Three Key Issues to Watch out for in the Digital Control of Power Electronics

Your Digital Power Future – Roadblocks to Avoid

ELMG
power electronics digital control

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Digital Control of Power Electronics – Three key Issues

Everyone is going digital – is it the right way forward?

Before we look at the three key issues it is good to go through why digital control of power electronics is really useful.

The main and key reason is that digital control of a power converter provides flexibility. And flexibility is useful for a number of reasons. The function of the product can be changed by changing the firmware or the software. There is a verification and validation cost associated with flexibility. This cost is often worth bearing as a digital controller running in a programmable processor or FPGA can allow commonality of parts and so purchasing advantage. Effectively the production repeat cost of firmware and software is zero. Some of you may say this is not true but on a product BOM the cost of the software or firmware is usually zero rather than the code's amortized development cost.

There are specific advantages that digital control of power electronics provides when compared to traditional analogue control. These include

- Flexibility
- Configurability
- Re-tuning the loop for component variation such as Electrolytic capacitor freeze out at low temperatures
- Management of the non-linearity of the converter
- Self measurement of the loop response in closed and open loop.
- The ability to tune the switching times precisely to minimize the power loss and maximize the efficiency.

All of these are possible and are very useful for power converter control. However there are some differences with a digital controlled converter compared with an analogue controller. These differences can be problematic if you are not ready for them.

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So what should the digital controller be implemented with?

This is a good question and one that does not have one answer. Many microprocessors are able to control power electronics. Other options are digital signal processors (DSP) and field programmable gate arrays (FPGA). The processing power and the allowable control loop delay determines which of these is the most suitable. The FPGA can provide the least loop delay as it can process the signals very quickly in parallel.

It may come down to what technology is the most familiar and most comfortable.

It is great idea to use digital control for power electronics. Hopefully it will allow the power electronic converter to be more efficient and more flexible. So let's get back to the three key issues.

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Three Key Issues.

So you are building a digital controlled power converter or considering it. This is good. And if you are reading this before you get started developing the product then even better. Hopefully information on the three issues detailed below is useful in how you choose you controller and your power converter. So let's just go through the reasons why you are going digital once again.

- Flexibility
- Switching control
- A common control platform technology
- The repeat cost on code is zero
- The digital controller can deal with the non-linearity of the power converter
- Increased efficiency through switching instant control
- Increased efficiency through topology change that brings new control challenges that are best met digitally.

And in the digital controller there will be issues. Here are three to take care of.

1. Numeric precision

The digital controller is made up from an analogue to digital converter (ADC), some digital filters which implement the controller and then a digital to analogue converter typically in the form of the pulse width modulator (PWM) or a variable frequency/period oscillator (VFO/VPO). Each of these has a limited number of bits and has an effect on the precision and noise performance of the entire system.

Number of Bits

The analogue to digital converter has a limited number of bits. Typically analogue to digital converters have eight, ten, twelve, fourteen, sixteen, eighteen or twenty bits. The increasing number of bits means increasing cost. Determining how many bits are required for the ADC is the first step in designing the digital controller.

The limited number of bits means that the measured output voltage or current is quantized and the dynamic range is limited. This means that the precision to which the output can be controlled is limited to the step size in the ADC. If the precision is not accurate enough then the feedback loop will not be able to measure the difference from the required output value. Effectively the precision of the output control will be limited to the least significant bit step

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of the ADC. Typically there is a trade-off between dynamic range and precision in the ADC. It is useful to use some precision extension techniques on ten and twelve bit ADC inputs to get both a high dynamic range and accurate output control. Precision extension techniques can include only sampling the error signal created with an analogue summing amplifier or using two ADC channels together to provide the precision and the range.

Digital filter implementation

The internal calculations for the filters involve multiplications and additions. These are the typical MAC (multiply and accumulate) instructions in a DSP. These MACs realize the digital filters that provide the integrators, phase lift networks, differentiators and low pass filters that are used in closing the control loops. Each multiplication by a filter coefficient effectively reduces the precision of the signal. This reduction is especially noticeable in digital integrators and digital filters with narrow bandwidth. This loss of precision can, if it is large, lead to the digital filter failing to operate on small inputs.

Managing the digital precision of the digital filter is done by ensuring that as many bits as possible are retain in all the calculations by using coefficients that are chosen to maximize the retained signal level without clipping in large transients. Another precision extension system is the retention of extra result bits in the internal filter accumulators. This has a remarkably useful effect on reducing digital power control system noise.

2. Timer precision

The pulse width modulator (PWM) or variable frequency/period oscillator (VFO/VPO) operates from timers with a set time resolution from the clock. That is time is quantized. Thus the period or duty of the oscillation or modulator cannot vary continuously as is can for its analogue equivalent. This quantization leads to errors in the control of the power converter. Consider the case where the timer clock runs at 40MHz. If the variable period oscillator register has 256 bits then the maximum frequency that the VPO can make is 10MHz and the minimum is 39.0625kHz. The example LLC resonant power converter needs a variable frequency of 500kHz to 210kHz to perform the control. This means the VPO count register has a usable range from 80 to 191. This is 111 counts which is 6.8 equivalent bits or almost seven bits. If the processor has a 16 bit word then the VPO precision removes 9 bits of accuracy and quantizes the control loop. Effectively the 6.8 bit precision is a quantisation of available switching instants. The quantisation is a non-linearity introduced by the timer accuracy.

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The relatively simple solution to the timer precision problem is to retain the 9 bits that were chopped of the VPO input and use these to create a VPO output that has the same long term average as the 16 bit input to the VPO. This is known as precision extension modulation and is the solution for the limited timer precision that often occurs on microprocessors and digital signal processors when the converter switching rate is high.

3. Power converter behavior

It is a usual to go to digital control with a new power converter development rather than swap analogue control for digital leaving the converter the same. This choice to update the converter along with the control is because the power losses, converter volume and converter costs are all required to be reduced and digital control can aid this.

So digital controllers are often applied to a new converter perhaps with MOSFET synchronous rectifiers, dual rate switching control or a complex LCL grid connection filter with synthetic damping. These new high performance converters are chosen for extremely high efficiency and so necessarily have very low power losses. The removal of losses leads to the converters often having more variable control transfers with operating point changes and variable damping as energy loss has been removed. Along with this variability, the lower damping especially at light or no load, leads to converters that have no damping available to help with stability margins.

Some converters have extremely variable control characteristic. Measuring the converter behavior at a large number of operating points is often indicated along with linearizing the power converter control transfer.

Fortunately, a digital controller can be programmed to measure the power converter's characteristics directly and can also have configurable and linearizing operating point dependent control.

4. Other things to watch out for

In Digital Control of Power Electronic other issues to watch out for include

- Bandwidth limits due to sampling

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- Anti-aliasing filters which can have phase effect inside the control bandwidth or at the crossover frequency.
- The effect of processing delays which adds phase and can make it difficult to get adequate phase margin and gain margin.

Taking care of these three digital issues will make great strides toward getting the flexible digital power converter control operating correctly.

For all of these and more key issues in Digital Control of Power Electronics check out the course information for the ELMG Digital Power training course Introduction to Digital Power Electronic Control at www.ElmgDigitalPower.Com

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Additional Resources

The ELMG Way

If you've read through some of our free articles or purchased a product from us in the past, you may want to know about other resources to help you.

As you may have noticed in this report, the format we follow is to present easy-to-understand concepts and simple-to-implement steps. Each of which in builds upon the one before in a sequential system, so you can continually advance along your path. Here's a guide to help you understand the process we've developed to maximize your skills in the shortest time possible.

Sign Up for Our Newsletter

If you like this report, check out our newsletters and free reports at www.ElmgDigitalPower.com. The newsletter will keep you in touch with what we are doing and it will be filled with stories and practical advice to ease your journey in developing your power converters and digital controllers for them.

Membership at the Digital Control group on LinkedIn

We help with a Linkedin Group called Digital Control where there are great discussions with like-minded people on digital control with power converters.

How to guides for sale

The How to Measure Power Converter Transfers Guide

This guide helps you advance from simply taking off the shelf power converter models to designing controller based entirely on accurate measurements of the power converter. Off the shelf models are generally inaccurate and subject to considerable sensitivity to parameter variation. Digital control techniques allow the measurement to be incorporated into the controller. This self-measurement technique along with the extremely valuable manual measurement and the use of analyzers is covered and explained.

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How to Linearise your Power Converter Guide

This shows you the way to reduce the variation in the power converter control transfer. This is one of the key challenges in designing rugged and robust controllers for power converters. This will help you to design higher bandwidth controllers with more consistent performance across the varying operating conditions.

Onsite Training Courses and Online and Homestudy Training courses

Introduction to Digital Control of Power Electronics Training Course

The **Introduction to Digital Power Electronics Training Course** is a two day onsite course that covers the basis of control design. Digital control is introduced simply and the design process for digital controllers is explained. Then the limitations and drawbacks for the digital control and how to avoid and design around them are covered. The course is available either as a two day on site course, an online live course which takes eight sessions of two hours, or a home study course which can be completed in your own time. Get the course outline at

www.elmgdigitalpower.com/products/introduction-digital-control-power

When there is a course with sign up open you are able to reserve place on the course with your credit card.

Power Electronics and Control Mentoring

The mentoring process is an opportunity to work with me privately by phone, internet video conference and email to address your specific power electronic control interests and challenges. All of the experience and unique expertise, including how to avoid instability destroying your converter, is available.

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About the Author

What do you do when the DC Drive you are working on draws enough current that all the lights in the building go out and the copper busbars vaporize?

ELMG CTO Dr. Hamish Laird

When this happened to me I was working on the current control loop in a DC Drive. It was not stable and caused a large short in the power converter. At first I thought I was dead as all the lights went out. Then my friend was talking to me and asking if I was OK.

I could not hear him as the explosion had been very loud when the copper conductor bars had vaporized. I did not work on the converter for the rest of the day.

As the day went on I realized that I was glad to be alive. I also realized that control of power converters was something that I wanted to spend more time working on. And this is the journey. It started with the explosion due to current loop instability and moved to a doctoral degree in accurately modeling power converter non-linearity. From there a continuing interest and active university research into digital power converter control along with consulting to power digital power electronic companies.

The journey involved detailed modeling of converters with methods such as state space and classical averaging to non-linear techniques such as describing functions and frequency coupling models of converters. And always along the way there was constant measuring of power converter control transfers using different methods. And these measurements were usually surprisingly different to those predicted by the models

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Looking back the first company I worked for controlled power converters with digital control systems and it seems that the mix of digital control, power electronics and control theory and practice has brought me here.

Currently I am enjoying the new and ever increasing interest in digital control of power electronics as a great opportunity to learn more and help deliver new and improved products.

The Surprising Journey

So an explosion and subsequent research into power converter detailed modeling and control with DSP and FPGA is how I end up here. That explosion changed my life. It showed me that the control of converters was going to be something I would need to get a good handle on. This was mainly due to not wanting converters to blow up in my face. This self-preservation has been, and is, one of the big drivers in my interest in controlling power converters.

If you had told me twenty years ago that I would be dealing with the stability of power converters I would have said that was unlikely and that I was destined for management but it seems that is where I am.

So I have been looking at power converter control for twenty years and digital control of power converters for almost as long. I never found a single source of information or wisdom about all this stuff and am still looking for it. I have a feeling that I will not find it but that along the way I am getting closer to where I want to be with my understanding of power converter control.

I am still actively involved in power electronic research at University of Canterbury. This is a great grounding as it constantly reminds me of where I have come from and how much wonder there is in power electronics and power electronics control. Over the years at the University of Canterbury I have worked with some amazing equipment and some even more amazing colleagues. These people have proved to be more inspirational as I have gone along in my journey. I hope that my contribution to the field will be as useful as theirs.

And so I find myself looking back to where it all began for me – third year power electronics at the Univeristy of Canterbury. Thus my journey has come back to where it started. And with this in mind , it's my desire to help work on getting digitally controlled power converters running really well.

If You are Ever in Christchurch, New Zealand

While my power electronics control travels take me far and wide, my favorite place is Diamond Harbour, just outside of Christchurch, New Zealand, where I live with my wife and two daughters. So if you're ever in Christchurch, give me a call or drop by to say hello.

I Want to Hear from You

At ELMG we believe in your success. So if you have any questions, comments or suggestions please let me know. I'd love to hear from you.

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And if we can, we'll take care of it.

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