Don’t overdesign your battery for IIoT applications

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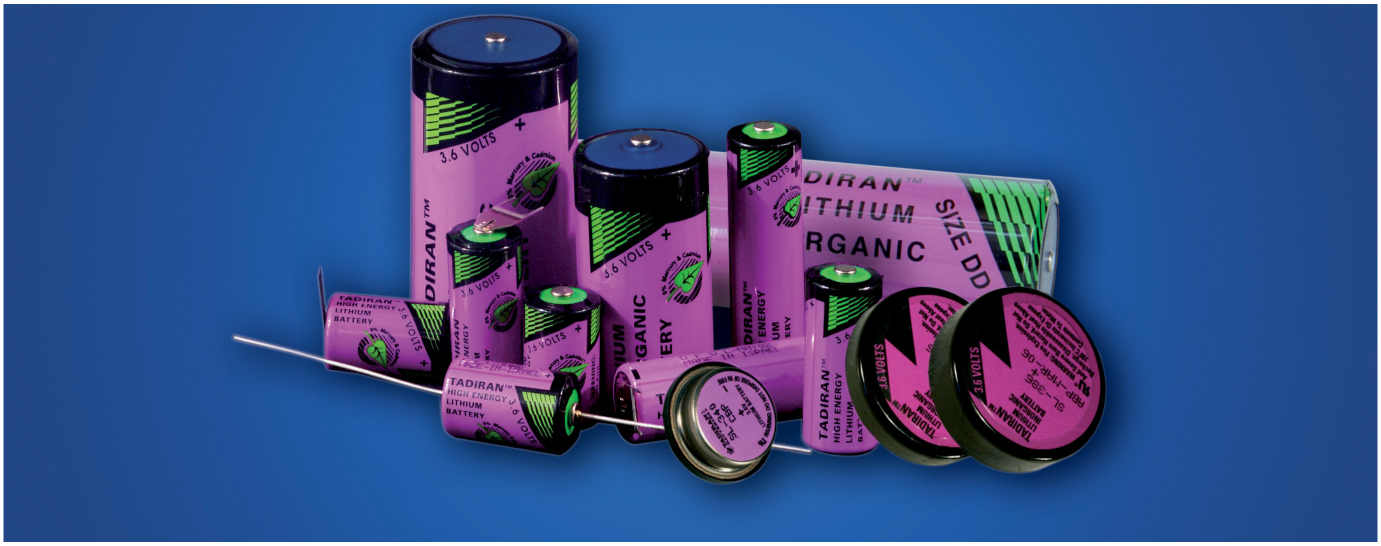

The rapid expansion of the Industrial Internet of Things (IIoT) has impacted every sector of industrial automation.

The IIoT enables greater use of data intelligence by combining ‘big data’ analytics and artificial intelligence (AI) to enhance M2M communications and interoperability, improve workflow, maximize operational efficiencies, support quality improvement, and allow for the deployment of predictive analytics to proactively schedule equipment maintenance and equipment rebuilding programs. IIoT communications infrastructure is being further extended by scalable technology platforms that are cloud-accessible and fully interoperable.

Remote wireless connectivity has enabled rapid expansion of the IIoT by eliminating the traditional cost hurdles associated with hard-wiring, since it can cost $100 or more per foot to hard wire any device, even a light switch. Eliminating the need to hard-wire a device increases opportunities to deploy systems control and data automation (SCADA), automated process control, quality assurance, asset management, safety systems, machine-to-machine (M2M) interfaces, and related technologies.

The proliferation of wireless technology has led to increased demand for various consumer and industrial grade batteries. Since every device is unique in terms of its energy requirements, care must be taken to specify the right battery in order to avoid an overdesigned solution.

Is extended battery life an important consideration?

Many wireless devices found throughout a factory floor are easily accessible, operate at moderate room temperatures, and can be routinely replaced without disrupting daily operations. When extended battery life is not a critical consideration, it creates the ideal scenario for using consumer grade alkaline and lithium batteries.

Conversely, if the application requires extended battery life, especially in extreme environments, then an industrial grade battery is usually required. A common example involves wireless mesh networks that consist of packs of highly scalable nodes (or motes) that collect and relay data and manage network performance and security using Time Synchronized Channel Hopping (TSCH) technology.

Extended battery life is influenced by the cell's annual energy usage and its annual self-discharge rate. Battery operating life can be extended through the use of low power microprocessors, components, and circuitry, along with the use of energy-conserving low power communications protocols such as ZigBee, WirelessHART, LoRa, or IEEE 802. 15.4e, as well as WiFi and cellular phone technologies.

The vast majority of low-power wireless devices use primary (non-rechargeable) lithium batteries that operate mainly in a 'stand-by' state that draws little or no current, awakening periodically or at pre-programmed intervals to query the data and awaken only if pre-set data thresholds are exceeded. Through intelligent design and manufacturing, low-power wireless devices often exhaust more available battery capacity through annual self-discharge than is lost from daily activity.

Delivered by helicopter near the North Pole, Oceantronics' GPS/ice buoy measures wind, temperature, sunlight, ice thickness, and GPS location of icebergs. The device was originally powered by a large battery pack (left) using 380 alkaline D cells (54 kg). The redesigned battery pack (right) substituted 32 bobbin-type $LiSOCl_2$ D cells and four hybrid layer capacitors (HLCs) to reduce size and weight (3.2 kg).

Courtesy of Sigred Salo NOAA/PMEL

When designing any industrial grade wireless device, you typically face competing requirements of achieving ideal product performance versus paying the lowest possible price, with compromise solutions often resulting in unnecessarily large and heavy batteries. While oversized batteries may allow the wireless device to function, such inefficiency can cost you in terms of product bulkiness, overly frequent battery replacements, along with added shipping expenses, especially to remote, hard-to-access locations.

In order to make a more informed decision when specifying a battery, design engineers need to consider the following parameters as part of the vendor evaluation process:

Operating voltage affects the number of cells – Basic math tells you that it requires more than twice as many 1.5v cells to deliver the same voltage as a single 3.6v cell. Selecting a battery that delivers higher voltage could save money by requiring the use of fewer cells and/or reducing the size and weight of the device.

Extreme temperatures can have an effect on voltage – Exposure to extreme temperatures reduces battery voltage under pulse. If you select a battery with a limited temperature range, then deploy it in a harsh environment, you may need to specify oversized batteries in order to compensate for an expected drop in voltage under pulsed load. One solution is to utilize a bobbin-type lithium thionyl chloride ($LiSOCl_2$) battery that features extremely high energy density (which aids miniaturization) along with the ability to handle high pulses at extreme temperatures. Using this type of extended temperature battery may eliminate the need for carrying extra capacity and/or voltage in order to compensate for expected losses in voltage under pulse.

Self-discharge rate affects capacity – Certain battery technologies suffer from high self-discharge rates of up to 8% per month, thus requiring a larger battery to compensate for the expected losses in available capacity. Alkaline batteries are notoriously short-lived, albeit inexpensive. In certain situations, this type of trade-off may be acceptable if product miniaturization is not an important requirement or the battery is easily replaceable. By contrast, an industrial grade battery featuring very low annual self-discharge could enable the use of a smaller battery or possibly eliminate the need for future battery replacements. This is an important consideration for applications involving hard-to-access locations where battery replacement is difficult or impossible and battery failure is not an option.

For example, a superior-quality bobbin-type LiSOCl2 battery can feature an annual self-discharge rate of just 0.7% per year, thus able to retain over 70% of its original capacity after 40 years. By contrast, a lesser grade LiSOCl2 battery made with essentially the same chemistry could have a higher self-discharge rate of up to 3% per year. While the differential may not seem overly large, over time this differential really adds up over time, as the battery that loses 3% of its capacity to annual self-discharge will exhaust 30% of its original capacity every 10 years, making 40-year battery life impossible.

Power or energy – It's easy to confuse the need for power (a measure of short-term energy consumed) with the total amount of energy required (battery capacity). Certain wireless devices are designed for infrequent use but must operate reliably to deliver continuous high pulse energy for relatively brief periods of time without consuming large amounts of total capacity.

Be aware that most commercial battery technologies are not designed to deliver a high power-per-energy ratio, thus demanding the use of a greater number of cells to compensate for their low pulse design. As a result, compromise solutions often require the use of oversized or additional batteries, which results in added bulk and unneeded capacity.

Pulse size – Increasingly, remote wireless devices connected to the IIoT are requiring high pulses to support two-way wireless communications and remote shut-off capabilities.
Alkaline batteries are ideal for delivering high rate energy but suffer from major performance limitations such as low voltage (1.5v), a limited temperature range (0°C to 60°C), a high self-discharge rate that reduces life expectancy, the inability to deliver high pulses, and crimped seals that may leak. Alkaline batteries may need be replaced every few months, resulting in a higher cost of ownership, which can be especially problematic for remote wireless applications.

For example, the popular CR123A 3.0v lithium manganese oxide (LiMnO2) battery can deliver twice the voltage of an alkaline cell, which can reduce the total number of batteries required. However, CR123A batteries cannot deliver high pulses, making them ill-suited for two-way wireless communications.

Standard bobbin-type lithium thionyl chloride (LiSOCl2) batteries are ideal for long-life low-power applications but are not designed to deliver high pulses due to their low rate design, as they can experience a temporary drop in voltage when first subjected to a pulsed load: a phenomenon known as transient minimum voltage (TMV). One way to minimize TMV is to use supercapacitors in tandem with lithium batteries. While popular for use in consumer electronics, supercapacitors are not ideal for industrial applications due to limitations that include bulkiness, a high annual self-discharge rate, and a limited temperature range. Solutions involving multiple supercapacitors also require the use of balancing circuits, which adds cost and requires additional energy.

Another sensible solution is to combine a standard bobbin-type LiSOCl2 battery with a patented Hybrid Layer Capacitor (HLC). The LiSOCl2 battery supplies background current in the 3.6 to 3.9v

Primary Cell	$LiSOCL_2$ Bobbin-type with Hybrid Layer Capacitor	$LiSOCL_2$ Bobbin-type	Li Metal Oxide Modified for high capacity	Li Metal Oxide Modified for high power	Alkaline	$LiFeS_2$ Lithium Iron Disulfate	$LiMnO_2$ CR123A
Energy Density (Wh/1)	1,420	1,420	370	185	600	650	650
Power	Very High	Low	Very High	Very High	Low	High	Moderate
Voltage	3.6 to 3.9 V	3.6 V	4.1 V	4.1 V	1.5 V	1.5 V	3.0 V
Pulse Amplitude	Excellent	Small	High	Very High	Low	Moderate	Moderate
Passivation	None	High	Very Low	None	N/A	Fair	Moderate
Performance at Elevated Temp.	Excellent	Fair	Excellent	Excellent	Low	Moderate	Fair
Performance at Low Temp.	Excellent	Fair	Moderate	Excellent	Low	Moderate	Poor
Operating life	Excellent	Excellent	Excellent	Excellent	Moderate	Moderate	Fair
Self-Discharge Rate	Very Low	Very Low	Very Low	Very Low	Very High	Moderate	High
Operating Temp.	-55°C to 85°C, can be extended to 105°C for a short time	-80°C to 125°C	-45°C to 85°C	-45°C to 85°C	-0°C to 60°C	-20°C to 60°C	0°C to 60°C

Table 1 Comparison of Primary Lithium cells

		TLI-1550 (AA)	Li-Ion
		Industrial Grade	18650
Diameter (max)	[cm]	1.51	1.86
Length (max)	[cm]	5.30	6.52
Volume	[cc]	9.49	17.71
Nominal Voltage	[V]	3.7	3.7
Max Discharge Rate	[C]	15C	1.6C
Max Continuos Discharge Current	[A]	5	5
Capacity	[mAh]	330	3000
Energy Density	[Wh/l]	129	627
Power [RT]	[W/liter]	1950	1045
Power [-20C]	[W/liter]	> 630	< 170
Operating Temp	deg. C	-40 to +90	-20 to +60
Charging Temp	deg. C	-40 to +85	0 to +45
Self Discharge rate	[%/Year]	<5	<20
Cycle Life	[100% DOD]	~5000	~300
Cycle Life	[75% DOD]	~6250	~400
Cycle Life	[50% DOD]	~10000	~650
Operating Life	[Years]	>20	<5

Table 2 Comparison of consumer versus industrial Li-ion rechargeable batteries

nominal range, while the HLC acts like a rechargeable battery to deliver periodic high pulses, thus eliminating the effects of TMV without requiring a supercapacitor. This hybrid LiSOCl2 battery solution also features a unique voltage curve plateau when the cell is approaching its end-of-life. Programming the device to identify this voltage curve plateau enables the issuance of 'low battery' status alerts.

Rechargeable battery cycle life – If the wireless application consumes enough average daily energy to prematurely exhaust a primary (non-rechargeable) battery, then it could be better suited for a power source that combines some form of energy harvesting device with a rechargeable Li-ion battery to store the harvested energy. Increased daily energy consumption is often the result of more frequent data sampling and transmission. One example is a solar-powered municipal parking meter that routinely draws current to process credit card transactions or to enable IIoT connectivity that permits motorists to be alerted when an empty parking space becomes available.

When selecting a rechargeable battery, be mindful that a consumer grade rechargeable Lithium-ion (Li-ion) cell has an expected operating life of approximately 5 years and 500 full recharge cycles. If the device is intended to operate for more than 5 years and/or 500 recharge cycles, then additional cells may be required to help reduce the average depth of discharge per cell and thus extend battery life.

Also available is an industrial grade Li-ion battery that can operate for up to 20 years and 5,000 recharge cycles. Unlike consumer Li-ion rechargeable cells, these ruggedly designed cells can deliver the high pulses required for powering 2-way wireless communications (15 A pulses and 5 A continuous current) while also offering an extended temperature range (-40°C to 85°C) to increase system reliability.

Cheaper can actually be more expensive – While application-specific requirements invariably dictate the ideal choice of battery, it is important to think long-term to determine your total cost of ownership over the lifetime of the device.

Achieving low initial cost may be important if the device is not intended for long-term deployment and frequent battery replacement is acceptable. For example, if the wireless device is situated on the factory and battery replacement is not disruptive to the automation process, then it may make sense to pay a low initial price by choosing a consumer grade battery. However, if the wireless device is intended for long-term deployment in a highly remote and inaccessible location, then you will need to factor in all anticipated expenses associated with frequent battery replacement, which will inevitably eat up any initial savings achieved by specifying an inexpensive consumer grade battery.

The hidden costs associated with an oversized battery solution can also be an important consideration. For example, a compact and lightweight power supply can be invaluable to research scientists seeking to exert less physical energy and burn fewer calories while conducting experiments in frigid Artic conditions. Compact, lightweight batteries can also be highly beneficial to field personnel who must service and maintain remote storage tanks, pipelines, and pumping stations. Excessively bulky and heavy batteries can also increase logistical expenses, as battery shipment is heavily regulated.

With more and more low-power wireless devices being integrated into the IIoT, including wireless mesh networks that permit rapid scalability and interoperability throughout industrial automation, it pays to consider the total long-term cost of ownership when specifying a battery-powered solution.

About the Author

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Sol Jacobs has over 30 years of experience in powering remote devices. His educational background includes a BS in Engineering and an MBA.

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TADIRAN BATTERIES

* Tadiran $LiSOCl_2$ batteries feature the lowest annual self-discharge rate of any competitive battery, less than 1% per year, enabling these batteries to operate over 40 years depending on device operating usage. However, this is not an expressed or implied warranty, as each application differs in terms of annual energy consumption and/or operating environment.

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