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Technical Article

Energy Storage Systems Boost Electric Vehicles' Fast Charger Infrastructure

Stefano Gallinaro

Abstract

Electric vehicles (EVs) will gain more and more market share, eventually taking over internal combustion engine vehicles. Direct current (dc) fast charging stations will replace, or integrate, petrol stations. Renewable energies will be used to power them, such as solar and wind. People will desire to charge their EVs in less than 15 minutes and they won't want to wait in a queue for a unique charging pile.

Considering multiple charging piles, the charging peak power that the grid will have to locally provide is more than 1 MW. The grid can collapse in many points, or huge investments are needed to improve the transmission lines and the central power plants needed to supply a much higher base load. This load, however, is impulsive and must be merged with the intermittent energy generated by renewable sources such as solar and wind.

Energy storage systems can solve this problem in a simple and elegant way. We use fluids like petrol or gasses to store energy and reuse it when needed (for example, when fueling a car). With the same principle, we can store electric energy in batteries using electrons and chemistry. This energy can be then utilized to boost an EV charge to keep the grid stable by shaving the peaks of power or to provide supply in case of blackout.

The mobility market is changing. Nearly 3 million EVs will be sold in the year 2020, on a total of more than 80 million vehicles. While this can look like a niche market, the forecasts are for a booming growth up to 10 million EVs sold in 2025 and more than 50 million in 2040, on a total of 100 million. This means, by the year 2040, 50% of sold vehicles will be fully electric. All these vehicles need to be charged slowly, overnight at home, with a simple wall-box or with a few kilowatt dc charger for houses with a solar generation system together with a storage battery, fast at the charging piles on the street, or superfast in future fuel stations.

Together with the rising EV market, we see that the renewable energy generation market—which has recently experienced booming years for solar photovoltaic (PV) systems—is still growing at a good rate, thanks to a price reduction of about 80% in the last 10 years and the push to decarbonize. Representing less than 5% of today's global electricity generation, solar is expected to be more than one-third (33%) of the global electricity generation in 2050.

With a future made of intermittent loads, the EVs that need to be charged and intermittent energy sources—PV, as well as wind generation—present challenges such as how to combine these new players in the energy ecosystem, centered on the grid. Intermittent loads such as EVs will require extra dimensioning of the transmission lines to cover the higher power peak demands.

Solar production will change the way that central power plants operate to make sure the grid is not overcharged and that people will require easier access to electricity, and more and more self-usage of the electricity they produce at home will be with residential solar systems.

To make all entities work together smoothly and to benefit from the renewable sources and zero-emission EVs, energy storage systems must come into the game to make sure we can store and reuse the electrical energy that is generated when the demand is low (for example, solar energy generated at noon to be used in the evening) and to use the extra energy to balance the grid.

Energy storage systems (ESS) are the electrical equivalent of tanks for fuel or storage warehouses for coal. ESS can be used in multiple applications on both residential and industrial scale. In a residential application, it is simple to connect the PV inverter to the storage battery, to save and use the energy in the house or to charge the car overnight with the energy produced by the sun during the day. In an industrial- or utility-scale implementation, such as grid-connected services, ESS installations can be used for different purposes: from regulation of PV and wind sources to energy arbitrage, from backup support to black start (removing diesel generators), and, most importantly from a total cost point of view, investment deferral. In this last case, energy storage systems will be used to cover power peaks in the nodes of the grid, making sure the existing transmission lines don't need expensive upgrades. Another relevant user case is the off-grid installation, where ESS enables microgrid or islands to be self-sufficient.

Figure 1. Renewables, energy storage, and EV charging infrastructure integration.

The ESS market, considering all its possible applications, will breach the 1000 GW power/2000 GWh capacity threshold before the year 2045, growing fast from today's 10 GW power/20 GWh.

For this article, the focus will be on the ESS installations for the EV charging infrastructure.

The ac charging infrastructure, both for private installations and for public ones, is simple but power limited. Level 1 ac chargers work at 120 V ac, delivering at maximum 2 kW; level 2 is capable of 240 V ac and 20 kW and the power conversion from ac to dc is, for both, demanded to the vehicle on-board charger. The ac wall box is rather a metering and protection device rather than a charger. The vehicle on-board charger, for cars, is always rated lower than 20 kW, for cost, size, and weight limitations.

On the other hand, dc charging enables the possibility to charge the EV at much higher power: level 3 chargers are rated up to 450 V dc and 150 kW, and the newest super chargers (equivalent to a level 4) can go beyond 350 kW and 800 V dc. The upper voltage limit is set to 1000 V dc for safety reasons when the output connector is plugged into the vehicle. While using a dc charger, the power conversion is made in the charging pile, and the dc power output directly connects the charging pile with the car's battery. This removes the necessity of an on-board charger, with all benefits in reduced occupied space and less weight. Nevertheless, in this transition phase, when the EV charging infrastructure is still fragmented and different country to country, region to region, a small 11 kW on-board charger is mostly present in the electric cars, to give users the ability to still charge via an ac outlet if needed.

Increasing the charging power requires an increased operating voltage to make sure the current is kept within reasonable limits for the cable's size and cost, and implies the necessity to properly design and dimension the microgrid or the subgrid where the charging stations are installed.

Let's imagine a charging station of the future (in the year 2030), where the fuel consists of electrons and where the fuel is available from a pipe called transmission line, connected to the medium voltage (MV) grid via a transformer. Today the fuel is stored in big tanks underground and brought to the fuel station regularly by tank trucks. Having the new fuel—the electrons—always available from the grid seems an easy and issue-free solution, but we can see that this simple approach is not sustainable if we want to give drivers the possibility to charge their EVs in less than 15 minutes.

Our charging station has five dc charging piles capable of maximum 500 kW peak power output each. The worst case, for which the charging station must be dimensioned, is represented by five EVs charging fully depleted batteries at the same time. To simplify the calculation, we now consider zero losses in the power conversion stages and in the battery charging path. Later in the article, we will see how a proper design is influenced even by small power losses across the power chain.

Let's consider five EVs, each one with a 75 kWh battery (the cars available in the market today, with a full electric powertrain, have batteries from 30 kWh to 120 kWh) that needs to be charged from 10% state of charge (SOC) to 80%:

$$5 \times (70\% \times 75\ kWh) = 5 \times 52.5\ kWh = 262.5\ kWh$$

This means that an energy of 262.5 kWh must be transferred from the grid to the EVs in 15 minutes:

$$(262.5\ kWh)/(0.25\ h) = 1050\ kW$$

Slightly more than 1 MW of power must be provided by the grid to the EVs, for 15 minutes. The charging process of lithium batteries will require a constant current, constant voltage charging profile, where the power required to charge up to 80% of the battery is bigger than the last 20%. In our example, we stop the charge at 80% assuming maximum power.

The grid or, better, the subgrid where the charging station is located, must sustain peaks greater than 1 MW intermittently. Very efficient and complex active power factor correction (PFC) stages must be implemented to make sure the grid is kept efficient, without affecting the frequency and without creating instability. This also means that very expensive transformers to link the low voltage charging station to the medium voltage grid must be installed, as well as making sure the transmission lines bringing the power from the power plant to the charging station are properly dimensioned to cope with the peak power required. In case the charging station is charging a mix of cars and trucks or buses, the required power is higher.

The simplest and most economical solution, instead of installing new transmission lines and big transformers, is to use the power locally generated by renewable sources, such as solar and wind. This enables users to have a direct link to the charging station with extra power and not rely only on the grid. Realistically, solar photovoltaic (PV) installations in the range of 100 kW to 500 kW can be done at the charging station or near the subgrid where the charging station is connected.

While the PV source can provide 500 kW, limiting the power requested from the grid down to 500 kW, the PV source is intermittent and not always present. This brings instability in the grid, as well as enabling the EV drivers to charge their cars at the fastest speed only when the sun is shining at its maximum. This is not what the users want, and this is not sustainable.

The missing piece of this power electronics puzzle is the ESS. Acting like the underground tank for the fuel in today's stations, the ESS can be represented as a big battery capable of storing and delivering energy from the renewable sources to the grid or to the charging piles or back into the grid. The first key characteristic of the energy storage unit is being bidirectional and working on the low voltage side of the grid. The new installations will be targeting a dc bus voltage of 1500 V dc linking the renewable sources, the EV charging piles, and the ESS battery. A proper sizing of the ESS also has to be done to make sure the balance between peak power and energy capacity is optimal for the specific installation. This ratio strongly depends on the size of the local power generation, being through solar, wind, or other sources, the number of charging piles, other loads connected to the subgrid, and the efficiency of the power conversion systems.

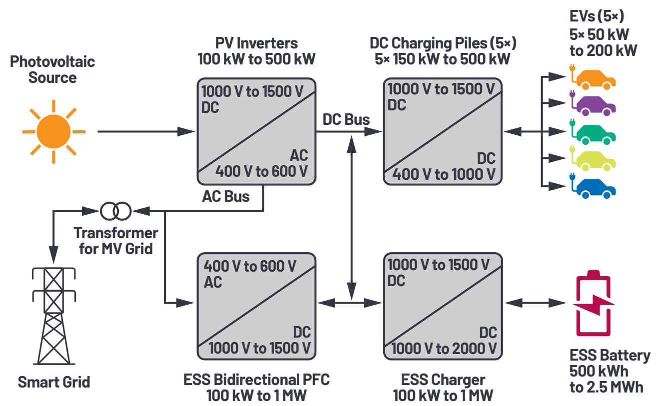

Figure 2. Power conversion in the EV fuel station of the future.

In this calculation, the energy storage system should have a capacity between 500 kWh to 2.5 MWh and a peak power capability up to 2 MW.

Having defined the critical components of the charging station—the sources, the loads, the energy buffer—an analysis must be done for the four power conversion systems that create the energy paths in the station.

The four power conversion systems are all sitting on the main dc bus, rated 1000 V dc to 1500 V dc. The higher the required power, the higher the dc bus voltage. 1500 V dc represents the industry standard today and for the next 20 years. While going at higher voltages is possible, this brings complications for the safety regulations, power components, and system designs, making it inefficient with the available technologies. That is not to say that in 10 years new technologies, such as power switches and protection systems, won't make it possible to move to 2000 V dc or higher.

Considering the PV inverter, we see that it has a double function of a dc-to-dc converter—for the power path going from the PV panels to the dc bus—and the function of a dc-to-ac inverter—for the power path going from the PV panels to the ac bus and then into the grid. The dc-to-dc conversion stage is the most important here, since the ac-to-dc stage can also be integrated into the main bidirectional power factor correction (PFC) inverter going from the dc bus to the ac grid. Considering state-of-the-art power electronics designs, the highest efficiency is reached with converters designed around silicon carbide (SiC) power MOSFETs. The comparison with silicon insulated gate bipolar transistors (IGBTs) shows an efficiency increase in the range of 5% (maximum load) to 20% (partial load). In our example, with a PV inverter rated 500 kW, 5% better efficiency means 25 kW less losses or higher power output—the equivalent of five houses' consumption or a big heat pump generating hot water or cooling the charging station building in the summer.

A very similar calculation can be made for both the dc charging piles and the ESS chargers. In both cases, two design approaches are possible: either big monolithic power converters rated more than 100 kW or many small converters rated 25 kW to 50 kW, used in parallel. Both solutions have benefits and drawbacks. Nowadays the multiple connections of small converters are leading the market because of lower costs due to economy scale and simplicity of design. Of course, a smart energy management system must be adopted.

Even for these dc-to-dc converters, moving from silicon IGBTs to SiC MOSFETs is bringing tremendous efficiency benefits, together with space and weight savings, at the cost of a slightly higher price—today 25% higher, expected to drop to 5% in the next five years. The efficiency gains alone can override this small price by saving (if we use the same 5% at maximum load):

$$\left(5\% \times 5\ Charging\ Piles \times 500\ kW = 125\ kW\right) + \left(5\% \times 1\ MW = 50\ kW\right) = 175\ kW$$

Finally, in the PFC inverter, 5% of 1 MW is again 50 kW, bringing the total power savings, just because of higher efficiency of SiC vs. IGBT, to 250 kW. This is like having an additional charging pile or the possibility to better balance the energy consumption overtime vs. the actual demand of loads.

To achieve these results, as we said, SiC MOSFETs are needed, but they cannot solve the issues alone. The way the SiC MOSFETs are driven is key to reach the required switching frequency needed to have the best trade-off between system design costs (driven by the MOSFETs, the coils, and the inductors) and efficiency. The designers target the switching frequency in the range of 50 kHz to 250 kHz. The requirements for the gate drivers are becoming more challenging, mainly in terms of shorter propagation delays and improved short-circuit protection.

Analog Devices ADuM4136 is an isolated gate driver featuring the state of the art *i*Coupler® technology. This isolation technology enables a common-mode transient immunity (CMTI) of 150 kV/µs to drive the SiC MOSFETs in the hundreds of kHz switching frequency range. This, together with fast fault management like the desaturation protection, gives the designer the possibility to properly drive single or parallel SiC MOSFETs up to 1200 V.

The isolated gate driver must be powered, and in ADI Application Note AN-2016, we show how the combination of the ADuM4136 gate driver with the LT3999 push-pull controller represents a noise free, high efficiency building block to properly manage SiC MOSFETs. The LT3999 is used to control a bipolar isolated power supply for the ADuM4136. The ultralow EMI noise design of the LT3999 isolated power supply, together with the possibility to switch up to 1 MHz, enable a compact and cost-effective solution.

The total propagation delay, including the dead time plus the propagation delay, is 226 ns for the turn-on and 90 ns for the turn-off. The driver delay times are 66 ns for the turn-on and 68 ns for the turn-off, while the dead times are 160 ns for the turn-on and 22 ns for the turn-off.

The goal of having a very high power density in the power converters is achieved without compromising efficiency.

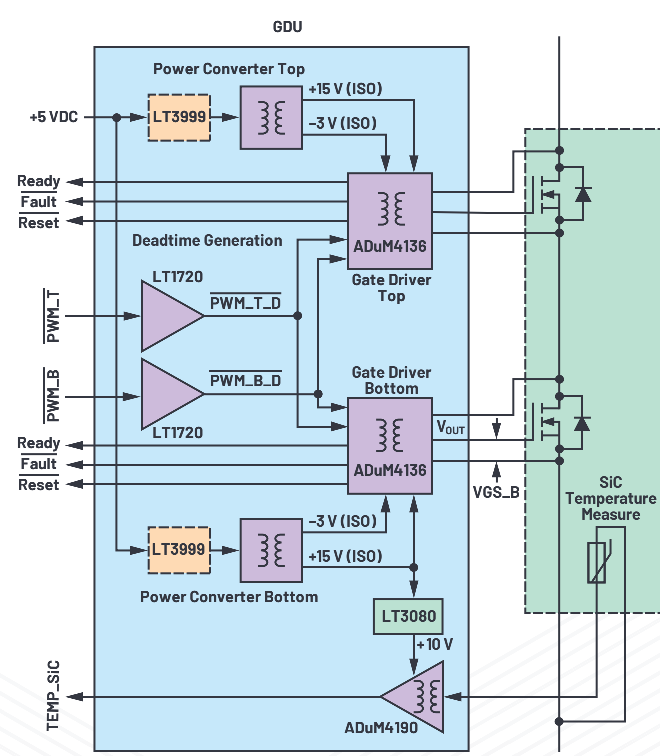

Figure 3. ADuM4136 and LT3999 gate driver unit.

While power converters are fundamental for the power conversion paths, in energy storage systems, the key component to assure the best total ownership costs is represented by the battery managing/monitoring systems (BMS). In a price break analysis, we can see that for megawatt range energy storage systems, more than half of the cost is driven by the battery rack: about $200 per kWh today, expected to decrease down to $100 per kWh in 2025. Having a reliable and precise BMS solution enables the battery to extend its lifetime by 30%, resulting in a huge cost saving and simplified operability of the complete charging station. Less maintenance means longer working time and no issues for the users, thus increasing the safety level by reducing the connected risks of repairing.

To achieve these results, the energy management system that is controlling the energy flows around the charging station must have a very accurate understanding of the SOC and state of health (SOH) of the energy storage battery. Precise and reliable SOC and SOH calculations permit the battery lifetime to extend 10 years to 20 years in the best case, and in general a 30% lifetime improvement is achievable without increasing the electronic costs related to the BMS. This leads to a reduction of the operating and ownership costs of at least 30% given by the increased lifetime of the battery. This, together with higher accuracy in the SOC information, provides the ability to use all the energy stored in the batteries and to charge them in the best possible way, avoiding overcharging or overdischarging, conditions that can drain the battery out in a very short timeframe and create risky situations like short circuits and fires. For predictive maintenance, and to be sure the energy and power flows are properly managed, knowing the battery SOC and SOH means being able to predict and adjust the algorithms involved in the grid stabilization, in the EV charging process, and in the vehicle-to-grid (V2G) connection where the vehicles are also seen as storage units.

The solution for having accurate monitoring is to use a multicell—up to 18 cells—battery monitor IC with a total measurement error of less than 2.2 mV. All 18 cells can be measured in 290 µs, and lower data acquisition rates can be selected for high noise reduction. Multiple stack monitor devices can be connected in series, permitting simultaneous cell monitoring of long, high voltage battery strings. Each stack monitor has an isolated serial peripheral interface (isoSPI) for high speed, RF immune, long distance communications. Multiple devices are connected in a daisy chain with one host processor connection for all devices. This daisy chain can be operated bidirectionally, ensuring communication integrity, even in the event of a fault along the communication path. The IC can be powered directly from the battery stack or from an isolated supply. The IC includes passive balancing for each cell, with individual PWM duty cycle control for each cell. Other features include an on-board 5 V regulator, nine general-purpose I/O lines, and a sleep mode, where current consumption is reduced to 6 µA.

Due to the short- and long-term accuracy demands of the BMS application, the IC uses a buried-Zener conversion reference rather than a band gap reference. This provides a stable, low drift (20 ppm/$\sqrt{kh}$), low temperature coefficient (3 ppm/°C), low hysteresis (20 ppm) primary voltage reference along with excellent long-term stability. The accuracy and stability are critical since they are the basis for all subsequent battery cell measurements and these errors have a cumulative impact on acquired-data credibility, algorithm consistency, and system performance.

Although a high accuracy reference is a necessary feature to ensure superior performance, that alone is not enough. The ac-to-dc converter architecture and its operation must meet specifications in an electrically noisy environment, which is the result of the pulse-width modulated (PWM) transients of the system's high current/voltage inverter. Accurate assessment of the SOC and SOH of the batteries also requires correlated voltage, current, and temperature measurements.

To mitigate the system noise before it can affect the BMS performance, the stack monitor converter uses a sigma-delta topology, aided by six user electable filter options to address noisy environments. The sigma-delta approach reduces the effect of EMI and other transient noise, by its very nature of using many samples per conversion, with an averaging, filtering function.

In the ADI portfolio, the LTC681x and LTC680x families represent the state of the art for battery stack monitors. The 18-channel version is called LTC6813.

In summary, to address the challenges of the future dc fast charging infrastructure, the critical aspects will be in the power conversion systems and in the energy storage systems. Two examples have been proposed, the combination of the ADuM4136 isolated gate driver with the LT3999 power supply controller for the power conversion stages designed with SiC MOSFETs and the LTC6813 battery monitoring device for the energy storage batteries. Many more areas of focus are present in these systems, from the current metering to fault protection devices, from gas sensing to functional safety. They are all extremely important and bring huge benefits, and ADI is actively working in all these subsystems to make sure we can sense, measure, connect, interpret, secure, and power all the physical phenomena producing reliable and robust data—data that will be used by high end algorithms to make sure most energy is converted from renewable sources to the loads, in this case the electric vehicles.

About the Author

Stefano Gallinaro joined Analog Devices' Renewable Energy Business Unit in 2016. He manages strategic marketing activities related to solar energy, electric vehicle charging, and energy storage, with a special focus on power conversion. Based in Munich, his business responsibilities span worldwide. Stefano studied electronics engineering at the Politecnico di Torino, Italy (BS) and began his career as an applications engineer at STMicroelectronics s.r.l.—Dora S.p.A., in Aosta, Italy. Before joining ADI, Stefano also worked as a product marketing manager at Vincotech GmbH in Unterhaching, Germany.

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EVs have gone mainstream, leading to an inflection point of high volume adoption. To stay competitive, system designers need to keep a close eye on both battery and BMS technologies, which profoundly affect the end-user experience. The LTC2949—ADI's latest foray into the BMS-monitoring fray—easily addresses multiple stack monitoring topologies and configurations.

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Thought Leadership Article

Green Buildings Get a Boost: Wireless Sensor Nodes as a Key Application for Energy Harvesting

Tony Armstrong

Energy Harvesting Background

It seems that everything is going green in today's environmentally planet-friendly mindset. The concept of energy harvesting has been around for over a decade; however, the implementation of ambient energy-powered systems in the real-world environment has been cumbersome, complex, and costly. Nevertheless, examples of markets where an energy harvesting approach has been used successfully include transportation infrastructure, wireless medical devices, tire pressure sensing, and building automation. Specifically, in the case of building automation systems, such things as occupancy sensors, thermostats, and even light switches have eliminated the power or control wiring normally associated with their installation and used localized energy harvesting systems instead.

Constructing smart buildings that will conserve energy, encompassing both commercial and residential structures, is a necessary prerequisite to ensure energy efficient structures do not draw heavily from traditional power sources that utilize fossil fuels.

In the case of commercial buildings, making them smart can be critical for the organization that is housed in them, since having a building that is energy efficient and streamlined helps to reduce energy costs while also providing a productive environment for the workers within them. However, getting to this point is not without its own set of drawbacks. For example, these buildings will require an infrastructure that can provide the necessary feedback to enable efficient operation of heating and cooling systems, lighting control, and efficient space utilization. This will most likely necessitate the use of the Internet of Things (IoT) as a methodology to monitor and control the environment and will increase their reliance on alternative power sources to effectively manage and control them.

IoT Trends for Smart Buildings

Smart buildings will continuously transform how people carry out their activities on a daily basis. Furthermore, along with conserving energy, smart buildings will help to save money. Already some IoT smart building trends are taking shape to enable this transition.

A good example is how predictive maintenance will make use of sensors (IoT) and other hardware devices to get a report on the state of a commercial building and all equipment in it. This feedback will enable the timing of any necessary maintenance when it is needed, in a timely and effective manner. Unforeseen issues that usually crop up with a preventive maintenance schedule can be overcome by using a predictive maintenance approach.

Furthermore, worker productivity can be adversely affected by air quality. Industry research in this area has shown that workers are 10% more efficient in their duty when they work from buildings with good indoor environmental quality compared to more conventional buildings. Again, IoT devices can be used to measure and check the air quality, as well as carbon dioxide levels in the air using various sensors that are part of a mesh network. These devices are connected to all areas of the building infrastructure, thereby enabling a way to keep the environment and everyone in it healthy and productive.

Another new trend that is expected going forward is the use of IoT supported applications in smart buildings. A good example of this is the use of thermal imaging to allow facility managers to check if their equipment goes outside of its operating temperature range. This can be easily detected, thereby allowing maintenance to be performed before the equipment disrupts its normal operational mode. For example, IoT will transform the way commercial facility managers can track information and measure and collect data; this includes inaccessible areas that were previously too hard to reach. Installing sensors in various parts of the building will track all information that they never had access to in the past. By using IoT interconnected systems, facility managers will now have access to all pertinent information using these systems.

Furthermore, IoT will make it possible for commercial owners to have buildings that are energy sufficient. This influences the design of the buildings and allows them to be eco-friendly and resource efficient. Moreover, these intelligent building management systems can be remotely managed from anywhere, making it possible to replace outdated heavy construction equipment with sensors that can be controlled using indicators such as vibration and temperature fluctuations. Clearly, this saves a lot of energy and money while also reducing the maintenance costs.

Finally, one of the most important impacts that IoT can have on buildings is energy efficiency. Sensor networks help to provide information that helps managers control their assets more effectively, while also reducing harmful waste in the environment. Examples include:

- Using sensors for temperature control
- Using actuators for HVAC controls
- Complex applications like providing complete energy automation for a building
- Considering weather forecasts to save real-time energy costs

Wireless Sensor Nodes: An Energy Harvesting Key Application

A key application of energy harvesting systems is radio sensors in building automation systems. In the United States, buildings are the number one user of energy production on an annual basis, closely followed by the transportation and industrial segments.

A wireless network utilizing an energy harvesting technique can link any number of sensors together in a building to reduce HVAC and electricity costs by adjusting the temperature or turning off lights to nonessential areas when the building or rooms within are unoccupied. Furthermore, the cost of energy harvesting electronics is often lower than running supply wires, or the routine maintenance required to replace batteries, so there is clearly an economic gain to be had by adopting a harvested power technique.

Nevertheless, many of the advantages of a wireless sensor network disappear if each node requires its own external power source. Even though ongoing power management developments have enabled electronic circuits to operate longer for a given power supply, this has its limitations, and power energy harvesting provides a complementary approach. Thus, energy harvesting is a means of powering wireless sensor nodes by converting local ambient energy into useable electrical energy. Ambient energy sources include light, heat differentials, mechanical vibration, transmitted RF signals, or any source that can produce an electrical charge through a transducer. These energy sources are all around us and they can be converted into an electrical energy by using a suitable transducer, such as a thermoelectric generator (TEG) for temperature differential, a piezoelectric element for vibration, a photovoltaic cell for sunlight (or indoor lighting), and even galvanic energy from moisture. These so-called "free" energy sources can be used to autonomously power electronic components and systems.

With entirely wireless sensor nodes now capable of operating at microwatt average power levels, it is feasible to power them from nontraditional sources. This has led to energy harvesting, which provides the power to charge, supplement, or replace batteries in systems where battery use is inconvenient, impractical, expensive, or dangerous. It can also eliminate the need for wires to carry power or to transmit data.

A typical energy harvesting configuration or wireless sensor node (WSN) is comprised of four blocks, as illustrated in Figure 1. These are:

- Ambient energy sources
- A transducer element and a power conversion circuit to power downstream electronics
- A sensing component that links the node to the physical world and a computing component consisting of a microprocessor or a microcontroller that processes measurement data and stores them in memory
- A communication component consisting of a short-range radio for wireless communication with neighboring nodes and the outside world.

Examples of ambient energy sources include TEGs (or thermopiles) attached to a heat-generating source such as HVAC ducts, or a piezoelectric transducer attached to a vibrating mechanical source such as a windowpane. In the case of a heat source, a compact thermoelectric device can convert small temperature differences into electrical energy. In the case where there are mechanical vibrations or strain, a piezoelectric device can be used to convert these into electrical energy.

Once the electrical energy has been produced, it can then be converted by an energy harvesting circuit and modified into a suitable form to power the downstream electronics. Thus, a microprocessor can wake up a sensor to take a reading or measurement, which can then be manipulated by an analog-to-digital converter (ADC) for transmission via an ultra low power wireless transceiver.

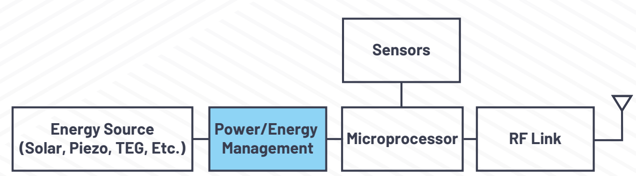


Figure 1. The main blocks of a typical energy harvesting system.

Of course, the energy provided by the energy harvesting source depends on how long the source is in operation. Therefore, the primary metric for comparison of scavenged sources is power density, not energy density. Energy harvesting is generally subject to low, variable, and unpredictable levels of available power so a hybrid structure that interfaces to the harvester and a secondary power reservoir is often used. The harvester, due to its unlimited energy supply and deficiency in power, is the energy source of the system. The secondary power

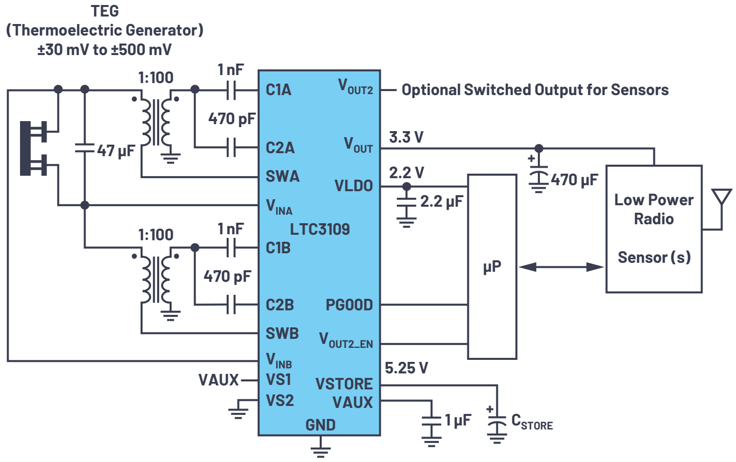


Figure 2. An LTC3109 typical application schematic.

reservoir, either a battery or a capacitor, yields higher output power but stores less energy, supplying power when required but otherwise regularly receiving charge from the harvester. Thus, in situations when there is no ambient energy from which to harvest power, the secondary power reservoir must be used to power the WSN.

Successfully designing a completely self-contained wireless sensor system requires readily available power-saving microcontrollers and transducers that consume minimal electrical energy from low energy environments. Existing implementations of such energy harvester blocks are shown in Figure 1. These typically consist of low performing discrete configurations, usually comprising 30 components or more. Such designs have low conversion efficiency and high quiescent currents. These deficiencies result in compromised performance in an end system.

Since high quiescent current limit how low the output of the energy-harvesting source can be, it must first overcome the current level needed for its own operation before it can supply any excess power to the output. This is where ADI's Power by Linear™ (PbL) product offerings can bring a new level of performance and simplicity.

An Energy Harvesting Example

The LTC3109 is a highly integrated dc-to-dc converter and power manager. It can harvest and manage surplus energy from extremely low input voltage sources such as TEGs, thermopiles, and even small solar cells. Its unique proprietary autopolarity topology allows it to operate from input sources as low as 30 mV, regardless of polarity.

The circuit in Figure 2 uses two compact step-up transformers to boost the input voltage source to the LTC3109, which then provides a complete power management solution for wireless sensing and data acquisition. It can harvest small temperature differences and generate system power instead of using traditional battery power.

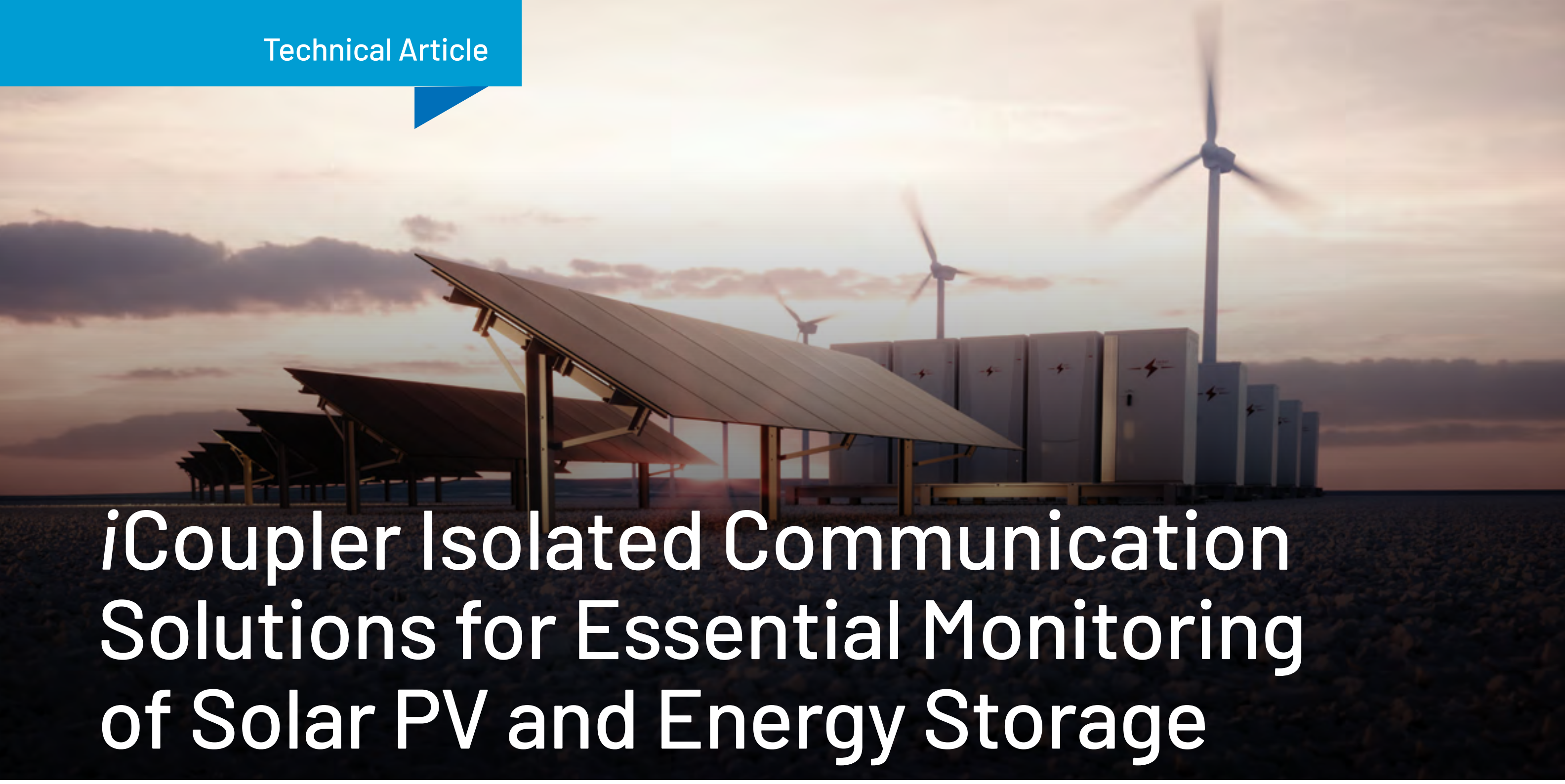
The ac voltage produced on the secondary winding of each transformer is boosted and rectified using an external charge pump capacitor and the rectifiers internal to the LTC3109. This rectifier circuit feeds current into the VAUX pin, providing charge to the external VAUX capacitor and then the other outputs. The internal 2.2 V LDO regulator can support a low power processor or other low power ICs.

Conclusion

With analog switch-mode power supply design expertise in short supply around the globe, it has been difficult to design effective energy harvesting systems for use in green buildings. One of the primary hurdles has been power management aspects associated with remote wireless sensing. Nevertheless, products like the LTC3109 can extract energy from almost any thermal source, thereby enabling a system designer to use an energy harvested power source. This not only reduces the use of fossil fuels but helps to make a greener building environment for current and future generations.

About the Author

Tony Armstrong was the business development director for Analog Devices' Power by Linear product group. He was responsible for all aspects of the power conversion and management products from their introduction through obsolescence. Prior to joining ADI, Tony held various positions in marketing, sales, and operations at Linear Technology, Siliconix Inc., Semtech Corp., Fairchild Semiconductors, and Intel. He attained a B.S. (Honors) in applied mathematics from the University of Manchester, England. Tony retired in spring 2020.



*i*Coupler Isolated Communication Solutions for Essential Monitoring of Solar PV and Energy Storage

Richard Anslow and Martin Murnane

New government policy combined with new regulation is driving renewable energy generation, and the solar market is expected to have strong growth in the future. Due to the current increase of power density in solar inverters and the demand for energy storage balancing, this generation of solar power leads to a need to significantly monitor all elements of a solar system. For solar PV applications, RS-485 communications are used due to inherent noise immunity. Adding *i*Coupler® isolated RS-485 transceivers provides a safe, reliable, and EMC robust solution for solar PV network communication interfaces.

RS-485 has several uses, the primary use being remote monitoring of power generation, power point trackers, and energy storage status (battery storage).

For solar applications like energy storage communications is critical, as it alerts the user of power generation and consumption activities within their solar installation. Several systems strategies may be installed such as bill management, PV self-consumption, demand charge reduction, and backup power. Backup power is the most popular, especially in the U.S., due to the various hurricanes causing havoc in the states of Texas and Florida.

Table 1. Domestic Energy Storage Strategies

Domestic Energy Storage Strategy	Definition
Bill Management Time of Use (TOU)	Minimizes electricity purchases during peak electricity consumption hours, while TOU shifts purchases to lower rates behind the meter customers. The goal of this strategy is to reduce the customer's bill.
PV Self-Consumption	Minimize the export of electricity generated by behind-the-meter PV systems to maximize the financial benefits in PV areas where utility rates are high.
Demand Charge Reduction	Reduce costs when utility companies charge excessively during peak times so customers can store energy.
Backup Power	This is a more common strategy and is the charging of any storage capable devices to use when the grid is down or at night time. This is more a backup power strategy, where low utility charges are available at peak times and there are low feed-in tariffs.

Solar generation, energy storage, and domestic consumption in a typical, 24-hour day is illustrated in Figure 1. Figure 1 is the primary reason why systems are designed for bill management in a solar system. During nighttime when there is no irradiation on the solar panel, energy consumed will be purchased from the grid where the grids are lowest. As soon as the sun rises irradiation appears on the solar panels, power is generated, and domestic self-consumption begins where any solar generation is either used in the household or is diverted to charge the energy storage unit. This allows bill costs to be controlled by reducing the energy drawn from the grid and using solar generated energy where low feed-in tariffs are available from utility companies.

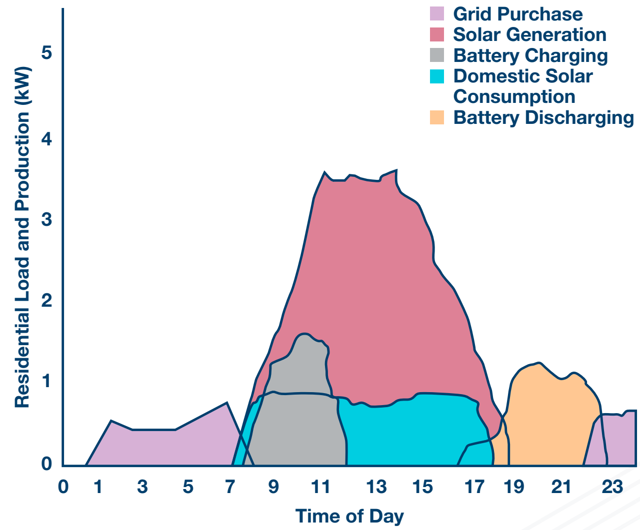


Figure 1. Solar generation, energy storage, and domestic consumption in a typical 24-hour day.

RS-485 is the communication application of choice for PC screen data updates such as current power, current consumption in the maximum power point trackers, battery charge and health, and CO_2 reduction, etc., are available, as can be seen in Figure 2.

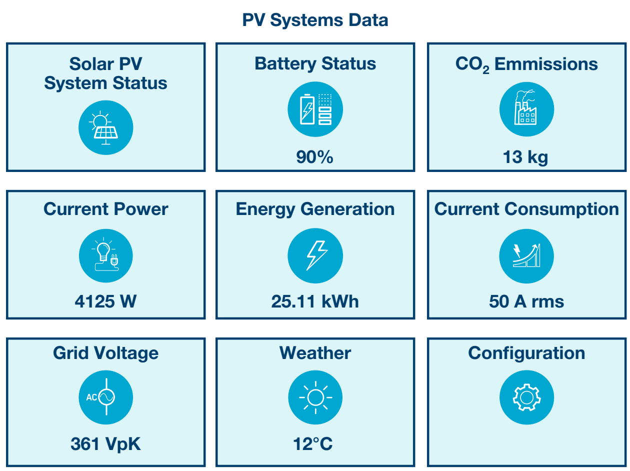


Figure 2. Typical PV monitoring system data from a PV solar system.

Figure 3 illustrates a typical solar system with input-for-input dc strings, dc-to-ac conversion, energy charging and storage, and battery management and communications. Analog Devices offers a complete power, communication, and control interface signal chain solution for solar PV and energy storage applications. *i*Coupler isolated gate driver solutions include the ADuM4135 and ADuM4223/ADuM3223; *i*Coupler isolated communication port solutions include the ADM2795E, ADM2867E, and ADM3054; and mixed signal processor solutions include the ADSP-CM40x.

Why Use RS-485 Transceivers with *i*Coupler Isolation?

*i*Coupler isolation provides a safe, reliable, and an EMC robust solution for solar PV network communication interfaces.

For solar PV networks the RS-485 or CAN communications interfaces often run over long cables in an electrically noisy environment. RS-485 communications are differential in nature and inherently noise immune. Adding *i*Coupler isolation increases noise immunity.

- The *i*Coupler family of digital isolation products has been tested and approved by various regulatory agencies, including UL, CSA, VDE, TÜV, CQC, ATEX, and IECEx. This regulatory agency testing provides a certified level of safety in the presence of high voltage transients and electrical surges that can occur in electrically harsh solar PV environments.
- The solar PV communications interface usually operates at low data rates—less than 500 kbps—which is an ideal operating range for RS-485 communications. Alternative implementations such as Ethernet operate at fixed data rates of 10 Mbps/100 Mbps or 1 Gbps, which are clearly overdesigned for the application requirement.
- *i*Coupler isolation has proven EMC robustness, which reduces field failures. Added EMC robustness reduces design and test time for interface circuits, allowing faster time to market for solar PV networks.

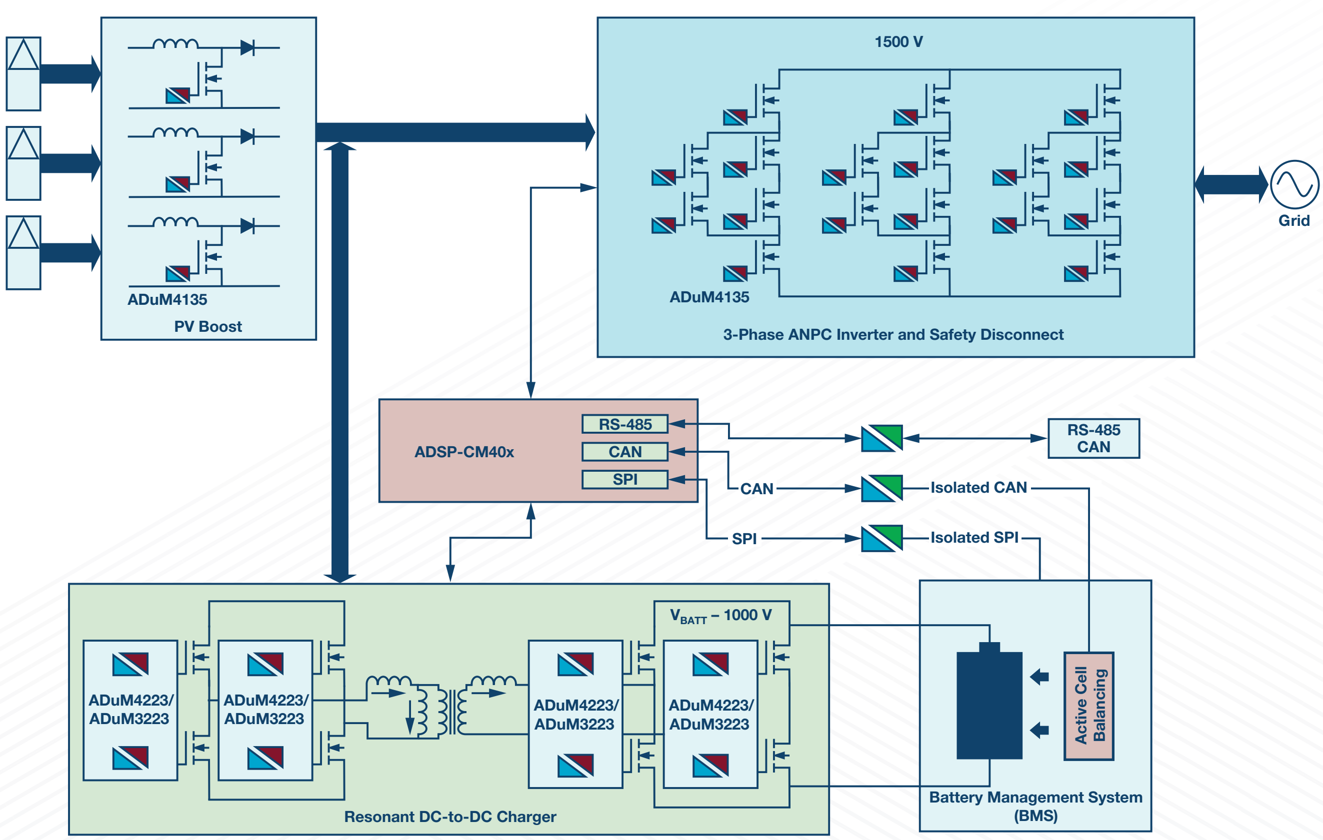


Figure 3. Block diagram of a typical solar system with storage.

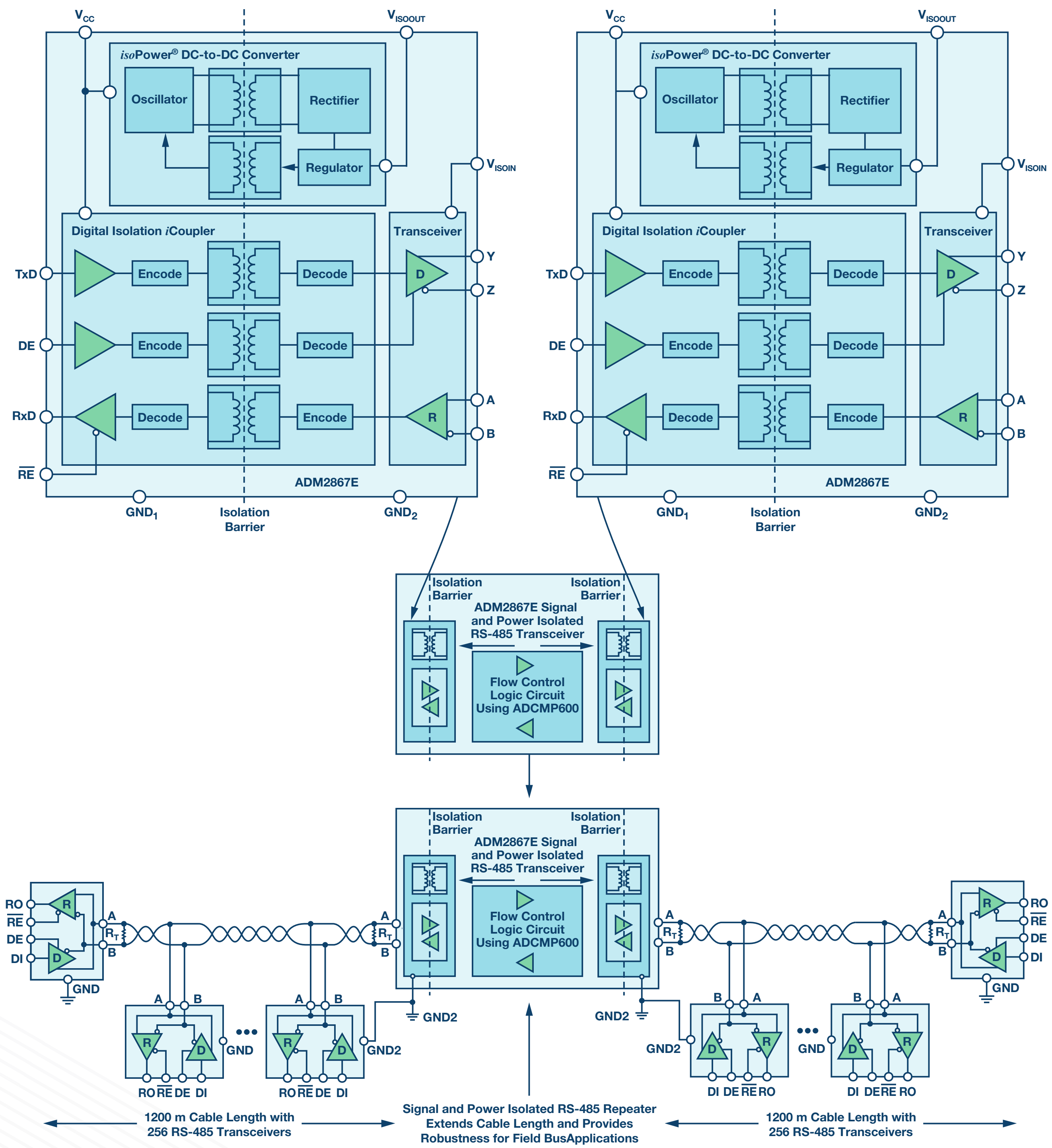


Figure 4. Signal and power iCoupler isolated RS-485 repeater.

Drop-In *i*Coupler Isolation Solution for Existing Solar PV Networks

For existing installations of solar inverters, which do not include *i*Coupler isolation robustness on the communications port, the *i*Coupler isolated RS-485 repeater is a powerful drop-in solution. The compact, signal, and power *i*Coupler isolated RS-485 repeater delivers robust isolation protection against electrical noise in electromagnetic capability (EMC) harsh solar environments.

The *i*Coupler isolated RS-485 repeater design consists of two RS-485 transceivers and two high speed ADCMP600 comparators. The ADM2867E is a fully integrated signal and power isolated data transceiver with ±15 kV ESD protection, and is suitable for high speed communication on multipoint transmission lines. The ADM2867E includes an integrated, isolated dc-to-dc power supply, which eliminates the need for an external dc-to-dc isolation block. An RS-485 repeater requires flow control, which is essential for controlling the direction of communication on the RS-485 bus. Using the ADCMP600 high speed comparator allows high speed flow control and directionality on the ADM2867E logic pins, which results in a reliable communication system. For complete design guidelines please refer to AN-1458 Application Note Isolated RS-485 Repeater with Automatic Direction Control.

*i*Coupler Signal Isolated RS-485 with Additional EMC Robustness

When designing an EMC communications interface, the circuit designer is often faced with a design and test iterative cycle. The circuit needs to be designed to meet system-level EMC standards and customer requirements. System-level IEC standards, such as IEC 61131-2 for industrial automation, specify varying levels of protection against IEC ESD, EFT, and surge, as well as immunity to radiated, conducted, and magnetic disturbances.

Analog Devices *i*Coupler signal isolated RS-485 includes additional certified EMC protection against these noted disturbances, reducing time to market for designs that need to meet strict regulatory targets.

In particular, the ADM2795E RS-485 transceiver integrates isolation robustness and EMC protection, which saves significant printed circuit board (PCB) board space for the solar PV communication port interface.

The ADM2795E is a 5 kV rms signal isolated RS-485 transceiver that features up to ±42 V of ac-to-dc, peak bus overvoltage fault protection on the RS-485 bus pins. The device integrates Analog Devices *i*Coupler technology to combine a 3-channel isolator, RS-485 transceiver, and IEC electromagnetic compatibility (EMC) transient protection in a single package.

The ADM2795E integrated *i*Coupler technology is certified by VDE0884-10, UL 1577, CSA, and CQC (pending).

- Working voltage: 849 V_{PEAK} (600 V rms) reinforced approved by VDE0884-10
- Withstand voltage: 5000 V rms approved by UL 1577

The ADM2795E performs robustly in several system-level EMC tests, which are certified by an EMC compliance test house (certification is available on request):

- IEC 61000-4-5 surge
- IEC 61000-4-4 EFT
- IEC 61000-4-2 ESD
- IEC 61000-4-6 conducted RF immunity
- IEC 61000-4-3 radiated RF immunity
- IEC 61000-4-8 magnetic immunity

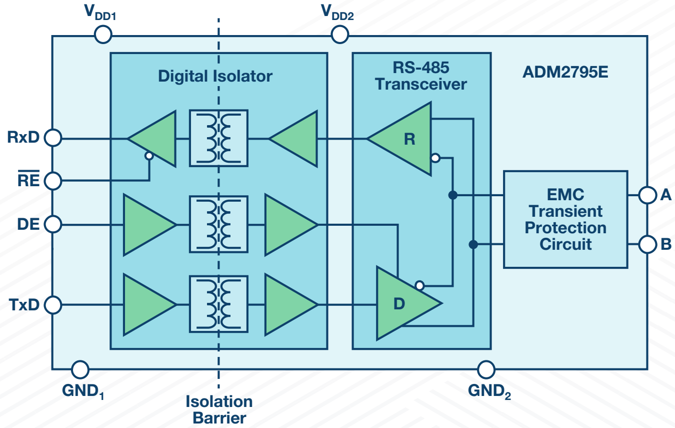


Figure 5. iCoupler isolated RS-485 transceiver with added IEC 61000-4-5 surge robustness on the A and B bus pins.

Conclusion

Analog Devices offers a complete signal chain solution for solar PV and energy storage applications. *i*Coupler isolated gate driver solutions include the ADuM4135 and the ADuM4223/ADuM3223, while *i*Coupler isolated communication port solutions include the ADM2795E and ADM2867E, with the ADSP-CM40x mixed-signal control processor offering a power communication and control interface. *i*Coupler isolation provides a safe, reliable, and EMC robust solution for solar PV network communication interfaces.

Analog Devices' interface and isolation portfolio has several options for isolating your RS-485 interface. The ADM2795E provides a complete, system-level EMC solution with compliance to IEC 61000 surge, EFT, and ESD standards, as well as immunity to conducted, radiated, and magnetic disturbances, which are common in harsh solar PV environments. The ADM2795E reduces time to market for designs that need to meet strict regulatory targets.

Signal and power isolated RS-485 transceivers, such as the ADM2867E, provide the most integrated signal and power isolated solution available on the market today. The ADM2867E can be used in a RS-485 repeater design to provide a path to adding *i*Coupler isolation robustness in designs that are already completed.

About the Authors

Richard Anslow earned both his BEng and MEng from the University of Limerick, Ireland. He has worked on new product definitions and customer-facing roles related to ADI's isolated communications portfolio.

Martin Murnane is a solar PV systems engineer in the Industrial and Instrumentation segment, focusing on energy/solar PV applications. Prior to joining Analog Devices, he held several roles in power electronics in energy recycling systems (Schaffner Systems), Windows-based application software/database development (Dell Computers), and HW/FW product development using strain gage technology (BMS). Martin has a bachelor's degree in electronic engineering and an MBA from the University of Limerick.

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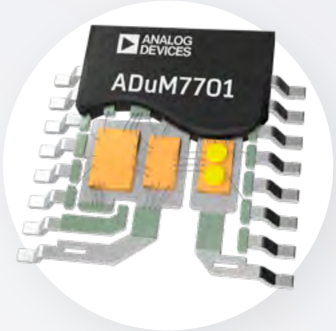

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Higher Reliability, Safety, and 30% Longer Lifetime with Advanced Battery Management in Healthcare Energy Storage Systems

Stefano Gallinaro

Abstract

Battery monitoring systems are fundamental enablers of different markets. Batteries play a key role in a range of applications, from going the extra mile in electric vehicles to storing renewable energy for the smart grid. The same and similar battery technologies are used in medical devices for increased safety of operation and for having the freedom to move instruments around in hospitals. All these applications run on batteries that need accurate and efficient semiconductors to monitor, balance, protect, and communicate. This article will explain how a state-of-the-art battery monitoring system, including cell balancing and isolated communication networks, can exploit the benefits of new lithium battery chemistries. Using innovative integrated circuits permits higher reliability and a 30% longer battery lifetime, especially for large scale energy storage systems.

Batteries used in medical applications need to meet very high standards for reliability, efficiency, and safety in all applications where they are typically used: patients' portable systems such as chest compression systems, hospital emergency room equipment, powered medical carts and beds, portable ultrasound machines, remote monitoring, and the newcomer in the market, energy storage systems (ESS).

Energy storage systems are not directly linked to patients, nor are they operated by doctors. They are the next step forward for uninterruptible power supplies (UPS). UPS have traditionally been used as backup power for the most critical applications (for example, emergency room devices, IT network critical infrastructure). Energy storage systems for hospitals are covering more and more functions, enabled by the new lithium-based batteries. They are becoming fully integrated with the hospital power grid, bringing advantages like:

- Complete backup power for entire facilities, rather than just a small, critical subset of facilities, as well as protection from blackouts, poor power/voltage quality from the grid, and reduced usage of emergency diesel generators. With megawatt hour (MWh) scale ESS, hospitals can operate even during prolonged blackouts, and they can participate in grid stabilization.
- Economic benefits on the electricity bill. With ESS, hospitals can directly control the usage profiles of electricity and reduce high power peak demands, which results in lower bills from the utilities.

Hospitals generally have sizable roof estate, which is good for installing photovoltaic (PV) systems to generate electricity. PV systems combined with ESS allow for the storage and self-use of generated electricity, while also providing economic benefits and a reduced carbon footprint.

Figure 1. Energy storage battery cells.

Lithium-based chemistries are now state of the art for the batteries used in various markets, from automotive to industrial to healthcare. Different types of lithium batteries have different benefits to better suit the power requirements for a variety of applications and product designs. As an example, $LiCoO_2$ (lithium cobalt oxide) has very high specific energy and this makes it suitable for portable products; $LiMn2O_4$ (lithium manganese oxide), with its very low internal resistance, enables fast charging and high current discharging, which means that it's a good choice for peak shaving energy storage applications. $LiFePO_4$ (lithium iron phosphate) is more tolerant to full charge conditions and can sustain being kept at high voltage for a prolonged time. This results in it being the best candidate for big energy storage systems that need to work during a power outage. The drawback is a higher self-discharge rate, but this is not relevant in the above-mentioned storage implementations.

The differing needs of applications requires a variety of battery types. For example, automotive applications need high reliability and a good charging and discharging speed, while healthcare applications necessitate high peak current sustainability for efficiency and a long lifetime. However, the commonality among all these solutions is that the various lithium chemistries all have a very flat discharge curve at a nominal voltage range. While in standard batteries we see a voltage drop in the range of 500 mV to 1 V, in advanced lithium batteries, such as lithium iron phosphate (LiFePO4) or lithium cobalt oxide ($LiCoO_2$), the discharge curve shows a plateau with a voltage drop in the range of 50 mV to 200 mV.

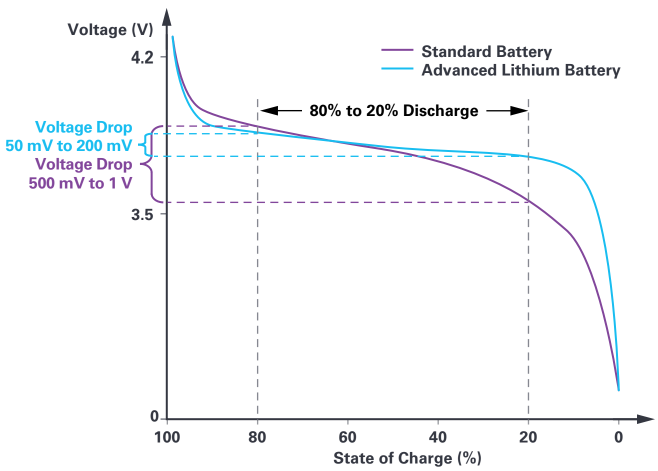

Figure 2. Lithium battery discharge profile

The flatness of the voltage curve has tremendous benefits in the power management chain of ICs linked to the battery voltage rail: the dc-to-dc converters can be designed to operate at a maximum efficiency point in a small input voltage range. Converting from a known V_{IN} to a very close V_{OUT}, the power chain of the system can be designed to have an ideal duty cycle of the buck and boost converters to achieve >99% efficiency throughout all operating conditions. Moreover, the battery charger can perfectly target the charging voltage and the loads are dimensioned according to a stable operating voltage to increase the precision of the final applications, such as remote monitoring or patient in-body electronics. In case of old chemistries or non-flat discharge curves, the dc-to-dc conversion operated from the battery will work with lower efficiency, which results in a shorter battery duration (–20%), or, when linked to medical portable devices, the need to charge them more often because of the extra power dissipation.

The main drawback of a flat discharge curve is that the state of charge (SOC) and state of health (SOH) ratings of the battery are much harder to determine. SOC must be calculated with a very high precision to ensure that the battery is properly charged and discharged. Overcharging can bring safety issues and generate chemistry degradation and short circuits that lead to fire and gas hazards. Over-discharging can damage the battery and shorten the battery lifetime by more than 50%. SOH gives information about the status of the battery to help prevent replacing good batteries and to monitor the state of bad batteries before an issue appears. The main microcontroller analyzes the SOC and SOH data in real time, adapts the charging algorithms, informs the user about the potential of the battery (for example, if the battery is ready for a high current deep discharge in case of power break), and makes sure that, in big energy storage systems, the balance between batteries in bad condition and batteries in good condition is optimal to increase the total battery lifetime.

By imaging a very old battery with a steep discharge curve, it is easier to calculate the state of charge of that battery by measuring the delta of the voltage drop in a small amount of time and knowing the absolute value of the battery voltage. For a new lithium-based battery, the accuracy required to make this measurement is orders of magnitude higher, since the voltage drop is much smaller in a given time frame.

For the SOH, old batteries discharge in a faster and more predictable way: their voltage discharge curve becomes even steeper and the target charging voltage cannot be reached. New lithium batteries will keep the same good behavior longer, but eventually can degrade with a more exceptional behavior and rapidly change their impedance and discharge curve just when they are close to end of life or being damaged. Extra care must be taken for temperature measurements, ideally at every single cell, to integrate the SOC and SOH algorithms with this information to make them more accurate.

Precise and reliable SOC and SOH calculations help extend battery lifetimes from 10 years to 20 years in the best case and generally result in a 30% lifetime improvement, which reduces the total cost of ownership of the energy storage system by greater than 30% after including maintenance costs. This, together with the higher accuracy of the SOC information, avoids overcharging or overdischarging conditions that can quickly drain a battery; minimizes the chance of short circuits, fire, and other risky situations; helps use all the energy in a battery; and enables charging batteries in the best, most efficient way possible.

The LTC6813 battery management solution (BMS) proposed in this article can be used in healthcare devices such as portable ultrasound machines and in large scale (megawatt/hours) energy storage systems (for hospitals, factories, grid stabilization, electric vehicle charging infrastructure, and residential units), as well as in industrial robots and vehicles. The portability of ADI technology brings terrific advantages in reliability and safety, as it's designed to work in different, harsh environments and is compliant to various functional safety standards, from the Automotive ASIL to Industrial SIL (for example, VDE AR 2510-2/-50, IEC EN 61508, and others).

One new and unique solution for having the most efficient and reliable battery monitoring system involves the combination of an 18-cell monitor and balance IC with a microcontroller to SPI slave isolated interface. A multicell battery stack monitor measures up to 18 series connected battery cells with a total measurement error of less than 2.2 mV. The cell measurement range of 0 V to 5 V makes it suitable for most battery chemistries. All 18 cells can be measured in 290 µs, and lower data acquisition rates can be selected for high noise reduction. Multiple stack monitor devices can be connected in series, permitting simultaneous cell monitoring of long, high voltage battery strings. Each stack monitor has an isoSPI™ interface for high speed, RF immune, long distance communications. Multiple devices are connected in a daisy chain with one host processor connection for all devices. This daisy chain can be operated bidirectionally, ensuring communication integrity, even in the event of a fault along the communication path. The IC can be powered directly from the battery stack or from an isolated supply. The IC includes passive balancing for each cell, with individual PWM duty cycle control for each cell. Other features include an onboard 5 V regulator, nine general-purpose I/O lines, and a sleep mode where current consumption is reduced to 6 μA.

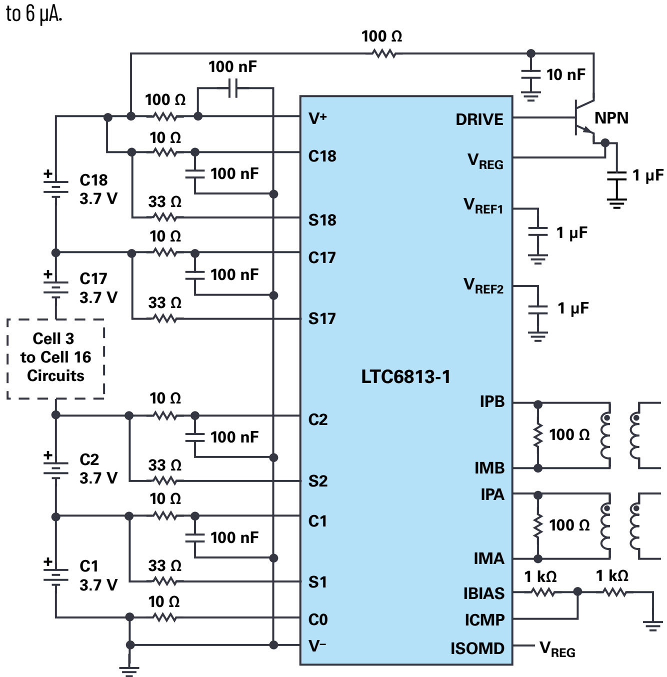

Figure 3. LTC6813 application schematic.

Due to the short- and long-term accuracy demands of the BMS application, it uses a buried Zener conversion reference rather than a band gap reference. This provides a stable, low drift (20 ppm/$\sqrt{\text{kHr}}$), low temperature coefficient (3 ppm/°C), low hysteresis (20 ppm) primary voltage reference along with excellent long-term stability. This accuracy and stability are critical since it is the basis for all subsequent battery cell measurements and these errors have a cumulative impact on acquired data credibility, algorithm consistency, and system performance.

Although a high accuracy reference is a necessary feature to ensure superior performance, that alone is not enough. The analog-to-digital converter architecture and its operation must meet specifications in an electrically noisy environment, which is the result of the pulse-width modulated (PWM) transients of the system's high current/voltage inverter. Accurate assessment of the state of charge and health of the batteries also requires correlated voltage, current, and temperature measurements.

To mitigate the system noise before it can affect the BMS performance, the stack monitor converter uses a Σ-Δ topology that is aided by six user selectable filter options to address noisy environments. The Σ-Δ approach reduces the effect of electromagnetic interference (EMI) and other transient noise, by its very nature of using many samples per conversion, with an averaging filtering function.

The need for cell balancing is an unavoidable consequence in any system that uses large battery packs arranged as groups of cells or modules, such as the big energy storage units used to supply hospital microgrids and subgrids. Although most lithium cells are well matched when first acquired, they lose capacity as they age. The aging process can differ from cell to cell due to several factors, such as gradients in pack temperature. Exacerbating the whole process, a cell that can operate beyond its SOC limits will prematurely age and lose additional capacity. These differences in capacity, combined with small differences in self-discharge and load currents, lead to cell imbalance.

To remedy the cell imbalance issue, the stack monitor IC directly supports passive balancing (with a user-settable timer). Passive balancing is a low cost, simple method to normalize the SOC for all cells during the battery charge cycle. By removing charge from the lower capacity cells, passive balancing ensures these lower capacity cells are not overcharged. The IC can also be used to control active balancing, a more complicated balancing technique that transfers charge between cells through the charge or discharge cycle.

Whether done using active or passive approaches, cell balancing relies on high measurement accuracy. As measurement error increases, the operating guard band that the system establishes must also be increased, and therefore the effectiveness of the balancing performance will be limited. Further, as the SOC range is restricted, the sensitivity to these errors also increases. A total measurement error of less than 1.2 mV is well within system-level requirements for battery monitoring systems.

In energy storage systems, a communication loop is mandatory to connect all battery cells. This loop transmits data from the system's battery to a cloud-based energy management algorithm that tracks charging and discharging events to determine the best way to maximize battery use or to keep the highest capacity battery fully charged in case of a power outage.

ADI's LTC681x and LTC680x families represent the state of the art for battery stack monitors. The 18-channel version is called LTC6813.

The battery stack monitor device needs to communicate with the master unit where a microcontroller or processor calculates the SOC and SOH values and regulates the charging and discharging profiles. Various forms of interconnection are possible, where the isolated communication channel is preferred for high voltage applications, such as energy storage systems (400 V to 1500 V) and portable devices with high capacity batteries (40 V to 200 V).

The isoSPI feature built into the LTC6813 battery stack monitor, when combined with an LTC6820 isoSPI communications interface, enables safe and robust information transfer across a high voltage barrier. isoSPI is particularly useful in energy storage systems that produce hundreds of volts via series-connected cells, which require full dielectric isolation to minimize hazards to personnel.

In these storage systems, where more than 18 cells are used, multiple LTC6813 BMS boards will need to be interfaced together. Here a robust interconnection of multiple identical PCBs, each containing one LTC6813 is configured for operation in a daisy chain. The microprocessor is located on a separate PCB. To achieve 2-wire isolation between the microprocessor PCB and the first LTC6813 PCB, the LTC6820 support IC

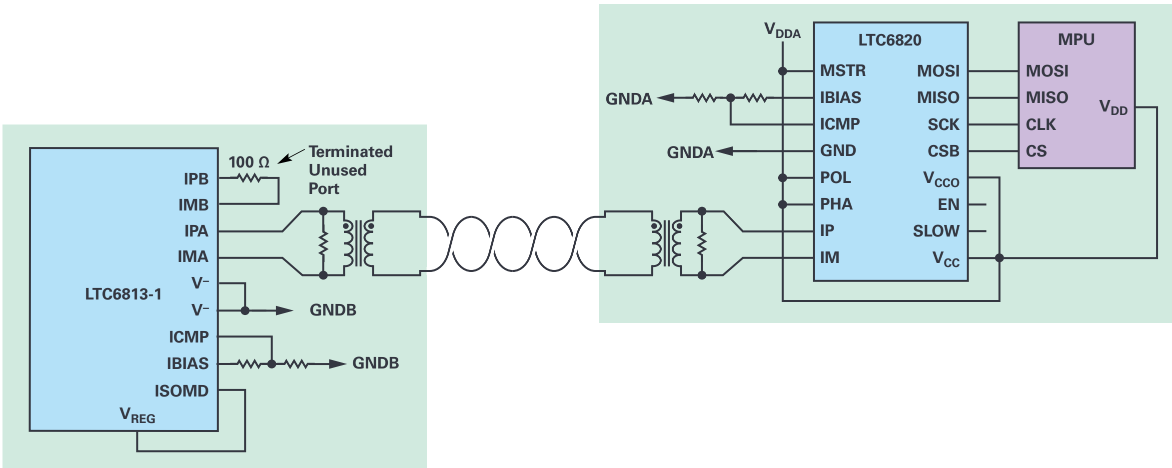

Figure 4. LTC6813 isolated connection with an LTC6820.

is used. When only one LTC6813-1 is needed, it can be used as a single (non-daisy-chained) device if the second isoSPI port (Port B) is properly biased and terminated.

The main design challenge for battery stack monitors with balancing and communication functions is to create a noise free PCB layout design, with critical trace routes far from the noise sources—such as switching power supplies—giving clear signals to the stack monitor. With ADI solutions, the stack monitor's great accuracy and precision can help optimize already good designs. The batteries will then be efficiently used, they will have a 30% longer lifetime, and they will operate in a safer way.

To support customers in designing their final products, ADI provides a full range of evaluation systems and platforms for the battery monitor devices, as well as a complete portfolio of variants to adapt to all needs.

About the Author

Stefano Gallinaro joined Analog Devices in 2016, in the Renewable Energy business unit. He is in charge of managing strategic marketing activities in the fields of solar energy, electric vehicle, charging, and energy storage, with a special focus on power conversion. Based in Munich, he has worldwide business responsibility.

Stefano studied electronics engineering at the Politecnico di Torino, Italy (B.S.). He began his career as an application engineer in STMicroelectronics Srl—DORA S.p.A., in Aosta, Italy. Before joining ADI in 2016, he worked for two and half years as a product marketing manager at Vincotech GmbH in Unterhaching, Germany.


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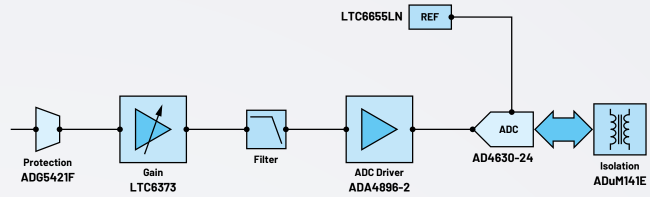

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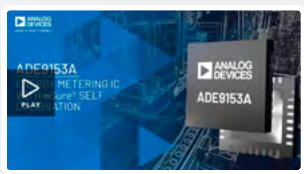

Analog Devices' ADE9153A is a high accuracy energy metering IC for single-phase, shunt-based metering applications. The *m*Sure® self-calibration feature allows a meter to calibrate its current and voltage channels with 1% accuracy without using an external reference meter. *m*Sure self-calibration supports Class 1 and Class 2 meters. For standards-based metering, customers should verify traceability requirements for their application.

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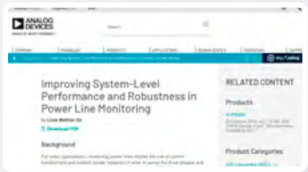
Design Note: Improving System-Level Performance and Robustness in Power Line Monitoring



For many applications, monitoring power lines implies the use of current transformers and resistor divider networks to sense the three phases and neutral voltages and currents. The AD7606B, due to its high input impedance, can directly interface with a sensor, easing the data acquisition system design as AD7606B provides all the required building blocks.

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Video: A Carbon Neutral Future: The Electrification Ecosystem's Impact on Business and Technology

Learn more about the electrification ecosystem's role in fostering a robust circular economy and battery lifecycle, and the future of sustainable electrification innovation.

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Video: Delivering a Better Battery for a More Sustainable Future

Explore this conversation in which ADI, GM, and Ford detail how they are individually and jointly addressing carbon neutrality in the battery supply chain. This session brings together different members of the electrification ecosystem to share their perspective on battery second life, sustainable material sourcing, and the role of governments and regulations.

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BR23764-1/23

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