Welcome to
Battery management deep dive training

OCTOBER 13-14, 2020

History of BMS deep dive training…

- **In 2004:** 1-day training for 6 engineers on gauges for Inventus (formerly Palladium)
- **In 2008:** 2 parallel tracks: charger and gauge with lab session, 50-60 engineers from BMS customers, distributors, and TI FAEs
- **Since 2011:**
  - An educational conference for professionals all over the world
  - **~ 150** battery-management experts in attendance
  - 2-3 parallel sessions (chargers, gauges, monitors and protectors)
  - 1:1 between customer and TIers for specific project collaboration
- **In 2020:** moved virtual

Our commitment to deliver high-quality content and support battery-management engineers in their design challenges has stayed unchanged throughout the years

BMS product portfolio

Battery Charger Products

Products

- **Linear charger**
- **Switching charger**
  - Buck with integrated FET
  - Boost/Buck-boost w integrated FET
  - Charger controller
  - Inductor-less charger

Applications

- **Industrial: Home automation, medical, vacuum cleaner, Robots, ePOS, power delivery, power tools, transportation**
- **Personal Electronics: Smartphones, Tablets, Notebook, e-cig, BT Speaker & Headset, Wearable, accessories**

Battery Gauge Products

Products

- **Gauge**
- **Monitor**
- **Protector**
- **Authenticator**

Applications

- **Industrial: Power tools, Garden tools, vacuum cleaner, E-Bike, E-Scooter, Medical, ePOS, Drone, Robotic UPS**
- **Personal Electronics: Smartphones, Tablets, Wearables, Portable Audio**

Battery Automotive Products

Products

- **Monitoring & balancer**

Applications

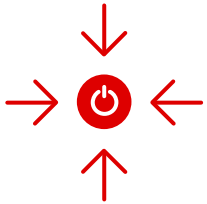
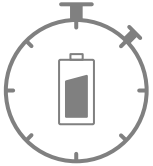
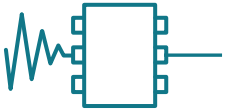
- **EV, HEV, e-Bus**
- **Energy Storage System**

Personal electronics

Industrial

Automotive

Key battery management trends

Power Density	Low I_Q	Low noise & precision
		
Achieve fast charging with highest power conversion efficiency to safely and reliably charge the battery with smallest solution size	Lowering quiescent current to extend battery and shelf life without compromising system performance	Maximize the battery capacity and cycle life for extending the battery run-time and improving safety

2020 BMS deep dive training agenda

			Day 1: OCTOBER 13		
CST (Beijing)	CEST (Berlin)	CDT (Dallas)	Keynotes & Opening Sessions		
10:00 - 11:00 PM	4:00 - 5:00 PM	9:00 - 10:00 AM	Warm welcome from Jinrong Qian & keynotes by Marian Kost Industrial system trends and opportunities for BMS		
			Chargers	Gauges	Monitors
11:00 - 11:45 PM	5:00 - 5:45 PM	10:00 - 10:45 AM	Will Zhou Battery charger design considerations for wearables and true wireless stereo (TWS)	Yevgen Barsukov Battery management for pulsed load applications	Matt Sunna, Ivo Marocco Cell balancing considerations for industrial and automotive applications
			Break		
11:50 PM - 00:35 AM	5:50 - 6:35 PM	10:50 - 11:35 AM	Yipeng Su Small chargers pack a powerful punch: combining buck-boost and USB Type-C™ power delivery for maximum power density	Githin K Prasad Fundamentals of battery gauging algorithms	Shawn Hinkle Design considerations for high-cell-count battery packs in industrial applications
			Break		
00:40 - 1:25 AM	6:40 - 7:25 PM	11:40 AM - 12:25 PM	Jeff Falin Key battery charger features to improve the user experience	Eric Vos How to automate the gauge learning cycle and basic functions to save R&D time	Terry Sculley How to stack non-automotive protectors and monitors in high-cell-count applications

			Day 2: OCTOBER 14		
CST (Beijing)	CEST (Berlin)	CDT (Dallas)	Keynotes & Opening Sessions		
9:00 - 9:45 PM	3:00 - 3:45 PM	8:00 - 8:45 AM	Ivo Marocco and Ankush Gupta Industry trends driving high-accuracy battery monitors for HEV/EV		
			Break		
			Chargers	Gauges	Automotive Monitors
9:50 - 10:35 PM	3:50 - 4:35 PM	8:50 - 9:35 AM	Sharafadeen Raheem Choosing the right battery charger topology for low-power applications	Dominik Hartl Gauge configuration featuring Impedance Track™ technology for applications with dynamic loads	Spencer Hu Design considerations for 48-V batteries in hybrid and electric vehicles
			Break		
10:35 - 11:25 AM	4:40 - 5:25 PM	9:40 - 10:25 AM	Kedar Manishankar Achieving simple, safe and efficient charging	Shirish Kavoor Introduction to BQStudio and TI tool chain for gauge evaluation	Taylor Vogt Comparing wired vs. wireless solutions in automotive battery management systems

Additional resources

- For information on BMS portfolio, type into your browser ti.com/battery
- The material used during this event will be available at ti.com/deepdive-2020
- You will receive a survey email at the end of each day. Please provide feedback on the sessions you attend
- If you questions, please post them at e2e.ti.com and our experts will come back to you

Industrial systems trends & opportunities for BMS

Battery Management Deep Dive Training

October 2020

Marian Kost

Director Industrial Systems

Agenda

- TI in industrial
- Industrial system engineering: strategy, focus, opportunity
- Industrial systems trends and opportunities for BMS
- System design case studies for BMS

Our company at a glance

Updated January 30, 2020

Revenue in 2019

- Analog: $10.22 billion
- Embedded: $2.94 billion
- Other: $1.22 billion

Capital expenditures: $847 million
R&D: $1.54 billion

Automotive and industrial comprised 57% of TI's 2019 revenue

- Industrial: 36%
- Automotive: 21%
- Personal electronics: 23%
- Communications equipment: 11%
- Enterprise systems: 6%
- Other: 3%

Approximately 30k employees worldwide

12k in the Americas

16k in Asia-Pacific

2k in Europe

80,000+ products for ~100,000 customers

14 manufacturing sites worldwide, tens of billions of chips produced each year

TI.com

Web presence, 120+ sales & applications sites across the globe

World's Most Ethical companies

Top 100 Best Corporate Citizens

Recognized by the Dow Jones Sustainability Index

We help engineers to build smarter, stronger industrial systems

The power to solve the toughest industrial challenges. Our products and system expertise help engineer smarter, safer, more robust industrial designs.

Product innovation

Analog and embedded products support complex industrial requirements

Rigorous testing to meet quality, reliability standards

Industrial is in our DNA

System expertise

Expertise in 13 market sectors and 500+ systems

2,000 fully tested, circuit-based reference designs

Help to meet functional safety requirements

Commitment to long-term supply

14 manufacturing sites worldwide

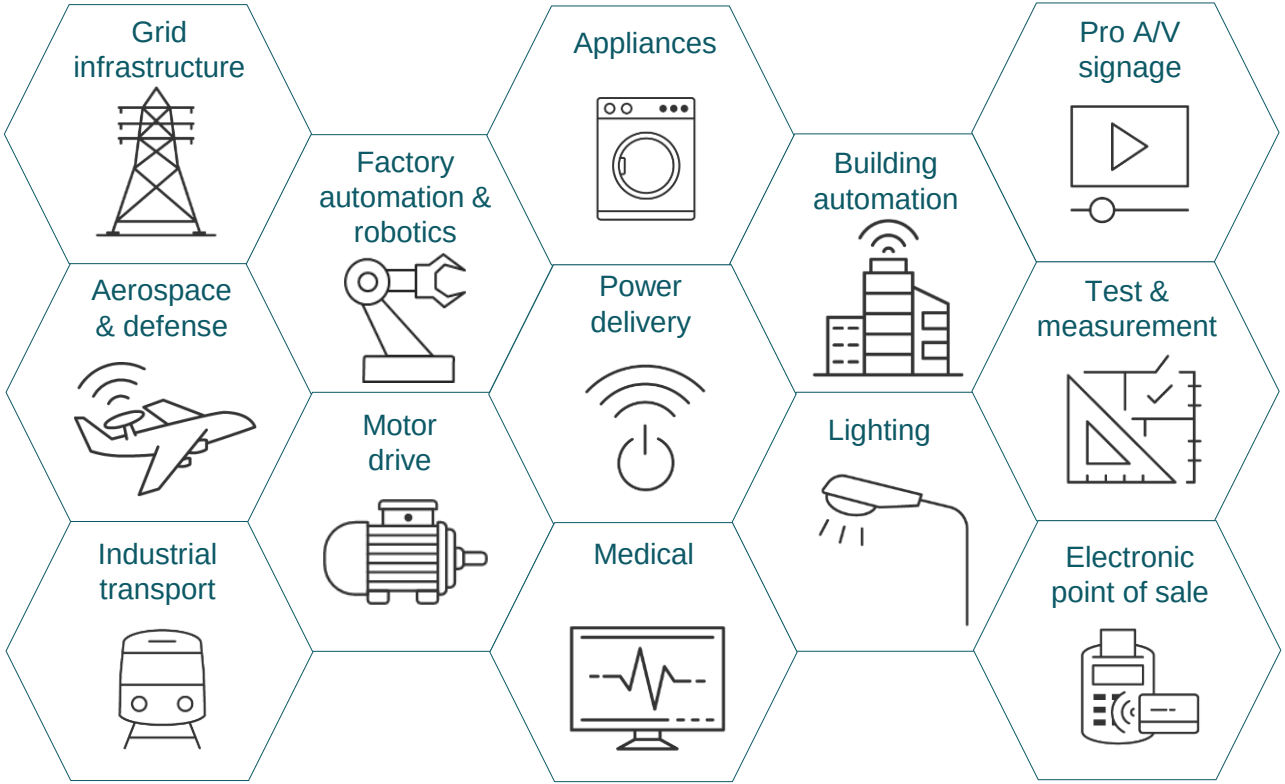
Proprietary processes and packaging

Proven track record of on-time delivery for product orders estimated ship date

Investments in strategic industrial markets

Global
cross sector
industrial

Power
Design
Services



Customer’s benefit: Industrial system engineering

Putting customer’s design challenges first

Global teams dedicated to strategic end equipment specific design challenges in addition to global field applications teams

Solve system design challenges with the largest industrial semiconductor portfolio and deep end equipment knowledge

Exchange global trends and innovate on system level as partners

From design kick off, part selection to system evaluation – a true design cycle partnership

Leverage global EE expertise to build the smartest solutions

Faster design cycles and increased innovation

Enable faster market leadership
by focused execution

Minimize time by faster system evaluation, risk mitigation and additional system resources

Sector team is made up of systems experts who have deep end equipment knowledge

TI system engineering: Faster time to market

Architecture definition / concept

Proving new architecture, e.g.:
- **SiC, GAN** – proving new levels of efficiency, power density, robustness
- **Wireless BMS** – concept, functional safety, feasibility, protocol selection
- **Functional safety topologies –** STO at PL e/SIL3, isolated PSUs

Architecture level comparison

BOM analysis
- On architecture level

Design for standard compliance

Joint architecture workshops

Subsystem / topology selection

(Sub)system simulation
- **Spice, TINA, MATLAB** – system power density, robustness
- Efficiency analysis of alternate power architecture
- Performance over lifetime calculation

Design recommendation for:
- Low EMC/EMI
- Thermal performance
- Space optimization

Functional safety concepts
- Propose solutions mitigating failure modes

Assess ASSPs vs. discrete approach for flexibility, cost and performance enhancement

Power tree optimization

BOM analysis & comparison

Schematics / layout HW design

Schematics / layout review

Customer specific hardware or reference design
- Paper design, prototype board, reference designs

Simulation

Design solution versus competitor
- Rework competitor design with TI solution

Manufacturability
- Package
- Height, width analysis
- Passives
- Space optimization

Prototype verification

Troubleshooting:
- Standard compliance tests
- EMC/EMI performance
  - Filter
  - EMScan
  - Open TEM cell
  - In-house chamber
- Thermal performance
- Signal integrity
  - Noise
  - Cross-talk
  - Spurs
- Root cause identification by customer problem statement

Customer specific hardware or reference design

Lab evaluation
- On-site at customer's lab
- At TI's lab
- Using existing reference designs / EVMs

BMS – Industrial systems trends and opportunities

Sector	Key end equipment	Industry goals	Industry adoption barriers	Future trends
Medical	***Imaging*** *Ultrasound smartprobe* ***Patient monitoring*** *Oxygen concentrator/ ventilator*	• Small form factor all in one design for point of care diagnostics and more accessible to rural areas • Enable seamless hospital and home monitoring • Portable design enable patient travel	• Balance of high-quality image and battery operation life (2+ hours) • Battery operation life with continuous monitoring and data transfer via various communication links • Longer battery life and meets FAA regulation	• Increasing channels, smaller form factor/light weight, longer battery operating time • Multi-modality monitoring, longer battery shelf life and operating time, environmentally friendly battery chemistry for disposable patches • Multi-battery system design to prolong operating time and meet FAA battery energy density requirement
Grid infrastructure	***Renewables*** *Energy storage, solar inverter*	• Make the electricity grid more efficient, resilient, secure, cost-effective and sustainable	• High upfront costs for end consumers • Need for highly skilled / experienced technicians to maintain and operate system correctly • Time of day tariffs – RES can help shave off peak loads if incentives are there for producers and consumers	• <u>Utility scale:</u> 1. Renewable energy growth forces supply vs demand needs 2. Clean energy requirements 3. Grid modernization / new infrastructure for expanded grid 4. Resilience of the electric grid/ push for DERs/ localized storage • <u>Behind the meter:</u> 1. Back-up power 2. Incentive to reduce peak demand and time-of-use rates 3. Grid independence
Power delivery	***Battery pack*** *e-bike/e-scooter/LEV* ***Telecom*** *BBU battery pack*	• Li-ion battery pack replacing lead-acid quickly in e-bike & telecom BBU, etc., markets • WW Li-ion e-bike battery pack volume increases in the millions • 5G telecom BBU battery pack TAM in China grows exponentially	• Complex BMS system functions required to guarantee the safety of Li-ion battery pack. Key functions like protection/gas gauge/monitoring /cell-balancing.	• China market: shared e-bike use case scenario requires the battery pack to be safer and smarter • EU market: functional safety (from EN15194: 2017) is must-have for e-bikes/e-scooters/LEVs to EU market

BMS innovating the future in medical

Medical market evolution and design challenges

Medical end equipment evolution		New design challenges
Cart based ultrasound  → **Handheld smartprobe** 		• Small form factor design • Thermal challenges • More than 2 hours operation time
Bedside patient monitoring  → **Telehealth patches** 		• Small form factor design • More than 14-day battery life • Environmentally friendly battery chemistry • Design optimization with 1.5 V battery
O2 concentrator  → **Portable O2 concentrator** 		• Meet FAA requirement for air travel • Synchronous charging and discharging with protection for multi-battery operation

CPAP & O2 concentrator: Dual battery charger

Subsystem: battery management

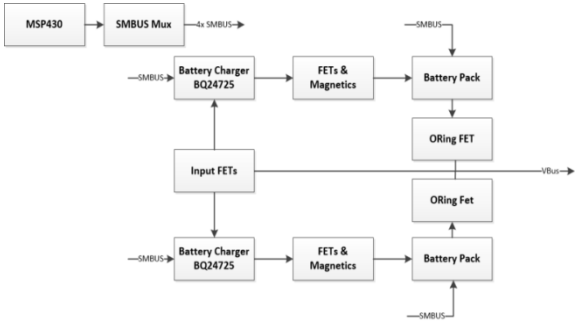
- O2 concentrator is a portable unit which concentrates the oxygen from air by removing nitrogen. It uses dual battery system to make optimum use of the charge and also limit the physical size of each battery.
- Many patient monitoring systems also have a requirement on two batteries

Design challenge

- Physical size of the battery is limited to single 100 Wh for air travel
- Simultaneous charging and discharging of two smart batteries (100 Wh) to enable longer back-up
- Power limiting when operated by an adapter
- Protection mechanism against overcurrent
- Seamless switching between batteries and adapter with overcurrent protection

TI solution

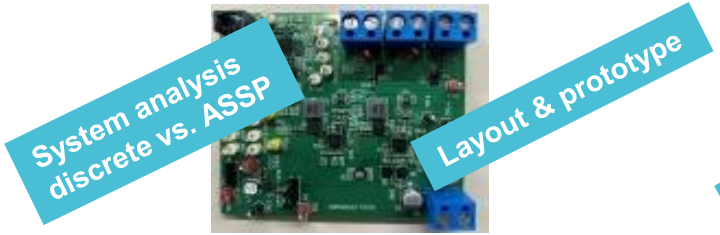
System level solution to control charge and discharge of two batteries (simultaneous charging and discharging)



Why TI?

- TI devices: BQ24725A * 2, INA381A, TLV7021, TLV9061, CSD17579Q3
- Key competition: dual smart battery system manager
- Cost optimized discrete solution compared to competition (>30% cost savings)
- Key additional features added in TI proposal to meet customer needs: adapter power limit, input overcurrent protection, system short circuit protection and battery disconnect circuit

Customer engagements

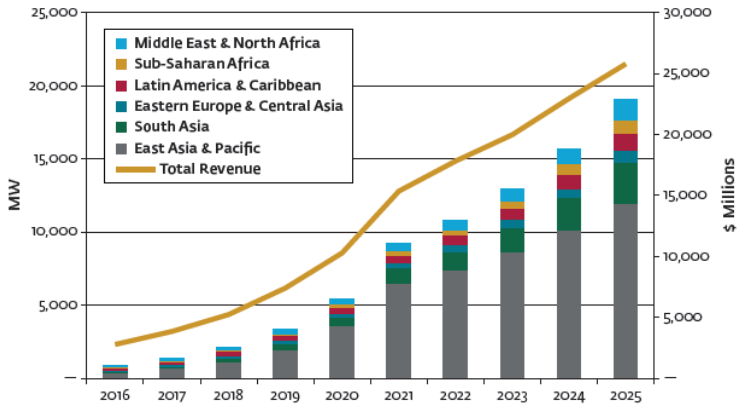


Charger 1 Vo	Charger 2 Vo	I input(A)	I load(A)	Vo Err
8.27	8.5	2.62	Open	
8.27	8.5	2.88		
8.27	8.5	3.15		
8.27	8.5			
8.1	8.34			3
7.6			1.76	2.7
7.3			2	2.55
		4.07	2.5	2.1
		4.09	3	1.6
	4.7	4.09	3.35	1.4
	4	4.09	3.5	1.4
2.8	2.9	4.09	3.75	0.7
1.4	1.4	4.16	4	0

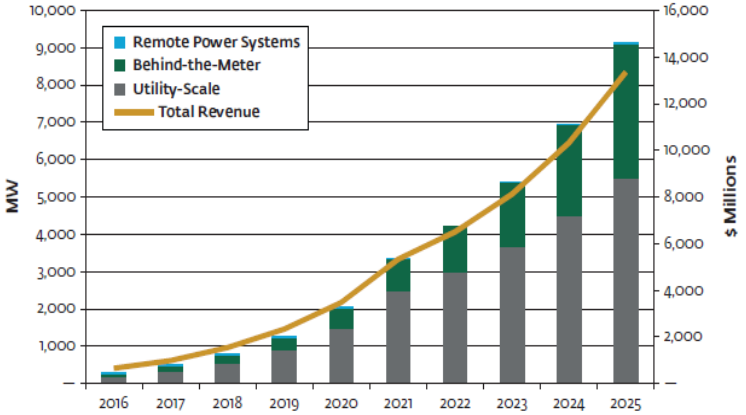
BMS innovating the future in grid infrastructure

ESS – Market growth projections

Projected annual stationary energy storage deployments, power capacity and revenue by region, emerging markets: 2016 - 2025



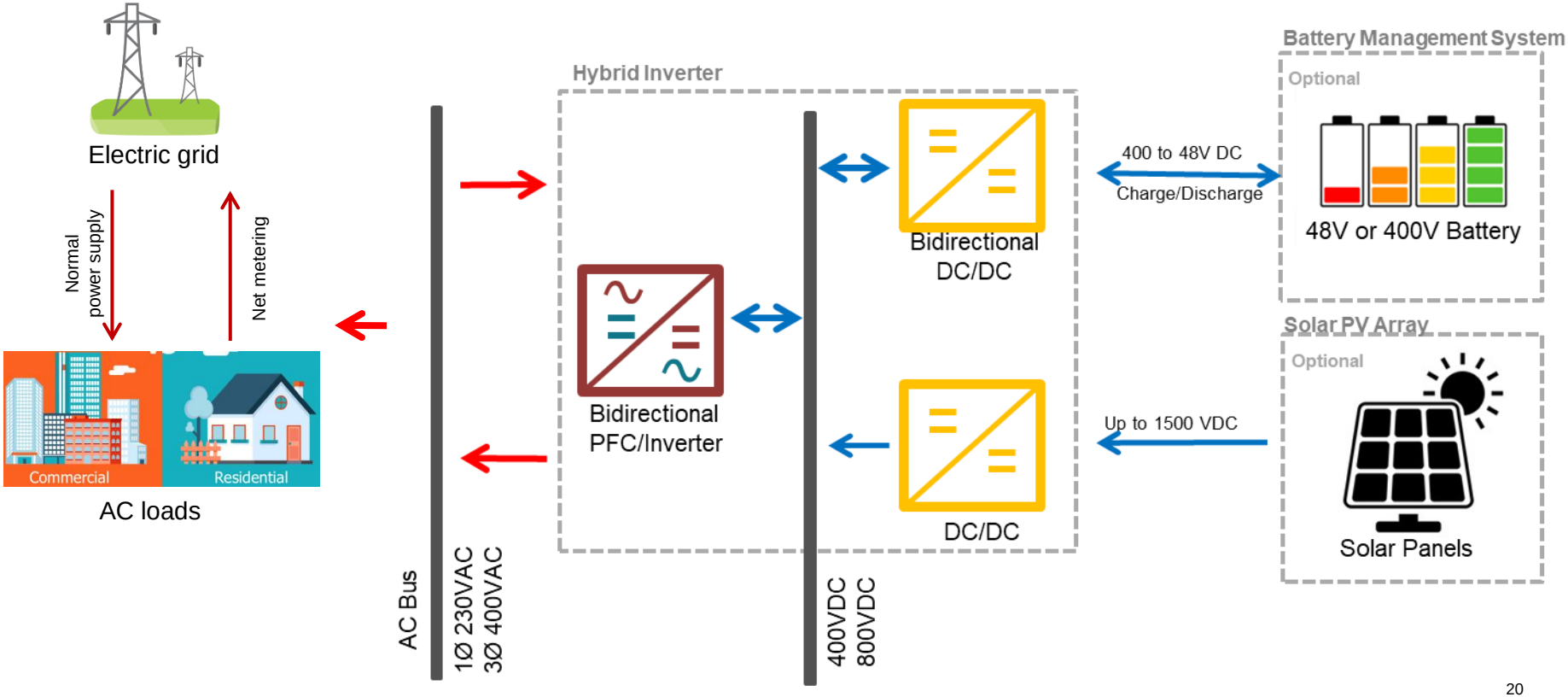
Projected annual stationary energy storage deployments, power capacity and revenue by market segment, China: 2016 - 2025



Source: Energy Storage Trends and Opportunities in Emerging Markets – IFC published in 2017

- Significant growth driven by China
- Growth in developed economies will come from behind-the-meter and utility scale ESS - US, Western Europe & Australia
- Lithium ion batteries are expected to have >60% of the market share in ESS batteries
- Once electric cars have had a few more years on the road, their used batteries are expected to become cheap, secondhand, stationary storage devices

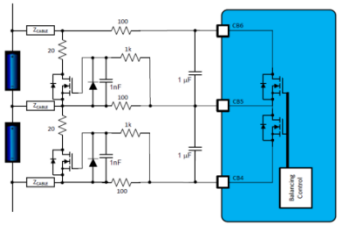
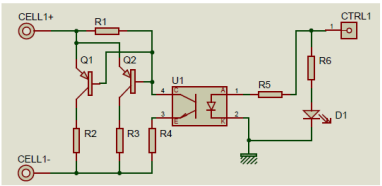
Bi-directional power conversion enables ESS



BMS reference design activities

BMS	Monitoring & protection	Monitoring, protection & cell balancing	Battery gauging	Communication
<100 V battery voltage	TIDA-010030 Accurate gauging, 13S, 48 V Li-ion battery pack reference design	TIDA-00792 Multi-cell 36-48 V battery management system ref. design	TIDA-010030 Accurate gauging, 13S, 48 V Li-ion battery pack reference design	TIDA-01400 Battery pack controller communications bridge
	TIDA-01093 Battery management module for 20S applications ref. design	TIDA-00817 16-channel active cell balance reference design	TIDA-01093 Battery management module for 20S applications ref. design	TIDA-01093 Battery management module for 20S applications ref. design
		TIDA-00717 16-cell EV/HEV battery monitor with passive balancing		
>100 V battery voltage	TIDA-01537 Scalable HEV/EV 6S to 96S lithium ion cell supervision demonstrator	TIDA-00817 16-channel active cell balance reference design	TIDM-TMS570BMS High perf. MCU for an EV/HEV battery management system	TIDA-01400 Battery pack controller communications bridge
		TIDA-00239 14-channel active cell balance battery management ref. design		TIDA-00239 14-channel active cell balance battery management ref. design

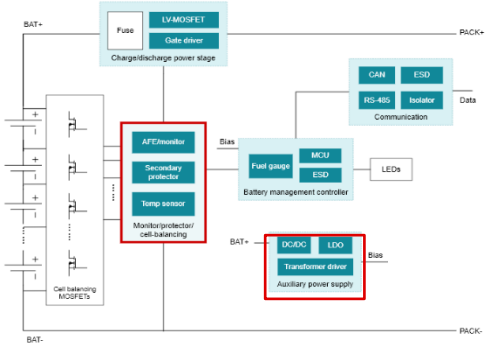
Energy storage system (ESS): 1kV pack

Top design care-about & customer requirement	Where is help needed?	Systems engineering action
1 kV BMS PACK FOR ESS **Provide details on this project** • Cell management unit (CMU) with passive cell balancing • Device: BQ79606A-Q1 • System needs **300 mA** balancing current to decrease the total balancing time	• Provide TI's total solution/TIDA to help evaluate BQ79606A-Q1 can support 300 mA balancing current with external circuit • Thermal effect is a key concern • Offer 2 system implementations to customize  	Action: Provide TI's total solution to help evaluate BQ79606A-Q1. **Support required to balance 300 mA current with external circuit**. A BQ79606A-Q1 EVM was ordered and **modified to add extra balancing circuit** and shared with customer **Test results** from modified EVM that can support 300 mA of current for PCB Joined **on-site verification to shorten development time and de-risk system level solution**

BMS innovating the future in power delivery

Over 10S industrial battery pack: 16S-17S battery pack

Target applications or subsystems



Solution is targeted for:

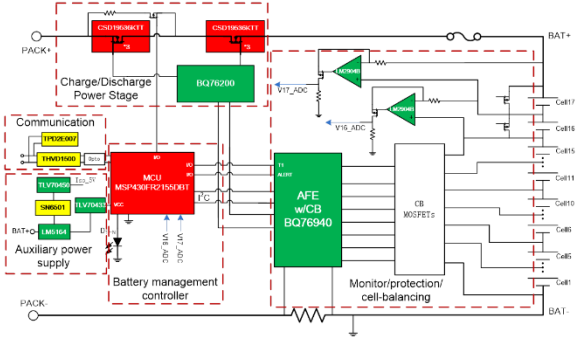
- Cost sensitive, 16S-17S, 60 V e-motorcycle battery pack for China or India market
- 16S 48 V $LiFePO_4$ e-bike or telecom BBU battery pack

Design challenge

- Cost competitive16S-17S battery pack solution by achieving the target accuracy with low cost GPAMPs and discrete circuits
- Load and charger detect functions in e-bike/e-scooter idle mode in low current consumption
- High voltage, current measurement accuracy

TI solution

- A 16S-17S low cost battery pack solution with load/charger detect functions and ultra low current consumption ***TIDA-010074***



Steps used to WIN

- Early engage, agreed architecture needs and proposed total system solution (TIDA-010074)
- Support schematic and PCB layout reference and review
- Share TI solution firmware program flow chat
- Customized lab tests
- Help on hardware debugging

Why TI?

BQ76942
LM358B
BQ76200
LM5164

- Cost competitive solution vs 2 stacked BQ76930
- Load and charger detect functions in e-bike/e-scooter idle mode with low current consumption (<200 µA)
- High voltage (±10 mV @ 0°C-50°C), current measurement (typ 1%) accuracy

WINS & scaling

- **WIN and MP in e-bike and telecom BBU 48 V products in China key customers**

- Scaling resources:
  Design files, blog, white paper

Key takeaways

- BMS applications are accelerating tremendously across many industrial sectors.
- Because system-level design challenges vary, a partnership approach to solving problems can make a substantial impact.
- TI is committed to driving future BMS trends and creating innovative solutions.