

Battery Management for Monitoring up to Six Lead-Acid Batteries at the Individual Battery and System Levels

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Overview

- Why Do We Need a Battery Fuel Gauge?
- Capabilities and Benefits of HDM BFG Technology
- BFG Application Examples
- BFG Configurations
- HDM's BFG Dual Tracking Methodology
- BFG Highlights Effects of Unhealthy Batteries on the Bank
- Re-Cap



Information is Power



You would not drive a car without a gas gauge...



Why would you execute a mission-critical operation, such as "silent watch", without a Battery Fuel Gauge?



Capabilities of HDM BFG Technology

- Battery Power Usage Information: Diagnostics and Prognostics
 - State of Charge (SOC) at 95% Accuracy
 - State of Health (SOH) at 95% Accuracy
 - Hours Remaining (HR) at 90% Accuracy
 - Battery Voltage (V)
 - Battery Temperature (T)
 - Current (I)
 - State of Life (SOL)
- Functionality
 - System Interface: CANBUS, RS232, Control Panel-Mounted Display
 - Real-Time Data and Estimations
 - Self-Calibration
 - Lightweight Packaging



Benefits of HDM BFG Technology

Operations

- Alerts crew when re-charging is necessary
- Provides Hours Remaining for silent watch
- Ensures mission capacity and success

Maintenance

- Identifies unhealthy batteries for replacement
- Facilitates Condition-Based Maintenance (CBM)

Cost-Efficiency

- Single BFG per system vs. multiple BFGs per system
- Simple configuration reduces install, operation, and maintenance
- Powerful tool for intelligent power management systems



BFG Implementation Mobile Application

- Customer
 - Navistar Defense
 - UK MOD/NATO
- Vehicle
 - Husky Tactical Support Vehicle
- Application
 - Monitors Battery SOC and SOH

Over 1500 HDM BFGs have been installed in Husky TSVs in Afghanistan supporting the NATO troops





BFG Implementation Stationary Application



- Customer
 - Raytheon Company
- System
 - R-Series Regenerator Hybrid Power System
- Application
 - USMC Experimental
 Forward Operating Base
 Phase IV Demonstration in 2010 at 29 Palms, CA

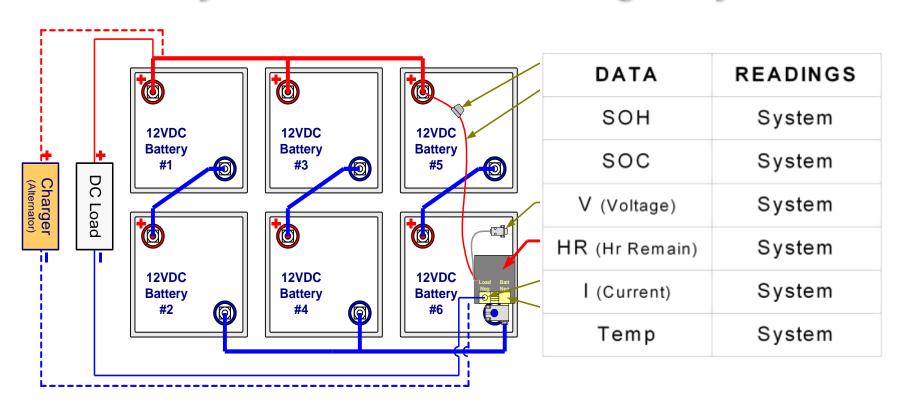
HDM BFG is critical component of intelligent Hybrid Power System



Battery Fuel Gauge Configurations



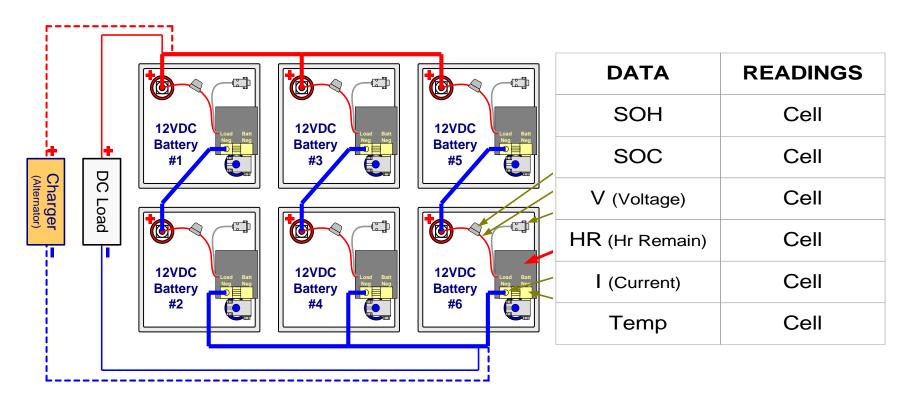
Configuration 1 System Level Monitoring Only



Advantage: SIMPLICITY



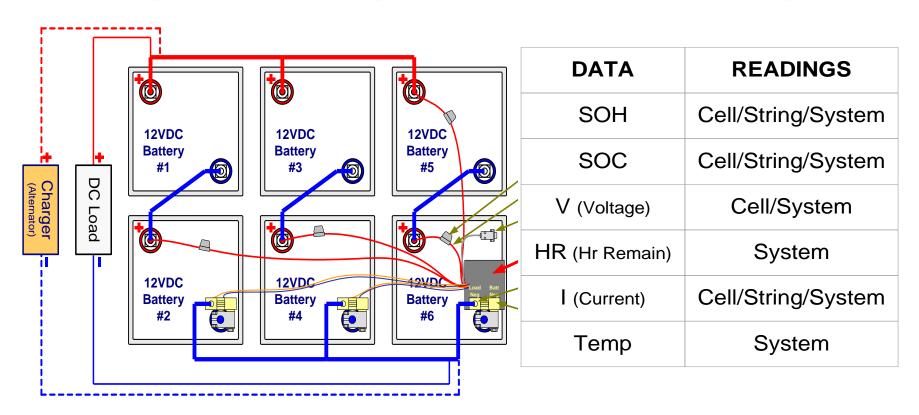
Configuration 2 Cell Level Monitoring Only



Advantage: PRECISION



Configuration 3 System/String/Cell Level Monitoring



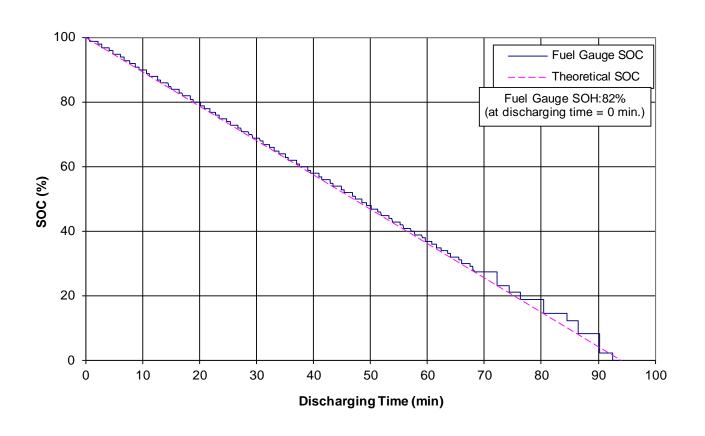
Advantage: SIMPLE, PRECISE & COST-EFFECTIVE



HDM's Battery Fuel Gauge Technology: Dual Tracking Methodology



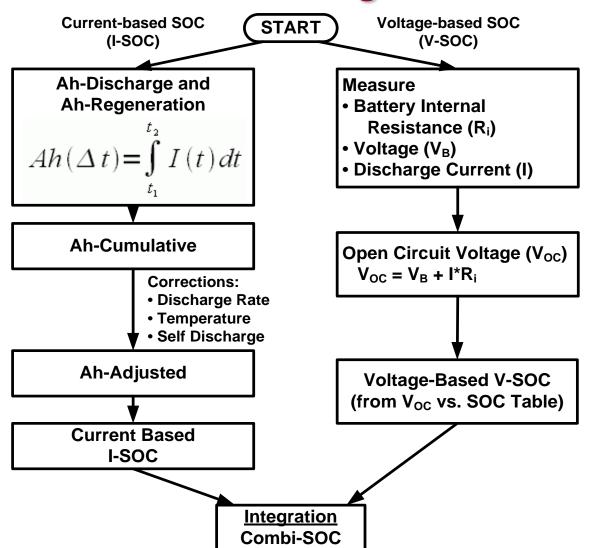
SOC Measurement Using Dual Tracking Method



SOC Accuracy at 95%

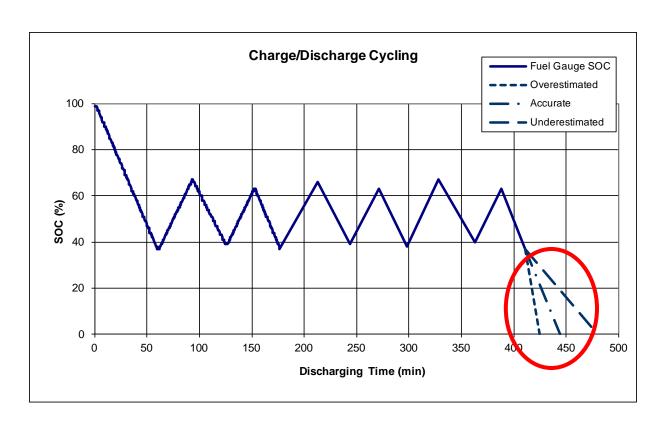


What is Dual Tracking Methodology?





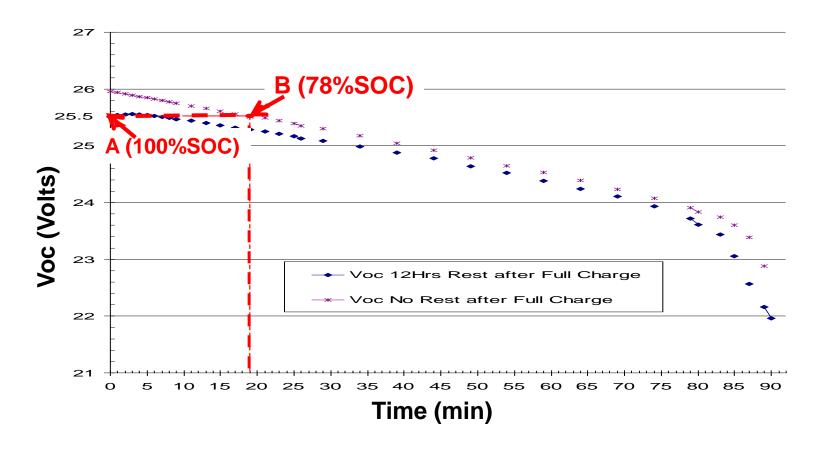
Error from Current-Based Tracking



Lack of precise charge and discharge efficiency information results in accumulation of SOC estimation errors



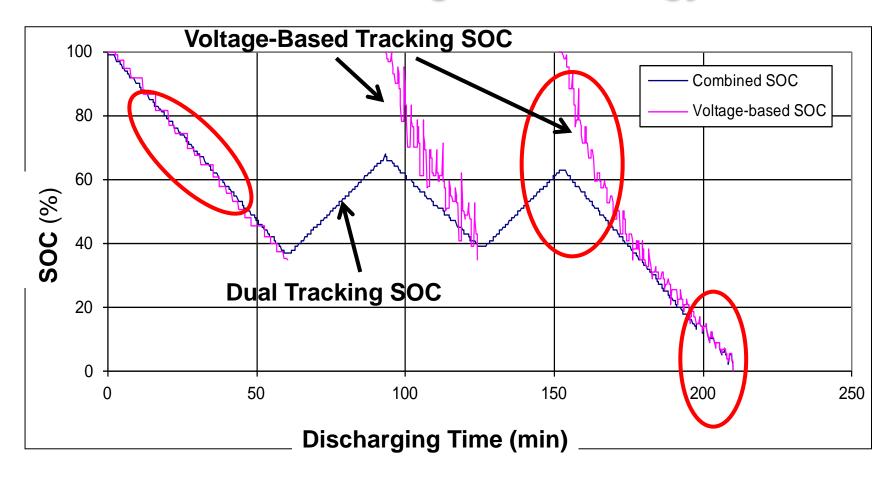
Error from Voltage-Based Tracking



Lack of voltage relaxation results in SOC errors



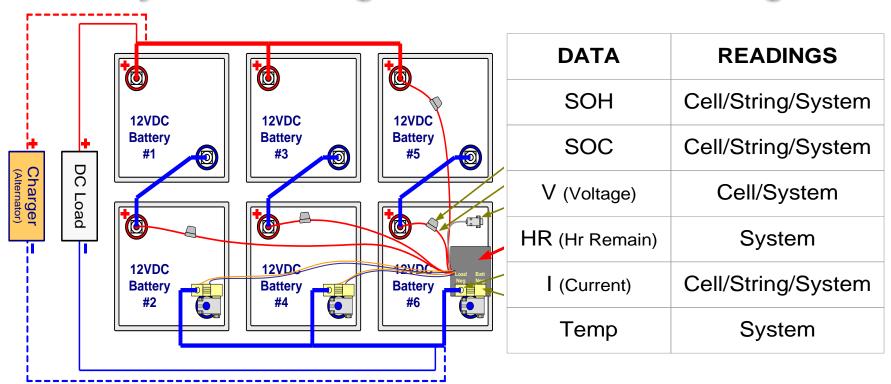
Dual Tracking Methodology



Dual Tracking Method is optimal for all loading conditions



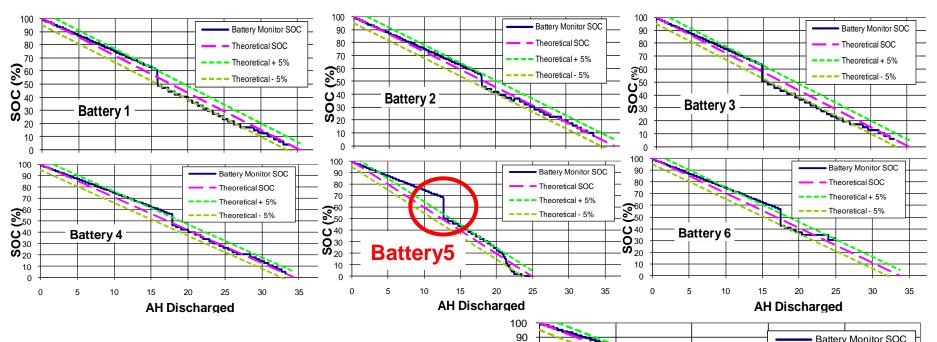
Configuration 3 System/String/Cell Level Monitoring



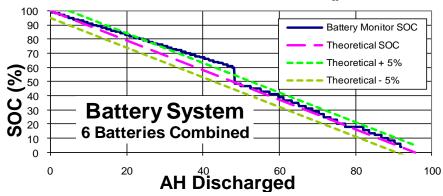
Advantage: SIMPLE, PRECISE & COST-EFFECTIVE



BFG Detection of Unhealthy Battery: Cycle 1

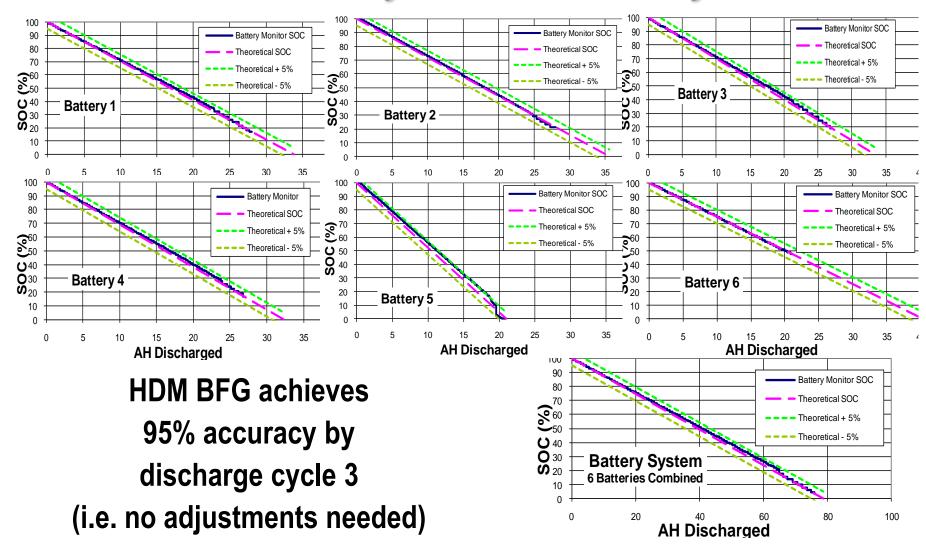


HDM BFG identifies weak battery during discharge cycle 1





BFG Accuracy Established: Cycle 3





Effects of Unhealthy Battery on Bank 1*

String #	Battery #	Individual Battery Voltage @ End Point	Discharge Current From To		SOC %	SOH %
1	1	11.3V		19A	10	73
	2	11.5V	12A		16	78
	3	11.4V	10A	18A	12	71
2	4	11.4V			12	73
	5	10.8V			0	50
3	6	12.0V	18 A	4A	36	78
Sum	Sum	System Battery End Voltage:	System Discharge Current:			
1 - 3	1 - 6	22.8V	~41A	~41A	0%	68%

^{*} Battery Bank 1: Optima Batteries

- String 3: Divergence of voltage and reduction in discharge current cause over-current stress on Strings 1 and 2
- Premature termination of discharge cycle, resulting in 19% loss in usable capacity



Effects of Unhealthy Battery on Bank 2*

String #	Battery #	Individual Battery Voltage @ End Point	Discharge Current From To		SOC %	SOH %
	1	11.3V			14	77
1	2	11.4V	33A 4	49A	19	80
	3	10.6V		6A	0	55
2	4	12.1V	33A		51	93
	5	11.2V			12	75
3	6	11.5V	34A 45A		22	87
Sum	Sum	System Battery End Voltage:	System Discharge Current:			
1 - 3	1 - 6	22.7V	100A 1	00A	0%	62%

^{*} Battery Bank 2: Hawker Batteries

- String 2: Divergence of voltage and reduction in discharge current cause over-current stress on Strings 1 and 3
- Premature termination of discharge cycle, resulting in 17% loss in usable capacity



Weakest Battery Threshold vs. Conventional Threshold at 21V

String	Battery #	Battery Voltage		Discharge Current			Charge Current	
#		@ End Point 1 (Bat 3 SOC=0%)	@ End Point 2 (Bat Voltage=21V)	@ 100% SOC	@ End Point 1	@ End Point 2	@ Low SOC	
	1	11.3V	9.9V					
1	2	11.4V	11.1V	36A	51A	20A	20A	
	3	10.6V	9.6V					
2	4	12.1V	11.5V	30A	6A	65A	3 A	
	5	11.2V	9.7V					
3	6	11.5V	11.3V	36A	45A	17A	19A	
Sum 1 - 3	Sum 1 - 6	22.7V	21.0V	102A	102A	102A	Set @ 42A	

By extending the system run-time (e.g. by 30 minutes), would be at the expense of the weakest battery



Single BFG at 95% Accuracy for up to 6 Individual Batteries

- Provides breadth and depth necessary for Cost-Effective Battery Management Systems and CBM
- User Level
 - Ensures power system reliability and performance
- Maintenance Level
 - Enables precision pinpoint of unhealthy batteries for CBM
- Incorporates theoretically scalable algorithm, for banks greater than 6 batteries (i.e. important for larger, stationary energy storage systems)



Thank You!

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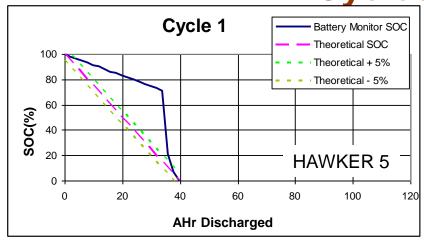
Web: www.HDM-Sys.com

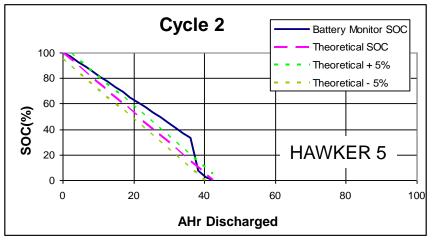


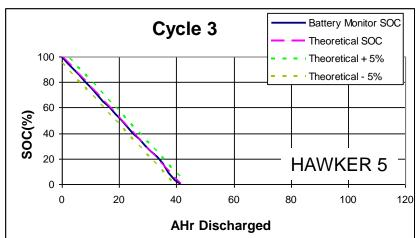
Appendix

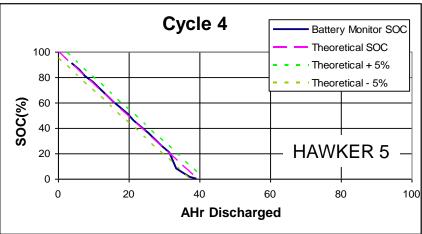


tal Tracking: Battery 5 in Battery Pack 1,2,3,5 Cycles 1 to 4



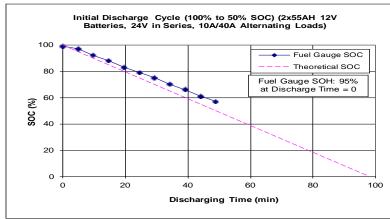


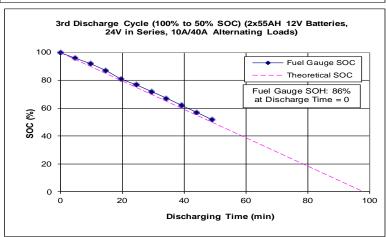


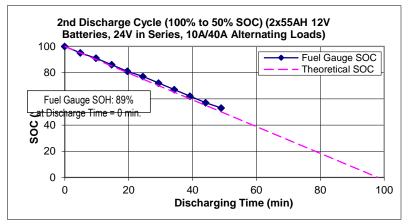


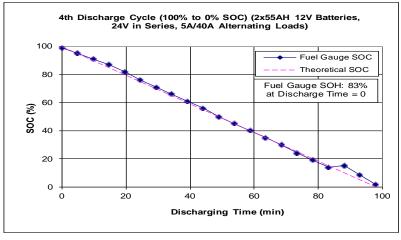
In a battery pack, HDM's BFG provides accurate SOC & SOH information within 2-3 cycles in a battery pack

SOC Measured by Dual-Tracking Method Scenario 2: Partial Discharge – Cycle 1 to Cycle 4







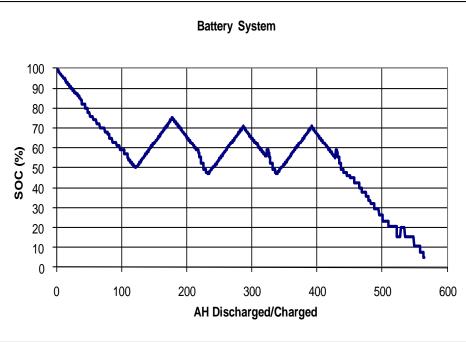


SOC error is within 5% at cycle 4



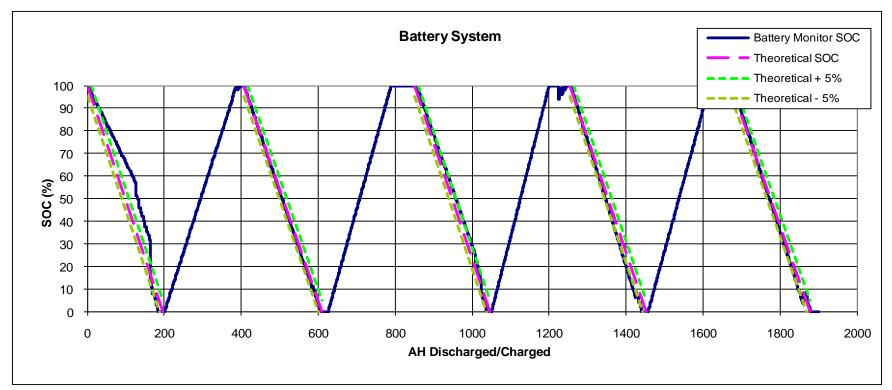
Partial Charge/Discharge Cycles of Battery Bank 2 — Battery #2/System





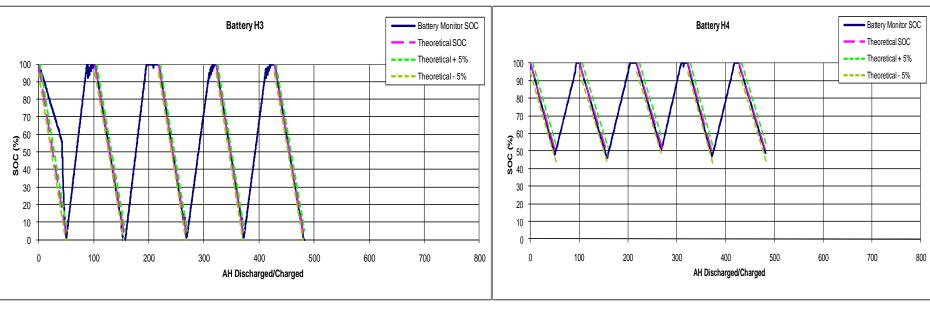
 SOC accuracy is 95% after four partial charge and discharge cycles

Whole Battery Bank (6 Batteries) Monitoring



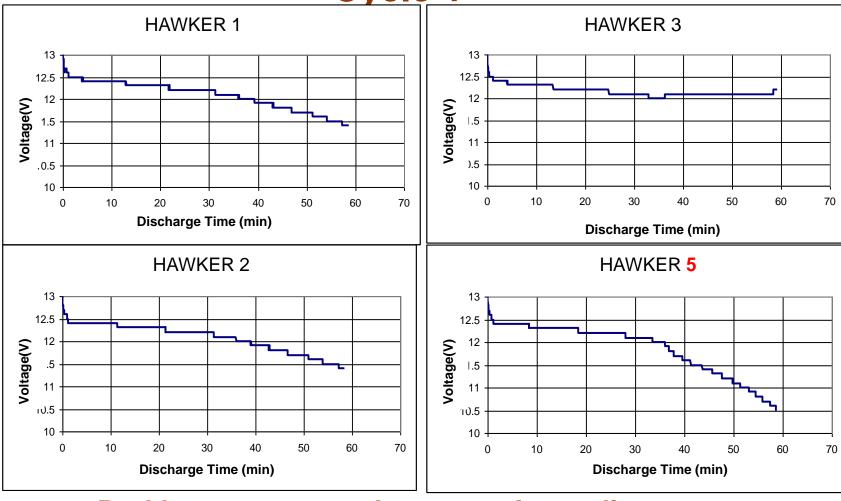
- SOC accuracy is 20% in first cycle, it quickly improves to 5% within a few cycles
- Total AH discharge is measured around 200 AH
- •System discharge termination point: is set when any battery in the system reaches a low voltage of 10.5V

5-Cycle-Profile of 2nd String of Batteries (3&4)



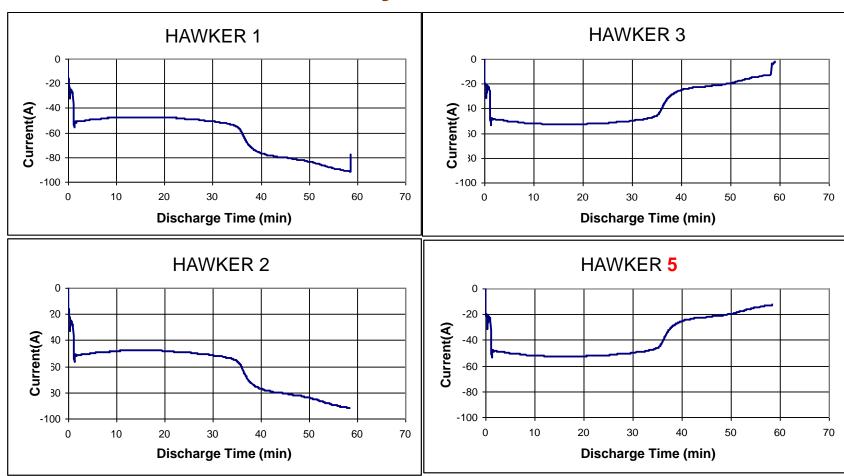
- Battery #3 is the weakest. SOH ~ 50%, other batteries are 75% to 80%
- At 1st cycle, SOC of battery #3 is 40%. After a few cycles, SOC is within 5% error
- Battery #3 capacity is only 50Ah and is fully utilized when the system reaches the termination point
- •Battery #4 in the same string only used up 50% capacity when system reaches the termination point

Voltage vs. Discharge Time of Battery Pack 1,2,3,5 Cycle 1



Bad battery causes battery voltage divergence in a battery pack

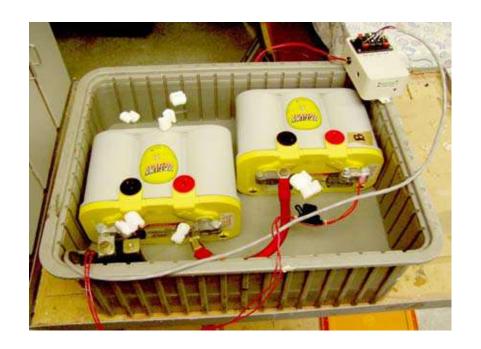
Current vs. Discharge Time of Battery Pack 1,2,3,5 Cycle 1



Bad battery causes discharging currents unbalanced between battery strings (1&2) vs. (3&5)



BFG: Water Submersion Test



BFG was submersed in water at 25°C for three hours, and was tested for operational performance