Digital Power, A Manufacturer's View

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Abstract

The fact that we are all gathered for DPF'04 is an acknowledgement that digital technologies have begun to take root in that bastion of analog creativity called a POWER SUPPLY. Having, years ago, surrendered our beloved smooth-flowing LINEAR systems to the harsh reality of bi-stable design, we now find ourselves threatened with even more bi-stable process encroachment in the form of digital control systems. Has the world gone mad? Maybe, but I prefer to think of the coming paradigm shift as recognition that digital technology, having matured in computing and motor control, is now ready for prime-time!! Results of significant design work, published and otherwise, point to digital control as not only feasible in low cost commercial applications, but potentially becoming the dominant mode in many of them within a very short time.
This paper presents one power supply manufacturer's perspective on the commercial potential for control of power conversion by digital means, not with the well-known precision of a market forecast, but from the standpoint of what it offers and the challenges it presents.

A Paradigm Shift

It's been a long time coming, but there is now good reason to believe that the promise of power switch control by digital means is truly taking hold. As an experimental concept the idea has been part of our literature for many years, but means to achieve practical implementation has had to wait for a particular combination of technical and economic factors to align. As the business of power electronics design and manufacture slowly recovers from its worst slow-down in memory, those factors seem to have aligned as a result of similar economic troubles in semiconductor markets and a strong, growing, demand for portable (battery operated) electronic products.

In a nutshell, chipmakers' search for more sources of revenue, as traditional markets dried out, led them to discover power management as relatively attractive new turf. Certainly, coupled with that search for market opportunity was a need within portable power industries to find ways to more effectively manage power consumption. Progress is made when a resource finds a need.

In true entrepreneurial style, start-ups and “spin-offs” soon began to appear to capitalize on new “digital” opportunities across the power conversion spectrum.

When chipmakers began to explore the envelope for power management in cell phones, PDA’s, laptops and the like, they also discovered fertile markets at higher power conversion levels. At the same time, power supply designers began to realize that unusual circuit topology possibilities, real-time adaptive operation and other advances, impractical to implement with available analog IC’s, were coming within the evolving capability of reasonably priced digital control schemes.

As a basis for discussion, let’s define “digital control”, in the context of power supplies as comprised of internal administrative or “housekeeping” functions and also PWM / control loop elements. A digital control sub-system is, then, one or more silicon chips that combine A/D conversion with control law processing, pulse width modulation and communication elements operating entirely (or mostly) in digital mode. Accompanying those major pieces are one or more microprocessors, some type of read/write memory, communication port(s) and miscellaneous op-amps and sensors.

A true digital control “chip” when applied within a power converter will sense a controlled parameter(s) (typically output voltage), generate power switch drive waveforms appropriate to adjusting the controlled parameter (the PWM function) and process feedback information according to specified control law to achieve performance characteristics and maintain system stability. In addition, the control devices(s) are equipped to store programs that might enable dynamic manipulation of control law, measure specified signal levels, compute data and communicate via a standard format channel. The more sophisticated types of digital control chips can generate multiple, essentially arbitrary, switch drive waveforms and manipulate them on-the-fly, change operating modes and achieve dynamic performance optimization.

How important are adaptations of digital techniques to power converter control? One could ask, “How important are digital techniques to computing”? While that might be slightly overstating the case, the message is valid. Digital processing applied to power conditioning is very likely to open doors not yet imagined by practitioners of the art. From what has been demonstrated so far, it is clear that benefits will be derived from several fundamental capabilities of digital control systems that can:

- Generate flexible power switch drive waveforms with programmable relationships to one another
- Offer Precision that can counter the effects of component tolerance, parametric drift, aging, etc.
- Adapt to changing environmental conditions
- Store data for operational purposes and /or record keeping
- Communicate with an external world that has long been in digital mode.

The Payoff

Of course, none of those powerful attributes are meaningful to manufacturers intent on profit, unless they enable Engineers to design more cost effective products. In fact, they do!

It has proven very difficult to compound physical size reductions over time with analog circuitry, at least to the degree that it has been applied to digital circuits. Cost is tied to physical size (in silicon) on a per function basis, so to the extent that traditionally analog power control and management functions can be "digitized", they become subject to the ever-shrinking size and cost model described by Moore's Law. It seems reasonable to expect that other natural laws will also apply, and we will see function expand to perpetuate price. Still, the opportunity is there to lower product cost as silicon integration leads to reduction of parts count and assembly size.

To a power conversion product manufacturer, the ability program a generic assembly with a particular power converter personality at the end of the assembly line offers exquisite cost reduction possibilities. Conceptually, digital control systems with operating characteristics and adjustment data stored in memory can offer cost benefit in at least four important ways;

- Product family variants can be defined by software instead of hardware.
- Parametric spread can be narrowed through adaptive control
- Production testing can be enhanced, or replaced, by stored self-test functions.
- Product identification, operating history, and tracking data can be internally stored and more easily managed.

Particular to the world of "standard" power supplies is an unavoidable proliferation of nearly identical units usually grouped into product families. Each member requires some individualized level of documentation, test routine adjustment, and record keeping. In many cases, family variants are comprised exclusively of production-set parameters dictated by stuffing options or in-line adjustment. Protection thresholds, output voltage, input range control, control loop dynamics are among those parameters that seem destined to be tweaked more often in the future as designers build-in system optimization schemes. To the extent that such factors can be "programmed" into an otherwise generic chassis, savings can be realized in inventory management, change order administration and other complexity-dominated areas.

Power supply output voltage precision is probably the most obvious domain where electrically programmable adjustment has value. Basic reference tolerance can be relaxed if a fixed offset can be loaded into the control loop to compensate yielding a very narrow distribution of output voltage without the need for physical adjustment. Similar methods can be applied to other internal power supply parameters narrowing their distribution to benefit statistically controlled production processes. Actually, many more intriguing possibilities exist for static and real-time dynamic optimization.

Many power conversion products have some form of self-test or diagnostic capability. Features of that sort are most common in complex systems where their value is highlighted and their cost is diluted. In highly cost-sensitive applications such features are rarely found, even when their cost-effectiveness is apparent, because of space constraints. If test-enhancement, self-test or performance reporting capability can take the form of a stored program, many more power converter boxes will be able to afford those advantages. Significant savings in production test can be realized when all, or part of, test control and monitoring resides within the item under test, and moves with it along the process flow. Some examples of test functions that might be supported by internal programs include:

- Burn-in cycling / monitoring
- Threshold detector tests (OVP, UVLO, etc.)
- Four-corner regulation
- Fault simulation
- Thermal tracking
- Test stand programming

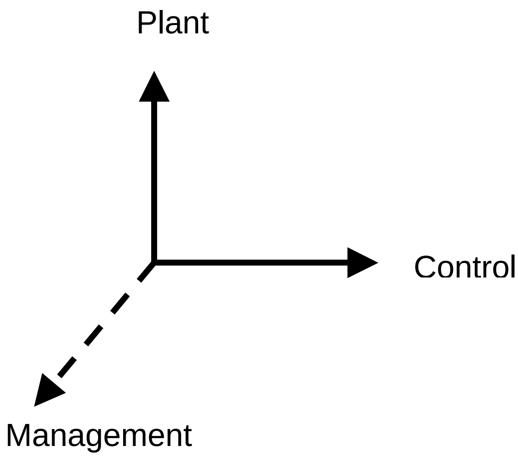
To our power supply manufacturer's customer, those same control systems offer windows into power conversion and management at chip, board, sub-system and system levels that have been either unavailable or accessed through substantial peripheral circuitry. At the very least, addition of digital control and communication mechanisms within power converters will:

- Allow reduction in dedicated power management space and cost.
- Offer potential for central power management in extended systems.
- Increase the range of control available for optimization

Board space and power "overhead" cost reductions arise from integrating what are most often discrete component circuits for voltage setting, margining, sequencing, hot-swap and fault detection into the power converter modules. Savings come from reducing the number of control devices, essentially eliminating redundant switching elements, sensors and control paths.

<u>An added dimension to Board-Mounted Power technology</u>

Power supply design has traditionally been a two dimensional challenge involving an energy handling section, usually called a "power train or "<u>plant</u>", and a <u>control</u> section that electrically manipulates the switches of the plant to achieve high efficiency voltage conversion and regulation. Beyond that, miscellaneous housekeeping circuits perform a standard suite of protection, adjustment and enable / disable functions.
Customers for power supply products are faced with a myriad of <u>power management</u> challenges involving apparatus to toggle power supply boxes so as to achieve overall efficiency and regulatory objectives at the SYSTEM level (i.e. multiple boards, back-planes and cabinets). Those challenges represent an emerging third dimension to power conversion technology.



Originally described as a Plant configuration driven by an analog Control scheme, power converters are evolving a third dimension, which Manages their operation in the context of parent system objectives.

A powerful concept, three dimensional power systems are made possible by digital technology applied in the Control dimension. Using stored information to manipulate converter operation, and communicating with a central supervisor, new optimization opportunities become practical.

Design complexity, in a sense, moves from a second-order to a third-order problem while, at the same time, requiring disciplines not commonly found in power supply engineering environments. To be successful, power equipment designers must develop software skills appropriate to device and system level coding. New test methods for production products and diagnostics for field use must be created. Design qualification for new power supply products can become much more complex in the presence of a dramatic increase in the number of variables to be accounted.

Clearly, for the third dimension to become reality in today's markets we must collectively agree upon standard communications means and protocols. All of us have experienced the challenges associated with relatively simple standardization efforts that cross competitive boundaries. Recent efforts along those lines, most notably in board-mounted-power products, seem to imply that interface standards might be more readily accepted going forward than they have been in the past. Interoperability of products from competing manufacturers is bound to become more important as power management features become widely used. In fact, it could be argued that recent shifts in competitive supplier attitudes toward power customers' need for multiple sources, is another enabling factor in the birth of digital power systems.

It will be interesting to see if power converter interoperability at the internal level (where the debate rages today) becomes more or less important relative to functional compatibility as viewed through a set of "standard" control ports. The latter is certainly a common model in computing environments and could well become so in power. On the other hand, as the number of variables in the operational equation increases, standardization becomes more difficult and nuances proliferate.

Challenges

Near the top of the list from a power supply manufacturer's point of view is the question of standards as applied to three-dimensional power conversion. It can be argued that two dimensions in side the "box" can continue to be specified by each manufacturer to reflect cost objectives, etc. But the third dimension, management, as a public interface, will require conformity at some level to assure acceptance by customers'. Challenge #1 is then:

- System level power management level interface definition(s)

Recent work on digital control of isolated power supplies has underscored the need for fast, accurate and stable means to electronically view sensed voltage levels across an isolation boundary. It is certainly possible to design conversion products that largely avoid this difficulty, but in the longer term, reliable, low cost means to communicate control information at high speed across boundaries is needed.

- Fast, accurate and stable digital signal isolation products

Stored programs in FLASH or other memory technologies suffer from degradation over time as a function of temperature. It appears that maintaining program and data integrity over long periods will be a challenge to digital control designers at least until substantially more data is available actual performance of low cost mixed-signal chips in that regard.

- Long term memory integrity, particularly in stressful environments

Noise tolerance is suggested as a basic advantage of digital control and, as a guiding principle, that notion seems valid. However, there are critical points in a power converter that may prove sufficiently sensitive to environmental noise as to cause apparent modulation or "jitter" that is offensive from an EMI standpoint if not operationally. Quantized measurement and processing leads inevitably to uncertainty in timing that is not commonly found in analog systems. Perhaps, ultimately, power engineers and users will need to add new concepts to their notions of what is "normal".

- Quantization effects and their associated perceptions