What the World Needs Now

by Dennis L Feucht

I am driving to Spanish Lookout, a largely agrarian colony in Belize of 1500 Mennonites on about 50,000 acres of land. It is located north of the Belize River and my Chrysler minivan is on the hand-cranked ferry crossing it. I am in thought, contemplating how to teach people with an average seventh-grade education about electricity.

"What is electricity?" I ask my class. "Is it a kind of fire?" "You tell us," they say. "We're here to learn."

"But what do you suppose?" I persist, wanting to stir up their sense of wonder about the topic. It's not fire, they conclude, nor a fluid. The first class is underway.

The colonists operate their own electric power plant, using 2-MW Caterpillar diesel generators, with an average load of 1.5 MW. Much of the power is not only for residences but for feed mills, metal shops, a chicken processing plant, and a sawmill nine miles north of the power plant. They have maintained the plant for years, though Jake, the thirty-something plant manager -- a short, wiry guy who is both personable and inquisitive -- has a fifth-grade education. Until recently he did not know the difference between voltage and current.

We meet in an upstairs room at the chicken factory, next to the power plant. About a dozen students from the colony are in attendance. Some are power plant workers; others are from colony businesses with large electrical machinery. For the second meeting I requested that they bring an electric load so that they can learn to measure resistance with my DMM. I did not expect several of them to bring their own DMMs. We work problems using Ohm's and Watt's laws. I teach some algebra along with electricity concepts.

The dominant supplier of electricity in Belize is Belize Electric, Ltd (BEL), which buys most of its power from Mexico as surplus. The surplus is dwindling as Mexico's Yucatan coast develops, which includes the popular vacation resort town of Cancun. A second hydroelectric dam is being built in the hills up the road from where I live in the jungle. In town, in the Cayo district in middle-west Belize, I see a few T-shirts protesting construction of the dam. It will create a large reservoir, flooding both rainforest and Mayan archaeological ruins (which are hard to not find).

While in town, running errands and connecting to the Internet I stop in at the house of my physicist friend, Mark, on the way home. Mark is gone but his five sons are there. I ask them the same question about electricity. Ben, the oldest at 14 years, and Matt, who is interested in electronics, both do not think electricity is fire or a fluid. They know about electrons but Matt gets the polarity wrong. It's a convention, I tell him.

"The quantity in electric theory that is electricity is called charge," I add. "The symbol for it is not C but Q."

"C is capacitance," the 12-year-old Matt informs me. Current is not C either, we all note. I have not been able to fool Mark's sons. No wonder; Mark himself got a physics degree from MIT in two years. CalTech let him in for graduate work without formal application. He has a PhD in particle physics. You never know who you'll find in Central America.

To avoid the long line of cars at the ferry, I usually drive east and take the Iguana Creek bridge over the Belize River, leading onto a wide gravel road bordering Spanish Lookout. The Mennonites maintain their own roads, and I speed up from 15 to 35 mph. My destination is the power plant along Centre Road, at the heart of the colony. In an earlier month, I had met Ken Manning at the power plant office, a spry and alert 75-year-old retired electronics design engineer who worked on the development of the first desktop computer hard-disk drive. I learned that he was my neighbor in the hills, only 4 miles away. He had been helping the power-plant people decide how to make modifications to their electric distribution, which was not compatible with the BEL system. I seem to have picked up where Ken was leaving off. I sat in on a meeting with a power-components representative from Guatemala who recommended capacitors for power-factor-correction of feed-mill induction motors.

"You need to learn about electricity," I tell Jake, "so that you can understand the trade-offs between what Ken and these distributors are suggesting. You need to be able to figure out what the consequences are for yourselves here at the plant." Jake agreed; a half-year later the class began. It lasted about a half year and was an all-around success. I hear about how the class helped some of my students with practical problems. And it provided the occasion for interacting with and getting to know some Spanish Lookout Mennonites.

Uncovering Design Habits

Where is this story leading, you might wonder. It might already be lost in the jungle, raising questions in the astute reader's mind about why a particle physicist (or the author) would be living in an underdeveloped country. What does a colony power plant have to do with electronics in the "real world"?

The frontiers of a technology -- in our case, electronics -- are pushed in various directions by factors that lie both inside and outside technology development itself. The realization that they must better understand the technology they have become dependent upon has elevated the Spanish Lookout Mennonites to new conceptual horizons. They have been technology users and now are expanding toward becoming technology understanders. I have been a design engineer all my life, and now, living in a simpler cultural context, I am rethinking the mental habits I have acquired about design. The decades-long increase in IC density has been a development within electronics which has led to the familiar habit of throwing more transistors at a problem. Perhaps it is time to consider a different approach, the minimalist approach of throwing more simplifying ideas instead. As a former engineering colleague used to say, simplicity is the ultimate sophistication. However, increased performance at reduced complexity does not seem a very important approach when the leading question is what to do with higher levels of integration.

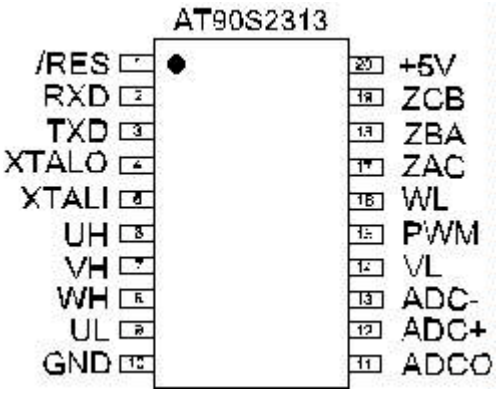
Secondly, influences from outside electronics can also reveal hidden design habits. While the developed world continues to be flooded with decadence-enhancing geegaws, both developed and developing worlds lack useful and needed products. The vast majority of electronics engineers live in the developed world and are shaped in their design outlook by it. The vast majority of people on earth with problems capable of technological solution do not. These people, especially those in India and China, are participating increasingly in the global economy. Like the Spanish Lookout Mennonites, many of them are inclined to benefit from simple, functionally optimal products. From my developing-world location, I have thought of a few new product ideas that could be useful here. I hope some of you design and bring them to market before I do.

A Low-Cost, Reliable Sinewave Inverter

The 300-W inverter that runs off my battery was purchased for about 50 US$ and outputs 120 V ac at 60 Hz -- depending on how you want to measure it. It is almost certainly an Asian import, with the typical lack of any manufacturer's documentation. If I were the manufacturer, neither would I want my name on this product. The waveform is a bipolar square-wave. I foolishly bought a second, identical, unit after the first one failed in 6 months. It too has failed. My engineering inquisitiveness led me to remove most of the available screws and trace the circuit. The unit has six power MOSFETs, two for the converter input stage and 4 in the H-bridge inverter. The shortcoming was in the primary. The circuit could have generated a sine input as a command to the PWM generator, to produce a 60-Hz sine-wave, but it did not. The additional cost of a sine source would have been small and the increase in waveform quality large.

Recently I went to a combination hardware store, restaurant, and gas station in the Mennonite colony. They sell inverters. I found a 1-kW unit with a schematic diagram. A perusal of the design once again sunk my hopes. It was pathological.

In this day and age, sine waves are not that expensive to generate. A reliable offering (at various power ratings) of sine-wave inverters would be an improvement over square-wave inverters. They could be made to sync with each other when multiple inverters are paralleled, allowing growth of the system along with the buyer's future cash flow. A $2 microcontroller with PWM output, found on various Atmel AT90S or Microchip PIC parts, could drive the PWM generator with a table look-up, or computed sinusoid. A proposed Atmel AT90S2313 pinout is shown below.

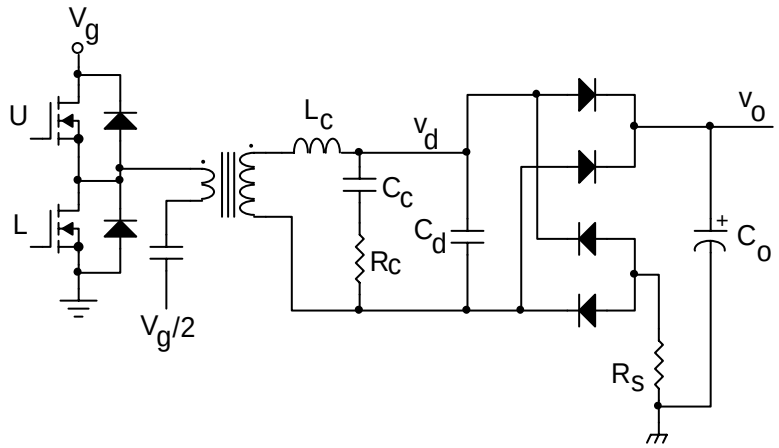


The built-in comparator (ADC-, ADC+) could be used to implement a Σ-Δ ADC, with two external resistors and a capacitor. ADCO is the output bit-line needed to complete the ADC. Through the ADC the microcontroller monitors the attenuated, rectified, and averaged output waveform to adjust the PWM magnitude for a set output voltage. The output voltage waveform(s) is (are) also attenuated and sampled, and the zero-crossings (ZAC, ZBA, ZCB) are used to synchronize with the power-line grid or other inverters. A microcontroller-based inverter also provides for essentially no extra cost a serial interface for status and warning monitoring. Enough pins on the 20-pin part are available for generation and zero-crossing phase detection of three-phase power. With only one PWM output 3-phase generation is limited to non-PWMed six-step waveforms, but with continuous-current-mode stepping, this at least can give four levels to the sine waveform. For single-phase generation, sine resolution is limited by the processor sampling rate.

Would I pay a few extra dollars (pesos, quetzals, or colons) for that? Sure. But will Javier, Catalina, or Luis? Increasingly so. And while inverters are the subject, why not extend the input range to include the new automotive 42-V system? At the low-power end of the product line, a 250-W inverter without a fan could power a notebook (or other) computer without the noise and the electromechanical unreliability of the fan, especially in the tropics.

A Miniature Spot Welder

Now here is something out of the ordinary. Imagine having a small box with probe-leads that could be used to make small spot welds. Small metal parts break occasionally and they could often be repaired with a capacitance-discharge (CD) miniwelder. I recently designed one based on converter boards left over from a C-bank charger for a magnetizer, used to magnetize permanent magnets. I did not need a 50-kA discharge, as did the magnetizer -- only 200 A to 500 A instead -- nor a huge C-bank, so I scaled the unit for up to 100 V of charging and with a switch-bank, to select the amount of C-bank capacitance. With two variables, the welder can be set optimally for different welding tasks.



The prototype unit is being field-tested by a jewelry maker who welds gold chain links with it. A few refinements are in process, but it appears to weld successfully. The C-bank charger uses a newer topology (shown below; see "Pulsed Power" under designware at http://www.innovatia.com) with zero-power switching (ZPS) and low converter loss.

Jewelry is desired in the developing world, not always for vanity or luxury but as a utilitarian way to store wealth securely, on one's person. In Honduras, attractive women have perfectly good natural teeth pulled and replaced with gold teeth as a store of wealth. But jewelry is incidental; many small metal parts that are replaced by a purchase in the developed world cannot so readily be found in the parts-challenged world, and repair may be the best (or only) recourse. Ordinary welders are available, but are too large for small parts. Hence the utility of a CD miniwelder. Perhaps it might also catch on in the developed world, as did the bread-making machines from Japan.

Optimal Battery Charger

As I sit in my cottage in the jungle, writing this article on a laptop computer powered by a 4.5-kW genset with a Yanmar diesel engine (built by an enterprising friend in Pennsylvania who got them at a good price), the generator is also charging a car battery under my desk. It keeps me going when I stop burning 3 US$/gallon diesel fuel. Under these circumstances, battery chargers take on a new and unprecedented importance, which are not unique to me.

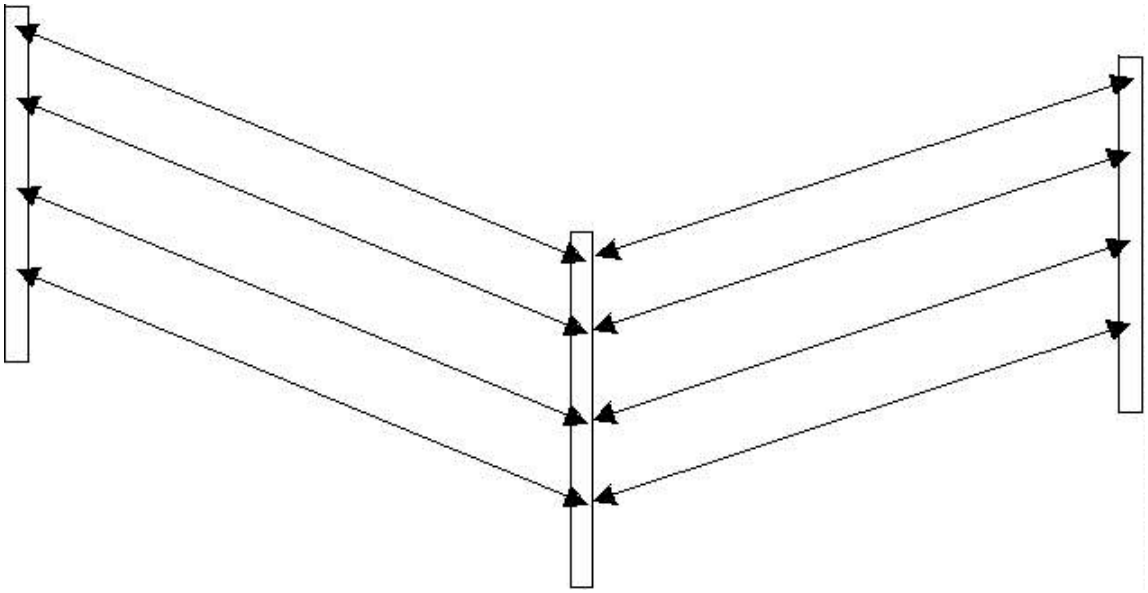
The low-cost American-made charger that I bought locally does indeed charge, but the charging current varies with line voltage. As generator speed (and hence voltage) varies, controlled by a centrifugal governor in the engine, the charging current follows it. Ideally, a charger should take a universal line input (85 Vrms to 265 Vrms) and output a controlled current based on an optimal charging algorithm. Is there such an algorithm, one might ask? Not in any commercial product yet. Such an algorithm has been developed but has not yet been applied.

Gary Bergstrom (g.bergstrom@ieee.org), an inventive engineer with an electronics laboratory in his house in the east Cleveland suburbs, patented what appears to be an optimal charging algorithm for lead-acid batteries. Tests have shown that it produces the least gas during charging of any of the methods tested on lead-acid batteries. His "differential ESR (equivalent series resistance)" or DESR method drives the battery with a current and measures the voltage, then changes the current by ΔI and measures the voltage again. The resulting $\Delta V/\Delta I$ is the battery dynamic ESR. The current continues to be adjusted until the minimum ESR operating point is found. This adjustment occurs throughout the charging interval. Tests comparing this algorithm with others in use show that it generates the least gas, which is related to the life (number of charging cycles) of sealed lead-acid batteries.

It is also increasingly recognized that by including some high-frequency components in the charging current, battery life can be extended, and "dead" batteries have even been rejuvenated. Some commercially-available "desulfonators" put out spikes of current. The hypothesis is that the high-frequency components shake loose the sulfur crystallized on the lead plates, dissolving the otherwise sulfated area once again into the sulfuric-acid solution where it rejoins the electrochemical activity. The hope is that it might be possible in this way to extend battery life indefinitely, until the plates warp. Such a feature should be built into the charger, and might simply be provided by not filtering the charger switching waveform.

A Perimeter-Based Security System

As the developed world becomes more rowdy and the developing world has yet to settle down, both need a kind of security system that provides an outer-perimeter defense for a home or business. While building security systems are commonplace nearly everywhere, one is needed that is optimal for the next level out from the building(s). Consider electronic posts placed in the ground to define a perimeter, as shown below.



The posts have a vertical array of IR diode or laser light-beams that are broken when an intruder passes between them. The links also form a communications network for relaying back to the base system the detection that is occurring. With multiple IR links between posts, the size and, as a low-resolution silhouette, the shape of the penetrating object can be determined. These posts could be solar powered, would automatically form a network, and begin working without manual configuration upon detection of another post. Each post would have a unique identifying number and be able to talk with posts on each side of it. At the base computer, pattern-recognition software could be trained to categorize patterns based on which beams are broken as the entering entity sweeps out a cross-section while passing through.

The advantage of this boundary defense system over cameras is that it can be automated and run without human supervision. Deterrent responses could be triggered: lights, a warning message over an outdoor loudspeaker, pepper spray, a flash pack, loud siren, disabling sonics, or for Earl Schwartzenegger fans, an automated Gatling gun. More simply, the family Rotweiler could be released instead.

Another approach to area security is to develop a low-cost ultrasonic phased-array sensing and deterrence system. Phased-array ultrasound is a well-established technology in medical diagnostic instruments. It can be applied in a simpler way to scan a volume of yard using a microcontroller to do the beam steering and focusing. The speed of sound allows microseconds of processing time, enough nowadays to compute the phasing for returning echoes. Once an intruder is identified -- perhaps by another low-cost controller running a pattern-recognition program -- an intense and focused beam of ultrasonic power is made to track the moving target. High-intensity sound can deter.

A Solar-Powered Refrigerator

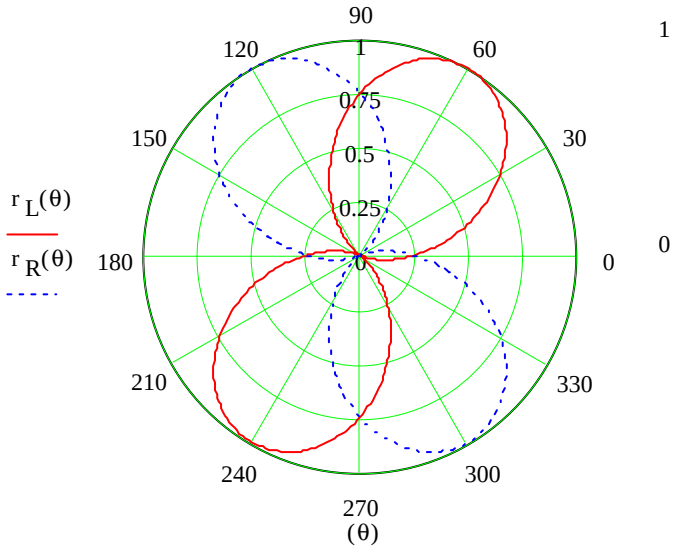
There is no reason to have to use electricity or gas to provide cooling where there is plenty of solar energy. Recreational vehicles typically use ammonia absorption refrigeration and run on propane or butane. The gas is burned to vaporize the ammonia. This substitutes approximately for the compressor in a vapor-compression refrigerator, which pressurizes the working fluid while also incidentally heating it.

Ammonia-absorption refrigeration need not use the depleting supply of hydrocarbon fuels as an energy source and also need not be relegated to RV use. In most places in the world, the sun can provide the heating, using a concentrating collector.

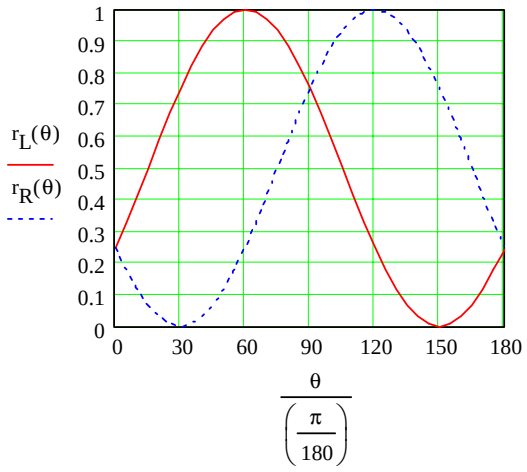
The collector is enabling technology in itself and would be a good component to design first, for it can also be used in solar thermal electric generation. Concentrated sunlight is required to achieve sufficient ΔT. A heliostat or parabolic trough can be constructed using metalized plastic film, which is relatively low in cost.

The electronic contribution is in tracking the sun. This can be achieved with only slight suboptimality in one dimension, to keep the collector cost low. The path of the sun as it sweeps across the sky is tracked, and as it shifts seasonally in the other dimension, the parabolic focal line, which is a fluidic pipe, is made somewhat longer to catch the glancing solar rays from the ends of the trough.

Solar tracking is not a difficult problem. Because of the intensity of the sun, even on cloudy days, LEDs can be used as directional sensors by offsetting the angle between two of them, as shown below in polar coordinates.



The sensitivity plots, based on a sinusoidal response pattern, are somewhat typical of common LEDs. When plotted in rectilinear coordinates as a function of angle, the following plot results.



It can be seen on both plots that the two LEDs receive equal intensity at 0.75 times their peaks when they are symmetrically offset from the normal sun angle by 30° each, where:

$$r_L(\theta) := R \cdot \left(\sin\left(\theta + \theta_0\right)\right)^2$$

and:

$$r_R(\theta) := R \cdot \left(\sin\left(\theta - \theta_0\right)\right)^2$$

with R = 1.

A simple analog circuit using comparators or a microcontroller with two ADC channels can seek the equal-signal angle, thereby tracking the sun. Additional circuitry is required which can be as simple as a quarter-cycle (full-step) step-motor drive.

This solution to the problem of finding a maximum is reduced to that of the simpler problem of detecting equality. It suggests a general method for finding extremas by comparing two offset, symmetrical functions having their own extremas. This is easily accomplished spatially in this case.

Closure

While increasingly sophisticated technology has led to new capabilities, and a wide range of products, global trends are pushing in the direction of simple, elegant (preferably field-repairable and documented) technology capable of meeting the world's basic needs for energy conversion, repair, and security. Besides the product ideas offered here, low-cost medical equipment is also a high priority, as are new products for non-geofuel energy generation. More transistors are not always better. But more simplifying ideas are.