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The Li-ion Smart Battery Challenges

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Smart Battery Issues

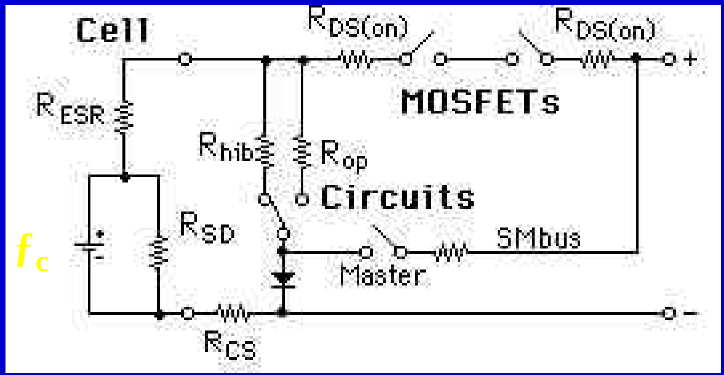
<u>Fuel Gauge Accuracy</u>:

- **Is Ampere-hours the right measurement unit?**
- **Parameter measurement resolution vs accuracy.**
- **Definable dependent parameter variables.**
- **Measurement and accumulation methods.**
- **Correlation of non-related data.**
- **Real Usage vs anticipated usage.**

<u>System Archetecture:</u>

- **Computational overhead vs system current.**
- **Cost(s).**
- **Safe operation and fail-safe degradation.**

An Approximate Li-ion Battery Pack Model



	Value Dependencies:	Accuracy dependencies
Series R (R_{ESR}):	Charge, Temp.	Current
Self Disch (R_{SD}):	Charge, Temp.	Time
On R ($R_{DS(on)}$):	Temp.	Current
Hib R (R_{hib}):	Charge	Time
Oper R (R_{op}):	Charge	Time, Activity

Ampere-Hours
or
Watt-Hours?

- **Ampere-Hours: Current into and out of the pack X time. Ignores drop in battery pack voltage caused by resistive drops and cell discharge characteristics. Varies greatly with temperature and load current.**

- **Watt-Hour: Pack voltage X current X time (hrs). Drops in capacity related to current and temperature are self-calibrating.**

Resolution vs Accuracy.

1. **Resolution is the size of the finest step within the analog-to-digital measurement system.**
   (mV or mA per bit)
   [Related to A-D converter only]

2. **Accuracy is how close to the actual value the analog-to-digital system can consistently measure. (+/-mA)**
   [Related to the entire measurement system]

Definable dependent Parameters.

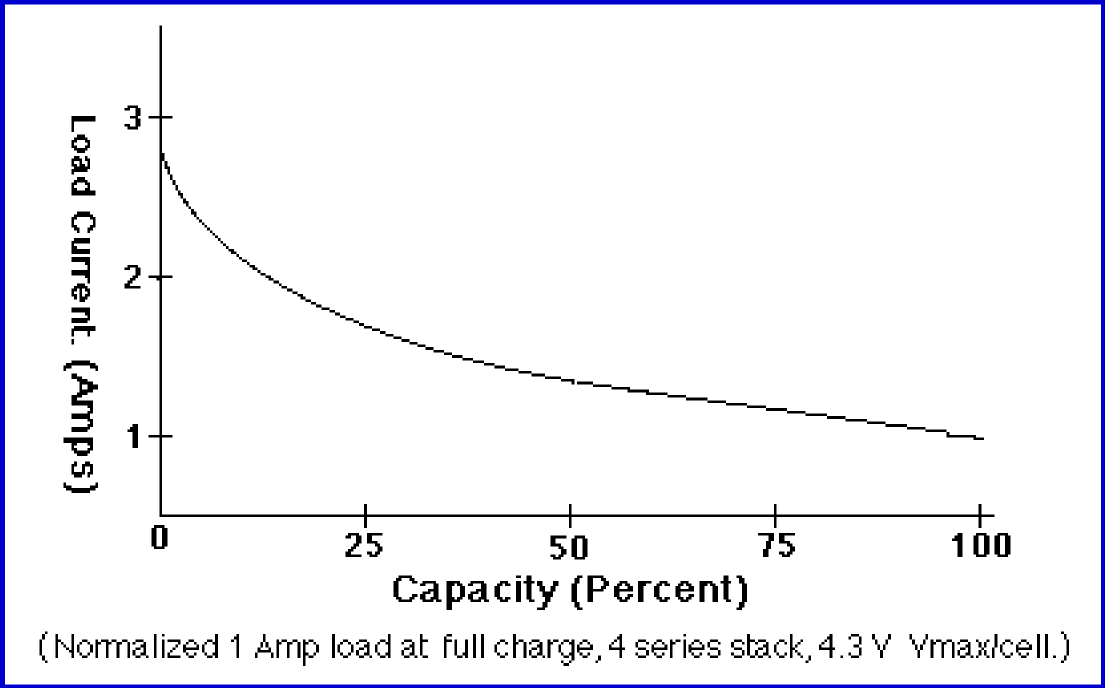
(below are industry averages)

Once a cell type and a manufacturer are selected variable parameters can be converted to mAHr units.

1. Capacity: (in A-Hrs)	**vs temp:**	**20-60**	**100%**
		0	**92%**
		-10	**88%**
		-20	**66%**
	vs Load:	**0.25C**	**+ 2%**
		0.50C	**0 %**
		1.00C	**- 4%**
		1.50C	**- 8%**
2. Self Discharge:	**vs temp:**	**+ 20 ºC**	**- 6 % Capacity/month**
		+ 60 ºC	**- 8 % Capacity/month**

Systems with Switching Power Supplies as loads.

Electronic circuits with regulated power buses are constant power loads.
Switching power systems are constant-power converters.



Correction Template

Capacity in Ampere-time:

$$\Sigma Q_{n(T)} = K_e \cdot K_{T_n}(I_n \cdot t) + \Sigma Q_{n-1}$$

Cross-check with voltage:

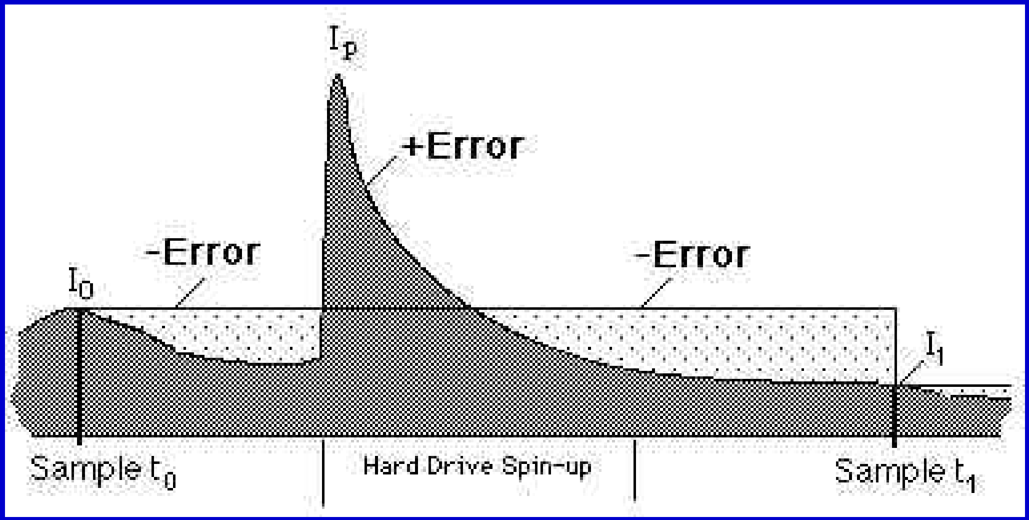
$$V_n \approx V_{OC}\Big|_{T_n Q_n} - K_e \cdot K_{T_n}(I_n \cdot t)\left[\Sigma R_{ESR}\Big|_{T_n Q_n}\right]$$

T-temp, t-time base, n-present sample, Q- capacity, R-resistance, V-voltage

Correlating Measured Data for Enhancing the Accuracy.

- Comparing the computed level of capacity with the measured cell voltages. (table lookup)
- Correcting the temporal computed capacity with the measured the pack's internal temperature
- Measuring each cell's ESR and exhibited capacity to determine early cell degradation and to predict the battery pack's end-of-life.

Sampled vs Integrating Current Measurements

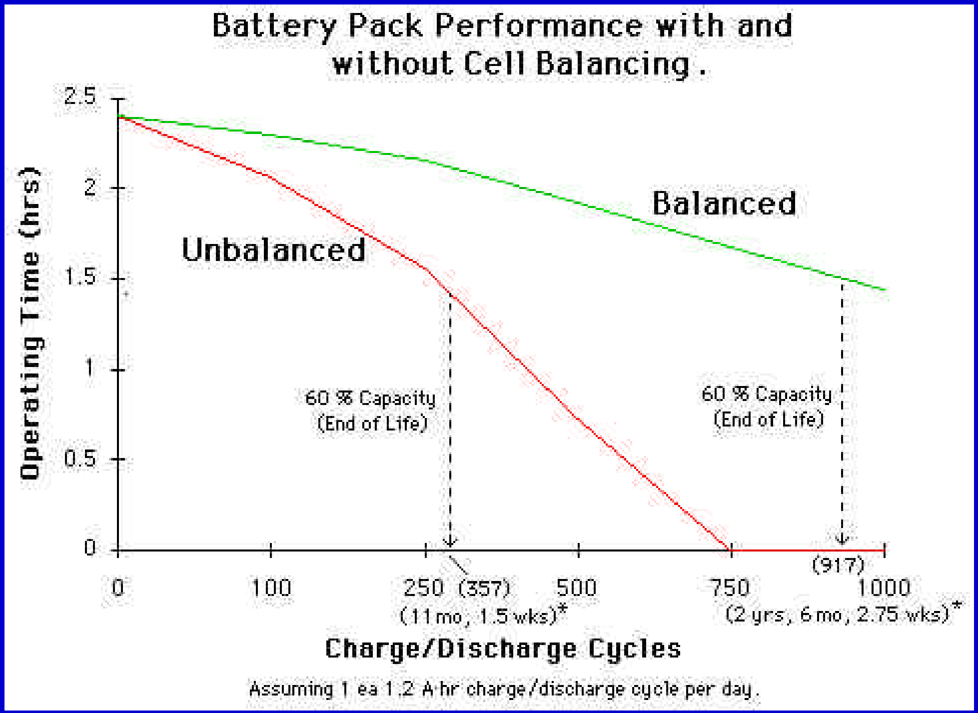


Sampled: Direct Ampere-time conversion

Integrated: Coulombic accumulation evaluated once per time increment.

Life Simulation of a 4X1 Li-ion Battery Pack.

Assumptions: 1.) Cell 1 has self discharge rate of 7 % per month, all others 6 % per month.
2.) Cell 2 has charge acceptance rate of 98.9 %, all others 99 %.
3.) Cell 3 has cycle-life capacity degradation to 50 percent after 1000 cycles, all others 60 %.
4.) All cells are initially matched in capacity and state of charge.



Battery Pack Usage and "Abusage".

<u>Common conditions:</u>

1.) The aftermarket is full of suppliers who do not adhere to respected market practices. (ex: Chargers that have open-circuit voltages that are higher than the battery system can withstand.)

2.) If a function is not automatic and embedded within the system, do not expect the user to perform the function. (ex: full-cycle learn cycles)

3.) Users do NOT know how to read, nor do they keep the user's manual on file!

4.) When initiating an end-of-capacity alert/shutdown, always keep a small amount of capacity in reserve. Those users one sees on the side of the road with a gasoline can.

Computational Overhead and System Current.

"To reduce cost, push hardware functions into firmware."

"Every CMOS clock pulse causes the expenditure of microJoules of energy."

<u>Tradeoffs:</u>

1.) Perform functions only when required (ex: SMbus data conversions).

2.) Do not oversample the environment. (ex: MCU samples cell voltage(s) less than once every 5 seconds, etc.)

3.) Simplify operations to minimize required clocks and run clock at lowest possible frequency.

4.) MCU sleeps as much as possible when no activity is required.

System Testing.

- **Each major system fault should be detectable and identifiable after the battery pack is assembled.**
- **The battery system should have an embedded, and accelerated final test program.**
- **The SMbus protocol need not be preserved during final test. (ie pertinant test information brought out on IIC or RSR232 line)**
- **Spend the monies on embedded test programs, not specialized test equipment.**
- **Time, production persons, equipments, and wasted resources (watts) are hidden costs to the system designer.**

Graceful System Degradation

Rule: All anticipated failures should be detectable and cause a condition that is safe even though the system may not be operational.

Examples:

1.) Shorted Li-ion Cell: Circuit should detect and undervoltage and open the discharge MOSFET and not recover as long as condition persists.

2.) Open Li-ion cell sense lead: Circuit should detect and undervoltage and open the discharge MOSFET and not recover as long as condition persists.

3.) Li-ion Safety IC fails: The microcontroller and a separate OVP should sense the condition and cutoff the charge MOSFET.

4.) Microcontroller enters runaway: MCU should have a watchdog timer, safety IC should operate independently and not allow MCU to perform active pack functions.

5.) Either MCU or safety IC enters latch-up: Interfaces and supply buses should be isolated enough to allow independent operation. DO NOT place the Safety function on the same die as the microcontroller!

6.) If MOSFETs short-circuit, a fuse and a blowing circuit should be included as the final battery pack killer.