Energy harvesting will fuel the 4th industrial revolution

The ability to operate without wires or batteries is significant

By: Matthieu Chevrier, Texas Instruments

Today's zeitgeist – or spirit of the age – within factory automation and process control professionals is to move towards "smart factories," often referred to as the upcoming fourth industrial revolution. If we look at previous industrial revolutions in order to help prepare for the next one, a pattern emerges. In each revolution there was a combination of a new organization of information with a new source of energy. Examples through history include mechanical weaving looms with steam engines, the production line with oil, and robots with electricity.

The challenge that the new energy source needs to address is that of scalability. Manufacturers have a sea of devices spread over multiple factory sites and plants, and all need power at each location. Incumbent solutions using wires and batteries fail to answer this new challenge. Fortunately, the new energy source that will fuel the fourth wave of industrial revolution is already known – energy harvesting.

What is energy-harvesting?

Energy harvesting is an umbrella concept for self-powered systems which produce their energy from ambient sources. Amongst the possible ways to power a system are sunlight, indoor light, pipes with hot fluids flowing, pumps and motor vibrations, the list is almost endless. Energy harvesting generates power for the system where it is needed, it eliminates the need for more cables and increases reliability in applications where cables can lead to system issues caused by heavy vibrations (pumps), or systems with hinges (robots).

Energy harvesting also improves upon battery-powered radio systems. Process control equipment vendors have online simulators for their wireless highway addressable remote transducer protocol (WHART) products showing that battery lives can be as low as a few months. With energy-harvesting-powered devices, there is no need to send a technician anymore. Additionally, because energy harvesting technologies have wider temperature ranges than batteries, the system can be deployed in places with extremely low temperatures where batteries simply cannot function.

Maturity of energy harvesting

Despite all of its benefits energy harvesting has not yet crossed the chasm to reach its full potential. The two main reasons are economics and technical. On the economic side one has to look at a simple CR2032 battery, which can provide 200 mAh (2600J) for a few cents in high volumes. Amorphous photovoltaic (PV), or today's most mature energy harvesting technology, can provide 5 μW for 20 years and more (3000J) under reading light conditions (200 lux). This is a fraction of the battery's cost, and dye-sensitized solar cell (DSSC) / organic PV (OPV) offer the potential for even further reductions. Batteries are still the main technology today because, for shorter periods of time (say five years and power consumptions above 20 μW), batteries are still more cost-competitive.

As the system's average power goes down and expected life time goes up, energy harvesting is making its way into more markets. However, beyond economics, another challenge is on the technical forefront. It is the need for the full system design to achieve an economically viable solution.

While extremely talented designers are coming out of our universities, finding designers capable of assessing how much light energy is available on an average factory floor, or the amount of heat generated by a pipe in an oil factory, is a much higher challenge.

Designing for energy harvesting
Designing for energy harvesting is an incremental process. It involves engineers working hand in hand on the harvester and system electronics. On the harvester, two key aspects are critical to the success of the full system. Firstly, you have to select an energy harvester that provides the maximum amount of energy in a given environment, which is a function of the actual energy source.

For instance, a factory floor lit by LED or fluorescent lights has a spectrum that allows a DSSC/OPV panel to give more than twice as much as a c-Si panel [1] with the same active area. Alternatively, to monitor the outdoors of a chemistry plant will require a crystalline silicon (c-Si) panel to match the sunlight spectrum.

On the harvester's electrical output side, understanding its electrical parameters is key to ensure that the power management impedance matches that of the harvester. For a PV, dynamic impedance adjustment is key [1, 2].

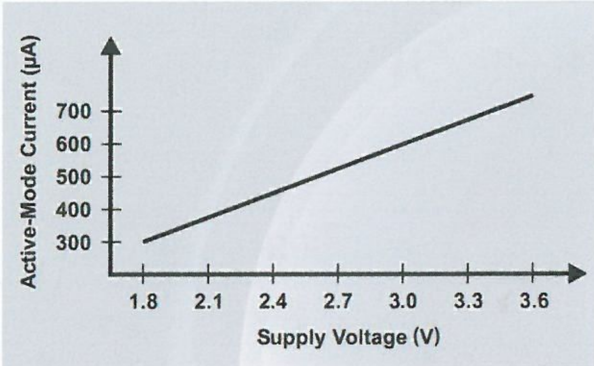

Figure 1: Two key parameters for optimizing current consumption for energy harvesting systems

Secondly, another key parameter is to understand the dynamic changes in the power source and how to adjust according to the power source's sampling rate. Indeed, being able to enable or disable harvesting power management based on input power availability is a further critical step to achieve total system efficiency. An example of such a design is available in reference [3].

Driving a low-power microcontroller
On the application side, let us look at a couple of practical examples. **Figure 1** shows two key parameters for optimizing current consumption for energy harvesting systems. The active-mode current measurements depend on the voltage supply measurements, which are taken using a microcontroller.

The easiest way to power a microcontroller (MCU) is to power it directly from a 3.6V battery using **Figure 1** leads to this equation:

$$P_A=3.6*700\mu A=2.5mW$$

If, however, we adapt the equations from reference [4] to an MCU powered by a nanopower buck convertor (like in the bq25570 or TPS62736), we get **equation 2**. Comparing **equation 2 and equation 1**, we observe a reduction by a factor of more than double the total power dissipation.

$$P_A=V_{Batt}{}^{*}I_{QDCDC}+V_{SOC}{}^{*}I_{SOC}=3.6V{*}0.3\mu A+2.2V{*}\frac{400\mu A}{\eta^{*}V_{Batt}}=900\mu W$$

As a result, powering a low power MCU from this type of nanopower buck convertor brings significant gains.

Electronics optimization – reduce sleep current with a nanotimer
Another important aspect for low duty cycle systems is to optimize power consumption in "sleep" mode, in other words, when no processing is needed. For years the best practice was to run the MCU in real-time clock (RTC) mode as it was the lowest power mode possible which periodic wake-up was enabled.

A new family of devices, nanotimers, were released to further improve the total power consumption. The benefits are best highlighted when comparing a typical low-power sensor (see

SYSTEM 1	Normalized (1 sec)	SYSTEM 2 WITH TPL5000	Normalized (1 sec)
MSP430 active (1MHz at 3V)	1.58E-08	MSP430 active (1MHz at 3V)	1.58E-08
MSP430 in LPM3	6.00E-07	MSP430 in LPM4.5	1.00E-07
Op amp	1.55E-08	Op amp	1.55E-08
ADC ref	5.96E-09	ADC ref	5.96E-09
ADC core	1.56E-09	ADC core	1.56E-09
IRLED	1.26E-06	IRLED	1.26E-06
TPS61040	1.00E-07	TPS61040 in shut down	1.00E-07
--		**TPL5000**	5.00E-08
Total	2.00E-06	Total	1.55E-06
Standby current	7.00E-07	Standby current	2.50E-07
Lifetime	**8 years**	**Lifetime**	**10 years**

Table 1: Current consumption curves.

Table 1). In our example standby power is reduced by a factor of nearly three, a wake-up cycle of every second still leads to a gain of more than 25 percent!

A practical implemantion of such a low-power system based on nanotimers and achieving 60 nA average power consumption while still reacting to input changes is available in reference [3].

Looking forward

While the data management changes coming are getting increasingly clear for factory owners and plant managers (cloud computing, big data, machine learning, and many others) the energy source required to make this sea of sensors and actuators is still reserved to a few niches.

It is my experience that the perceived technical challenges are now more related to the difficulties to get access to the relevant expertise, rather than inherent technical or commercial challenges. As this expertise becomes more available, the rate of adoption will continue to accelerate. The fourth industrial revolution is just around the corner!

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