Adaptive Control of DC-DC Converters with Auto-control™

Adaptive control is an essential and well-established requirement in many kinds of electronic systems, from avionics to robotics and industrial control. The technology has an equally vital role to play in power conversion, providing more precise control, greater system reliability and improved mean time between failures (MTBF) in systems such as computers and networking equipment.

But despite these advantages, most power converters lack adaptive capabilities. Traditional, analog power control systems are completely non-adaptive, employing components such as resistors to implement fixed compensation loops. And even many of the newer digital power conversion products offer little or no real adaptive capabilities.

True adaptivity—the ability to respond on the fly during operation to varying electrical conditions—is still the exception in power conversion. This paper sets out the requirements of an adaptive power conversion system and describes one technology, Powervation’s Auto-control, that achieves these goals.

Adaptive Control in Power Conversion

Control systems in power conversion have two main objectives: to ensure a constant output voltage and deliver a rapid transient response. In other words, controllers must suppress spikes and other deviations from the target voltage, and they must do so as quickly as possible (within microseconds). They must do this in the face of widely varying plant dynamics, due to factors such as step loads in current (i.e., when changing modes or adding/dropping phases), electrical noise, thermal fluctuations and long-term changes in the electrical characteristics of system components due to aging.

In today’s power conversion products, the term “adaptive control” has become something of a misnomer, typically used to describe some form of single-parameter control such as power FET dead-time optimization or control mode switching. In such cases, a tuning algorithm applies a set of predefined rules or formulae to an input signal in order to adjust a process. Examples in DC-DC conversion include phase add and drop in multiphase DC-DC converters, and switching between DCM and CCM control modes at a predefined point. Figure 1 illustrates this sort of “open loop” scheme.

Figure 1 Open Loop Adaptation
This sort of scheme is sometimes described as “adaptive” in conventional DC-DC converters. But note that it has no ability to analyze the actual results of the adjustment and modify parameters accordingly. This “one-size-fits-all” approach typically results in overdesign, with a large margin of safety built in for worst-case scenarios, but sub-optimal performance in other circumstances.

This is certainly true for traditional analog controllers, whose coefficients are implemented by fixed components and are frozen in the system design. But it is also the case for many of the newer digital controllers, despite their claims of adaptivity. These devices may allow some parameter modification—e.g., by permitting designers to interactively set and reset coefficients via a GUI. But these parameters are typically loaded once at bench test or start-up and do not adapt during runtime to changing conditions. For all intents and purposes, the parameters are fixed.

A true adaptive system, on the other hand, has the ability to continuously adjust parameters based on the actual performance of the system at any given time. This closed loop adaptation scheme is shown in Figure 2, where output feedback is applied to the tuning algorithm in order to optimize the process.

A true adaptive control system is thus defined as follows: An adaptive controller is a controller with adjustable parameters and a mechanism for adjusting the parameters in a way which optimizes a measured property of the system.

We are now in a position to offer a meaningful definition of true adaptive control: “An adaptive controller is a controller with adjustable parameters and a mechanism for adjusting the parameters in a way which optimizes a measured property of the system.”
Benefits of True Adaptive Control in Power Conversion

The primary advantages of adaptive control techniques in power converters are better voltage stability and transient response. Simply put, the converter is able to maintain optimal output under all conditions. This, in turn, contributes to better system reliability and longevity (MTBF).

A secondary benefit is engineering efficiency. With traditional, non-adaptive controllers, the designer must derive and specify the control parameters based on a detailed knowledge of the plant dynamics. And since the dynamics depend on the specific system hardware, this time-consuming task must be repeated for every different hardware configuration.

A true adaptive controller, by contrast, automatically calculates optimal parameters during operation to fit the conditions at hand. Rather than analyzing the plant transfer function of particular systems and manually deriving the control parameters, engineers need simply specify the design objectives, such as the closed loop bandwidth in a DC-DC converter. The controller does the rest, computing the necessary coefficients on a case-by-case basis. Designers no longer need any prior knowledge of the plant, and a single controller can be used in a wide variety of applications, delivering superior performance in every circumstance. This simplifies the design process enormously.

Adaptive control can also reduce the cost of system components. In the conventional non-adaptive scenario, the power controller has no ability to adjust and compensate for variations and age-related changes in components. To be on the safe side, designers must therefore choose more expensive hardware with tighter specs. In the adaptive case, on the other hand, system designers are free to choose lower-cost components. The controller can perform any necessary compensation as the components age.

Adaptive DC-DC Converter

To illustrate these principles, consider the DC-DC converter shown in Figure 3.

The controller is represented by its numerator and denominator polynomials, $S$ and $R$, respectively, which specify the zeros and poles of the controller. The transient response of a buck converter can be estimated as the product of the load step current and the peak closed loop output impedance of the converter:

$$V_{\text{trans}} = \Delta I_{\text{load}} \cdot |Z_{\text{out}}|_{\text{max}}$$
In addition, the closed loop output impedance tends to peak in the vicinity of the closed loop bandwidth. In theory, therefore, the transient response can be determined from the expected closed loop bandwidth of the system and the impedance of the output capacitor [1]. However, the closed loop bandwidth of the buck converter is not a simple function of the controller transfer function. It also incorporates the power stage transfer function, which is not known—at least not with any reasonable degree of precision. Hence, designers have no way of choosing optimal parameters in advance.

By contrast, Figure 4 shows an adaptive controller in which the parameters of the plant are estimated by the ‘plant parameter estimation’ block and the controller is designed on the fly by the ‘controller design’ block to meet some pre-determined requirements such as closed loop bandwidth. Using such an arrangement, optimized transient response can be achieved over a wide range of power stage component values and conditions, with the closed loop bandwidth maintained automatically.

**Figure 3**: Representation of a Digitally Controlled Buck Converter

**Figure 4**: Typical adaptive controller
Powervation’s Auto-control™: True Adaptive Control for Power Converters

Adaptive control theory and practice has been well worked out in applications like robotics and process control, and designers have had a very large toolbox to draw upon, from gain scheduling (mode switching), to model reference adaptive systems, to self-tuning regulators and stochastic regulators. But DC-DC power converters present some special challenges. Power control requires a much faster transient response and sample rates (from a few hundred kHz to MHz). And this faster computation must be performed in a smaller silicon area due to space and cost considerations.

To these ends, Powervation has developed Auto-control technology. Auto-control overcomes the limitations of conventional solutions and brings true adaptive control to DC-DC conversion for the first time. Auto-control provides all the benefits of adaptive control described above—full adaptivity, greater robustness, superior performance and ease-of-design—with the speed and low die utilization that power controllers require.

While the details of Auto-control are proprietary, the results are demonstrable. Figure 5 illustrates the transient responses to load steps with various power stage L and C values with fixed control (a), and Auto-control (b). The improved robustness is clear, with much smaller voltage deviation as well as consistent responses despite varying components.

In addition to providing much more precise control over a wider range of conditions, Powervation’s techniques make it easier to implement energy-saving designs such as multi-phase systems. As depicted in Figure 6, the loop gain and bandwidth of a multi-phase DC-DC converter changes dramatically from 1-phase to 2-phase operation, and conventional non-adaptive controllers have a difficult time stabilizing the voltage. By contrast,
Figure 7 shows how the closed loop bandwidth remains constant with Powerversion’s Auto-control technology. This allows energy-efficient design techniques to be implemented in a way which fixed controllers or open-loop adaptive techniques cannot achieve.

![Bode plot](image)

**Figure 6** Bode plot of multiphase buck converter in 2-phase (full line) and 1-phase (dotted line) configuration

![Bode plot](image)

**Figure 7** Bode plot of multiphase buck converter in 2-phase (full line) and 1-phase (dotted line) configuration with Auto-control™
Summary

Adaptive control has become a widely-used term in DC-DC conversion in recent years, but the phrase is often misleading. Most controllers are fixed and cannot adjust their parameters in real time. Some claim to be adaptive and can adjust parameters according to predetermined rules, but, because they don’t monitor the result, the system performance is not optimized.

In this article we have attempted to present a more rigorous definition of adaptive power control, and describe the advantages of the technology for the power industry. By these criteria, Powervasion has developed the first true adaptive control for DC-DC conversion. Powervasion’s Auto-control continuously tunes parameters during operation and deals easily with a wide range of power stage variation and power stage dynamics, such as those seen in power saving modes. The benefits are substantial, and include greater voltage stability, faster transient response and unprecedented ease of design.

References

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