A Sensible 30A Energy Meter

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Introduction

Tell someone that you have a solar panel system installed on the roof of your home and you've likely opened yourself up to a slew of questions, including "How many panels do you have?" or "What size is your system?" Most people try and gauge your system's power rating in a sometimes roundabout way. Then, they may proceed to ask how efficient your panels are, if you are still tied to the grid, or how much the whole system cost you – all perfectly valid questions. However, if you're like me and like to explain the "big picture" first (and minimize the questions), try starting the conversation with an explanation of how much energy you consume and generate, since unlike power, energy is the endgame and true performance metric of any system from an electrical consumption and generation standpoint.

Monitoring energy has similar benefits in many applications, not just solar. Handheld, rack-mounted and in-line energy meters are widely available and can be used by people such as facility managers to track and allocate energy used by equipment or departments among many things. This may also include load profiling, where expected energy consumption patterns are compared to present usage and areas of concern are flagged based on deviations from modeled energy patterns. By sizing loads, people can determine how many widgets, including lights, computers, batteries, can be connected to a system at any time. Electric bikes and vehicles can report their energy use per mile and quantify the energy being extracted from or returned to a battery.

Although energy monitoring applications are plentiful, there are very few energy monitoring ICs in the market. Many system designers have gotten by with using power monitoring ICs, such as Linear Technology's 100V LTC2945 power monitor, and having a microprocessor keep track of both power and time while also calculating energy; although complex coding is not required, the main drawback with this solution is that computing resources are tied down. Linear Technology's 100V LTC2946 energy monitor is a more elegant solution that provides direct energy measurements, where users have the flexibility to choose their own sense resistor; however, the challenge arises when you need to measure high currents. Enter Linear Technology's long overdue LTC2947 energy monitor with an integrated 30A sense resistor, which makes energy monitoring extremely practical for today's most demanding applications.

Revisiting the Sense Resistor

When designing in a power or energy monitoring IC that uses a sense resistor for its current sense element, calculating the required sense resistor is generally a straightforward task. You simply apply Ohm's law – that is, you take the data converter's full scale voltage and divide by the load current. Then, you check your favorite electronics distributor's website to see what real resistor values are available. Simple enough, until you start measuring double digit currents.

Take the LTC2946 wide range I^2C, power, charge and energy monitor for example, which has a full-scale voltage of approximately 100mV. If the LTC2946 is used to measure a 30A rail, a 3.3mΩ sense resistor is required, which is readily available, but it will have to dissipate 2.9W of power! Very few people in the world, if any, would be willing to dissipate this much power for a simple energy measurement. Furthermore, because of the high power dissipation, the package will likely not be "standard" by any means and, therefore, fairly expensive. For example, Digi-Key sells Vishay's CSM3637P 3.3mΩ±1% 5W sense resistor, shown in Figure 1a, for $6.90 in 1kpcs quantities! Its 6mm x 3mm x 0.6mm bulk metal foil package practically makes it a 5W heatsink that's difficult to mount.

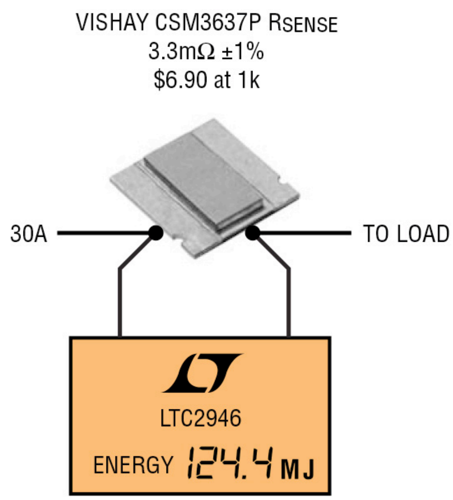


Figure 1a. LTC2946 measuring energy of 30A rail using 3.3mΩ sense resistor

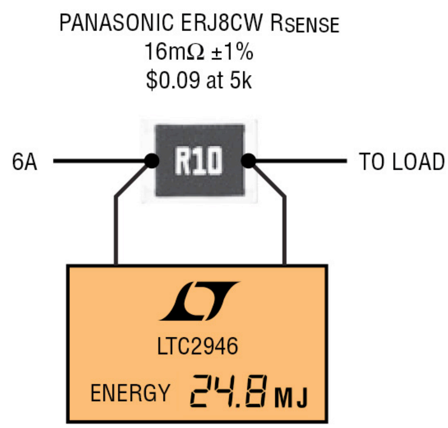


Figure 1b. LTC2946 measuring energy of 6A rail using 16mΩ sense resistor

Now, if the LTC2946 is used to measure lower currents, say a 6A rail, then a 16mΩ sense resistor is required and the power dissipation would be a more acceptable 0.57W. Digi-Key sells Panasonic's ERJ8CW 16mΩ ±1% 1W sense resistor, shown in Figure 1b, for a reasonable $0.09 in 1kpcs quantities; it is housed in a tiny 3.2mm x 1.6mm x 0.65mm 1206 package, which isn't difficult to mount and wouldn't add much to the overall board space. If anything, this makes for a 2.4% energy monitoring solution that works over the -40°C to 85°C operating temperature range, which may be too inaccurate for some applications; the 2.4% does not include any inaccuracy due to the thermocouple effects created by the external connections (i.e., leads and traces) between the LTC2946 and sense resistor.

Whether you want to measure a 30A rail or 6A rail, a simpler alternative to the LTC2946 would be the LTC2947 energy monitor, shown in Figure 2, which integrates a 300µΩ sense resistor and eliminates the headaches of using external sense resistors to measure high currents, including power dissipation, accuracy, temperature drift and size issues. When measuring a full-scale current of 30A, the voltage drop over the LTC2947's integrated sense resistor is only 10mV, causing a power dissipation of only about a quarter Watt or 10mW when measuring a 6A rail. In addition to low power dissipation, the LTC2947 offers high dynamic range due to its low offset of only -9mA (or 2.7µV). Temperature compensated energy readings are guaranteed to be 1.2% accurate at room temperature or 1.5% accurate over the entire -40°C to 85°C operating temperature range. Furthermore, the LTC2947 is housed in a 4mm x 6mm 32-pin QFN package, making it very effective in space-constrained designs.

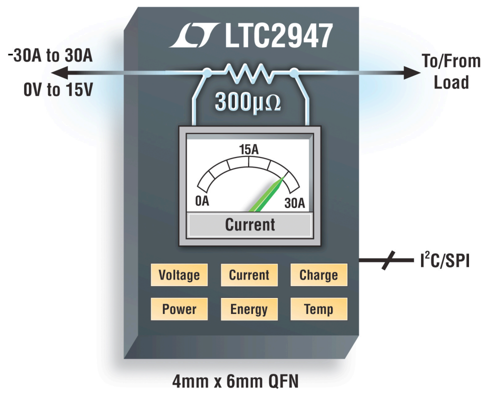


Figure 2. LTC2947 power/energy monitor with integrated sense resistor

Energy Measurements

The LTC2947 measures many parameters, including current, voltage, power, charge, energy, temperature and time. Refer to the block diagram in Figure 3. The LTC2947 uses three ΔΣ ADCs, two of which measure voltage and current while the third ADC calculates power. In continuous mode, the ADCs continuously and simultaneously measure current, voltage, power and temperature and update corresponding internal registers every 100ms. A single shot mode triggers a single set of round-robin measurements. When no measurements need to be made, the LTC2947 can park itself in either shutdown mode, where total current consumption is reduced to less than 10μA, or idle mode, where all circuitry stays active and ready to go into continuous, single shot or shutdown mode.

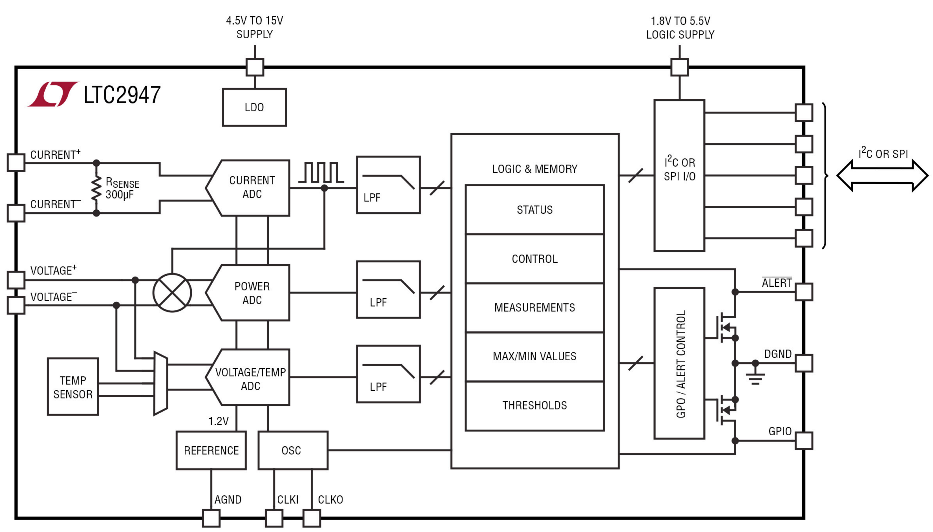


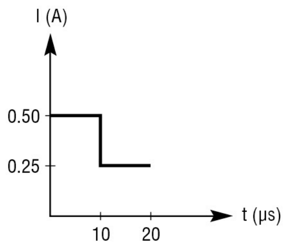
Figure 3. LTC2947 block diagram

The LTC2947's 1.3% accurate energy measurements are really owed to the unique way it calculates power. Unlike existing power monitors where power is multiplied at an ADC's conversion rate, the LTC2947 implements a unique measurement scheme that results in maximum power measurement accuracy. Each of the three ADCs in the LTC2947 is tailored for a specific task. The first ADC measures current from -30A to 30A and uses a continuous offset calibration to ensure that all input samples are averaged with equal weight and no samples are missed.

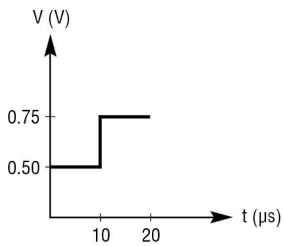
The second ADC measures both internal temperature and differential voltage at the same time the first ADC is measuring current. Temperature is both reported to the host and used internally by the LTC2947 to compensate for the temperature drift of the internal current sense resistor, resulting in more accurate current measurements. Because of the 0V to 15V rail-to-rail operating range, the LTC2947 is useful in many types of systems. Not only do 20V abs-max-rated supply and sense pins provide a lot of headroom for 12V applications, but the zero volt sense monitoring capability is just as useful in monitoring current levels during short circuit or blackout situations. Fault current levels at zero volts can immediately indicate whether the power supply or load has gone bad without additional circuitry.

The LTC2947's "secret sauce" when measuring power and energy really resides in the third ADC, which multiplies current and voltage at a 5MHz sampling frequency, prior to any conversion averaging. You see, in typical power or energy monitoring ICs, one or two ADCs are used to measure both current and voltage, and the results are multiplied to obtain power; however, because ΔΣ ADCs are normally used, the values being multiplied are inherently average current and average voltage, which will always contribute to some power error. Instead of multiplying averaged values, the LTC2947 multiplies raw (pre-decimation filter) readings of current and voltage, then converts the result. This enables the LTC2947 to accurately measure power in the presence of current and voltage variations up to 50kHz – far beyond its conversion frequency. This might happen if, for example, power is drawn from a battery with significant impedance.

Figure 4 shows an example of a current and voltage waveform that are changing phases over a 20µs interval, as well as how power would be calculated differently in typical power or energy monitoring ICs versus the LTC2947. In typical power or energy monitoring ICs, power is calculated as the average current multiplied by the average voltage. In the LTC2947, power is calculated as the average of multiplied samples (in this example, two samples are used). The LTC2947 0.218W power calculation more closely resembles actual power and the typical power or energy monitoring IC's 0.234W power calculation is a 7.3% error. The LTC2947 avoids this error and maintains accuracy with up to 50kHz signals.



$$
\begin{aligned}
P_{TYPICAL} &= AVE(I) \bullet AVE(V) \\
&= [(I_1 + I_2)/2] \bullet [(V_1 + V_2)/2] \\
&= [(0.5A + 0.25A)/2] \bullet [(0.5V + 0.75V)/2] \\
&= 0.234W
\end{aligned}
$$



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\begin{aligned}
P_{LTC2947} &= AVE(I \bullet V) \\
&= [(I_1V_1) + (I_2V_2)]/2 \\
&= [(0.5V)(0.5A) + (0.25V)(0.75A)]/2 \\
&= 0.218W
\end{aligned}
$$

Figure 4. Example of typical power calculation vs. LTC2947 power calculation

Since charge is the amount of current consumed over time and energy is the amount of power consumed over time, the LTC2947 integrates current and power over time to calculate charge and energy flowing to or from the load. It also keeps track of the total accumulated time that has been used for integration, where the integration time base can be provided either by the 1% accurate internal clock or an external 100kHz to 25MHz time base. Charge data can be especially useful in battery applications where charge is just one of many prerequisites to accurately determining the state of charge (SOC) of a battery. Moreover, energy data is proving to be more common in everyday applications, as it allows for dynamic loading versus relying on static power readings for activities.

Digital Convenience

The LTC2947 includes a host of convenient digital features that simplifies designs. The most apparent digital feature is the integration of a multiplier and accumulator which provide users with 24-bit power and 48-bit energy and charge values, alleviating the host of polling voltage and current data and performing extra computations. A separate 1.8V to 5.5V digital supply allows users to run logic levels at a voltage different from the supply being monitored.

The LTC2947 has minimum and maximum registers for current, voltage, power and temperature, which eliminate the need for continuous software polling and free the bus and host to perform other tasks. In addition to detecting and storing min/max values, the LTC2947 has threshold registers that can be used to issue an alert in the event any of the thresholds are exceeded, again, eliminating the need for the microprocessor to constantly poll the LTC2947 and analyze data. The LTC2947 can also be configured to generate an overflow alert after a specified amount of energy or charge has been delivered or when a preset amount of time has elapsed. For an energy monitor, an alert response can be equally as valuable as minimum and maximum registers, so a separate alert register is available and allows users to select which parameters will respond in accordance with the SMBus alert response protocol, where the Alert Response Address (ARA) is broadcasted and the /ALERT pin is pulled low to notify the host of an alert event.

Users can pin-configure the LTC2947 to support a standard SPI or I^2C interface to communicate with the outside world. Six I^2C device addresses are available so multiple LTC2947s can be easily designed into the same system. A stuck-bus reset timer resets the internal I^2C state machine to allow normal communication to resume in the event that I^2C signals are held low for over 50ms (stuck bus condition) for any reason; this sought-after stuck bus protection feature prevents a host from manually troubleshooting a bus stuck low, which might result in a system reset that is disruptive, costly and time consuming. The LTC2947 also provides a split I^2C data line, which conveniently eliminates the need to use I^2C splitters or combiners for bidirectional transmission and receiving of data across an isolation boundary.

Conclusion

The LTC2947 is a convenient board level energy monitor that integrates a 300µΩ sense resistor to eliminate common sense resistor challenges that tend to arise when measuring high currents. At any current level, three ADCs are uniquely designed to provide users with highly accurate readings of current, voltage, power, energy, charge, temperature and time. The -30A to 30A current range and 0V to 15V voltage range allows the LTC2947 to work in a wide variety of applications, including applications where bidirectional currents are present. The LTC2947's analog prowess is equally matched by its host resource-reducing digital features, including a multiplier, accumulator, min/max registers, configurable alerts and a very capable SPI or I^2C interface. Occupying only $24mm^2$ of board area, the LTC2947 is the most sensible device in Linear Technology's power monitoring portfolio to date.