Master measures pack current, controls contactors
  - Communicates with slaves via daisy-chain or star architecture
  - Master/slave communication uses few (e.g. two) wires—minimizes wiring-harness nightmare

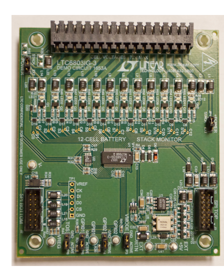






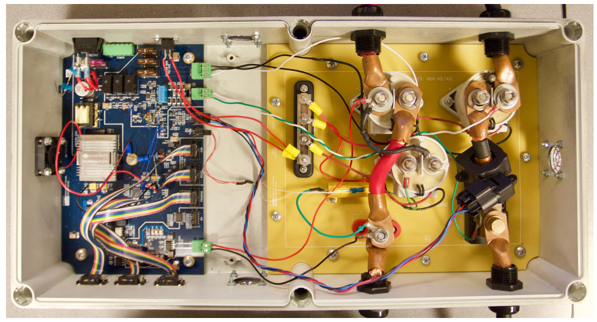

## BMS slave role

- BMS slave needs to:
  - Measure voltage of every cell within the module
  - Measure temperatures
    - Ideally of every cell, but in many packs some temperatures are estimated, especially if the pack has cells in parallel
  - Balance the energy stored in every cell within the module
    - As we will see in Course 5 of this specialization, this is needed as cells have different efficiencies, self-discharge rates, etc.
  - Communicate this information to the master



## BMS master role

- BMS master needs to
  - Control contactors that connect battery to load
  - Monitor pack current, isolation
  - Communicate with BMS slaves
  - Communicate with host-application controller
  - Control thermal-management

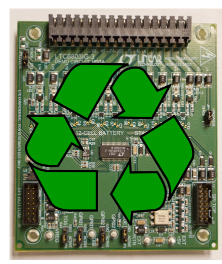






## Is slave design reusable?

- Is slave design reusable for different packs?
- Often "yes", assuming electronics flexible in terms of number of cells monitored, physical size matches different applications
  - While electronics design may be reusable in most cases, may need to redesign PCB footprint to fit individual applications
  - For high volumes there may be overall cost savings in developing a specific slave optimized for a given module
- Different cell chemistries need different voltage and temperature ranges, but these can often be accommodated via simple software changes

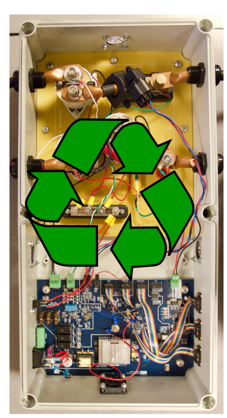






## Is master design reusable?

- Is master design reusable for different packs?
  - More difficult than for slave designs
- Master needs to be more flexible; for example,
  - Number and type of contactors it controls
  - Types of current sensors used
  - Ways it connects to charger, thermal management system
- This can be accomplished by incorporating extra analog and digital input/output in a generic design, which gives flexibility via software changes



## Summary

- For high energy and/or high power, we need to configure cells in parallel and series in high-capacity battery packs
- Safety, cost limit number in series; losses vs. cost give tradeoff for number in parallel
- Modular design has advantages in handling, testing, reduced NRE
- Modular pack design also motivates master/slave topology for BMS
  - Slaves handle voltage/temperature measurement, balancing
  - Master handles current/isolation sensing, contactor control, thermal-management





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