Powering Alternative Forms of Transportation with Industrial Battery Packs

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Providing a new way of transporting both people and goods, an emerging generation of battery-powered vehicles is now speeding down the road. Meanwhile, a worldwide trend toward environmentally friendly transportation, including e-bikes, e-scooters and e-motorcycles, is driving demand for longer-lasting battery packs in terms of both run time and overall lifetime.

More commuters are leaving their cars at home, opting instead for electrically powered two-wheel and three-wheel vehicles. There's also a growing popularity for fast, efficient and environmentally friendly delivery services. For this application, e-motorcycles are a good fit because these vehicles can accommodate higher-capacity batteries than those used in e-bikes and e-scooters. Greater battery capacity enables longer ride times, which helps save time and permits longer-distance deliveries and less frequent charging.

Meeting the challenge

Lithium-ion (Li-ion) technology is now the preferred battery chemistry for a wide range of mobile technologies. Li-ion batteries are lighter and smaller than their lead-acid counterparts, thanks to higher power density providing the same amount of energy. The design challenge is how to achieve longer-lasting batteries without significantly increasing the vehicle's total cost, as well as how to best protect the battery against fires, leaks, ruptures and other potential hazards. **Table 1** shows some of the differences between lead-acid and Li-ion batteries.

There are two ways to create longer-lasting Li-ion batteries: increase the total battery capacity or improve the energy utilization efficiency. Raising the total battery capacity requires the addition of more or larger battery cells, which can significantly increase the pack's overall cost and size. Improving energy utilization efficiency gives designers more usable energy without increasing capacity.

	Lead-acid batteries	Li-ion batteries
Energy density	40 Wh/kg	180 Wh/kg
Weight	~28 kg	~7 kg
Volume	Large (~2× the size of Li-ion batteries)	Small
Charging time	3 to 6 hours	2 to 4 hours
Battery life	1 to 1.5 years	2 to 4 years
Price	US$80 to US$150 for 48 V/20 Ah	US$150 to US$260 for 48 V/20 Ah
Maintenance cost	2% to 10% initial price	Negligible

***Table 1**. Lead-acid vs. Li-ion batteries.*

There are also two ways to improve energy utilization efficiency: increase the state-of-charge accuracy or reduce the current consumption of the battery management solution. To ensure the reliable use of the battery pack, it is necessary to make sure that the battery works within manufacturer-specified ranges for voltage, current and temperature.

A Li-ion battery's typical estimated lifespan is approximately two to three years or 300 to 500 charge cycles—whichever occurs first. A full charge cycle covers a period of use from fully charged to fully discharged and fully recharged again. As it ages, a Li-ion battery will gradually lose its ability to hold a charge. This loss is inevitable and irreversible.

As a battery loses capacity, the length of time it will be able to power a vehicle will decline as well. It's also important to remember that a Li-ion battery will slowly discharge when left unused. Minimizing power consumption while avoiding a complete discharge is the best way to improve battery energy utilization efficiency and maximize run time.

Li-ion batteries—particularly those mounted within a vehicle—are susceptible to overcharging, overheating, punctures, short circuits, internal failures and manufacturing mistakes. Failure and overheating leads to thermal runaway, a reaction within the battery that causes the internal temperature and pressure to rise at rates faster than what can be dissipated into the atmosphere. If the temperature rises high enough, a fire may occur, and if the pressure increases enough, the battery housing will swell and deform, potentially damaging the vehicle. Fortunately, battery packs are now designed to include circuitry that minimizes the likelihood of potential hazards.

Finding the right solution

There are several different types of battery packs available to power e-motorcycles. One choice is a 60-V model, which requires 16- to 18-series (16S-18S) Li-ion battery cells deployed in a pack. E-bikes and e-scooters often have a 13S, 48-V Li-ion battery pack.

Focused on e-bike and e-scooter battery packs, the "Accurate gauging and 50-µA standby current, 13-S, 48-V Li-ion battery pack reference design" shown in **Figure 1** provides low standby and ship-mode current consumption and high state-of-charge gauging accuracy, while monitoring

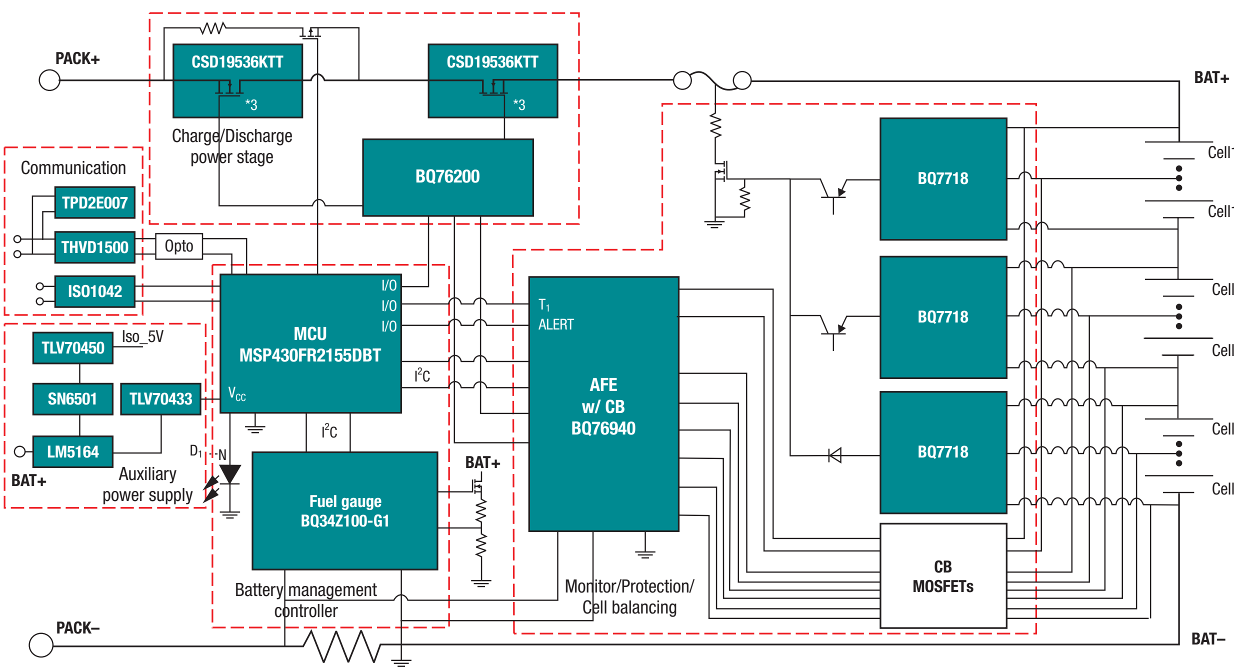

Figure 1. The accurate gauging reference design.

each cell's voltage, pack current and temperature. Li-ion battery packs are also protected against overvoltage, undervoltage, overtemperature and overcurrent conditions.

The reference design includes three easily stacked BQ7718 secondary overvoltage protectors, which helps pass the single-fault test to ensure that any single component failure doesn't leave the battery management solution without any voltage protection. The BQ34Z100-G1 Impedance Track™ fuel gauge can achieve battery monitoring accuracy within 2% error at room temperature in a new battery through its adaptive learning technology. It will also ensure good state-of-charge accuracy even when used with an old battery, or a battery operating in any temperature.

With a well-designed auxiliary power-supply strategy (**Figure 2**) and the high-efficiency, low-quiescent-current LM5164 DC/DC converter, the reference design helps batteries maintain 50-µA standby and 5-µA ship-mode consumption. Implemented for a

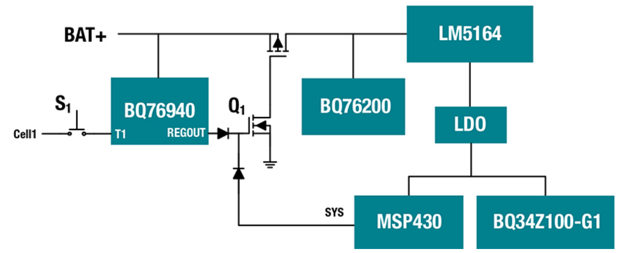

Figure 2. *Auxiliary power-supply block diagram.*

two-layer printed circuit board, the design supports firmware that's designed to reduce product research and development time.

Another reference design, the "16S-17S battery pack reference design with low current consumption" shown in **Figure 3**, is a low-standby and low ship-mode current consumption Li-ion phosphate or Li-ion battery pack design for e-motorcycles. The design includes a 9S-15S BQ76940 analog front-end for monitoring and protecting the voltage of the lower 15 battery cells. The LM2904B two-channel amplifier creates a voltage-to-current circuit for the 16th and 17th

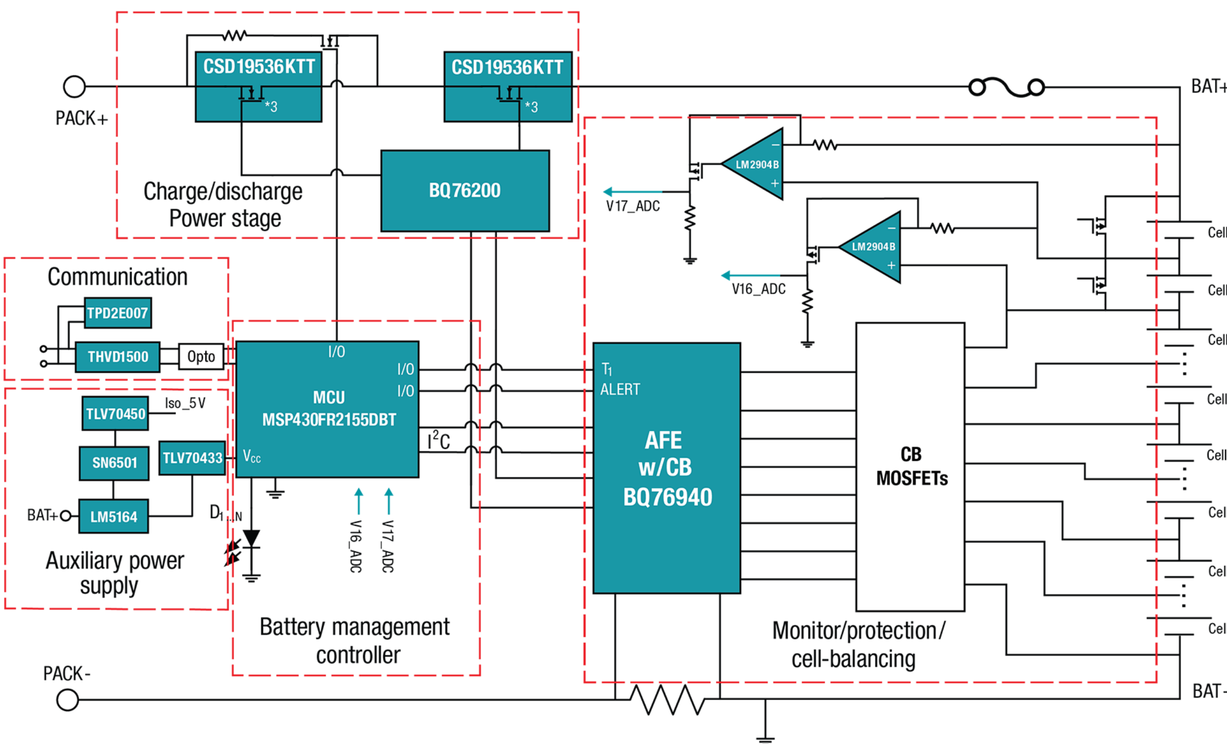

Figure 3. *The 16S-17S battery pack reference design.*

battery cell voltage measurement. Utilizing the correct firmware and hardware provides protection from overvoltage, undervoltage, overdischarge current, short-circuit, overtemperature and undertemperature conditions.

The BQ76200 high-side, N-channel metal-oxide semiconductor field-effect transistor (MOSFET) driver initiates the battery pack's charge and discharge, and it also has a channel to drive a P-channel MOSFET as a pre-charge or pre-discharge function so you don't need an external circuit. This design has little to no effect on cell balancing and while still maintaining accurate voltage-sensing after calibration. The design also incorporates auxiliary power to support 5-µA consumption in ship mode and 100-µA consumption in standby mode.

For a higher integration in 3-S to 10-S applications and 3-S to 16-S applications, TI offers the BQ76942 and BQ76952 battery monitors, respectively, which can provide a higher level of accuracy and performance.

Market projections

There's a growing market worldwide for Li-ion e-bikes, e-scooters and e-motorcycles, which represent a key component in global air pollution reduction strategies, particularly in cities where traffic congestion or the cost of electric cars is unattainable for most people and even many businesses.

A report released in January 2020 predicts that the global Li-ion battery market will expand at a compound annual growth rate of 9% from 2019 to 2027, reaching US$41.5 billion by 2027.

China now produces approximately 30 million e-bikes per year, relying primarily on low-cost lead-acid batteries. New regulations have limited the permissible weight of e-bikes to 55 kg, including battery weight. This new weight limit renders over 95% of existing lead-acid electric two-wheeled vehicles noncompliant.

According to a July 2019 study, the global e-scooter and e-motorcycle market is estimated to grow from 684,000 units in 2019 to 7.9 million in 2027—a compound annual growth rate of 35.8%. The study warns, however, that a lack of charging infrastructure and performance constraints create a potential growth hurdle.

The 2019 study noted that the e-motorcycle segment is currently the fastest-growing market. This is primarily because e-motorcycles can serve a variety of different work- and leisure-related purposes. E-scooters and e-bikes, on the other hand, are restricted by range and performance constraints, which generally limit their use to short-distance commutes and errands.

A demand for convenient, high-performance transportation, as well as advancements in battery and battery-support technologies, are likely to propel the growth of electrically powered two-wheel vehicles during the forecast period. Subsidies provided by governments worldwide are also contributing to global market growth.

The European e-scooter/e-motorcycle market is expected to register the fastest growth during the forecast period, followed by the North American and Asia-Pacific markets, the study reported. The e-scooter/e-motorcycle industry in these regions is inclined toward innovation, technology and the development of an advanced charging infrastructure.

Asia-Pacific is expected to be the largest e-scooter/e-motorcycle market, followed by Europe. Increasing concerns over carbon emissions from conventionally powered two-wheelers and a growing demand for energy-efficient commuting have led governments in these areas to enact favorable initiatives and regulations, which have propelled market growth, the study noted.

Conclusion

Automobiles and light trucks are the most popular forms of personal transportation in developed countries. Yet in the developing world, it's two-wheel vehicles—scooters and motorcycles—that dominate the road. China and India are the two largest markets for conventionally powered two-wheel transport, contributing significantly to these nations' air pollution problems. According to a 2018 study, approximately 20% of carbon dioxide emissions and 30% of particulate emissions in India are caused by conventionally powered two-wheel vehicles.

A new generation of e-bikes, e-scooters and e-motorcycles promises to provide mobility to millions of people worldwide without worsening pollution. All types of electric vehicles are already creating far less climate-threatening pollution than their gas-powered counterparts.

Optimizing electric vehicle production processes, combined with advanced battery monitoring and management technologies and the thoughtful disposal, recycling or reuse of batteries, promises to further increase environmental benefits. Meanwhile, as cleaner electricity sources become available, the benefits of electric vehicles will become even more apparent, and their use and popularity will continue to grow.