Reducing energy consumption in ICT applications using the Dynamic Bus Voltage architecture

Patrick Le Fevre - April 17, 2013

Dynamic Bus Voltage (DBV) technology is being foreseen as one of the most significant technological breakthroughs for the Information and Communications Technology (ICT) industry. System designers are seeking to reduce energy usage at the board level to make significant reduction in the environmental footprint of their systems at times of both high and low data-traffic demand.

The introduction of low-power-consuming silicon devices alone will not be enough to effectively limit the energy requirements of tomorrow’s network. However, the latest board-power-consumption monitoring and control technologies can significantly aid this mission by enabling energy savings of between 3 and 10 percent at board level with the use of advanced Dynamic Bus Voltage (DBV) architectures. The benefits become increasingly obvious when saving 1W at the board level results in an average saving of 2 to 3W at the system level.

Energy Demand and Environmental Concerns

The world is becoming increasingly dependent upon ICT with demand growing for more online services, faster networking and increased data processing and data storage capabilities. Looking at just one measure of demand, the number of Internet users worldwide has grown significantly over the past few years, passing the one billion mark in 2006, two billion by mid-2011 and more than 2.4 billion users by mid-2012. And there is still considerable room for the expansion of ICT functions for businesses, in national government and local authorities, and society in general, even in the largest well-developed economies.

This demand is driving the growth of ICT equipment in computing-intensive environments, including the setup and expansion of huge datacenters across the world. A strong environmental argument can be made in terms of overall energy usage for all the availability of all this networked processing capability, such as enabling remote working and reducing the need for commuting or travelling, in addition to many other services. But there are still concerns over the direct environmental impact of the fast growing data-processing facilities and infrastructure that drives the ‘cloud’. The European Commission DG INFSO (Directorate General - Information Society) report, published in September 2008, estimated that European telecoms operators had an overall network energy requirement equal
to 14.2TWh in 2005, rising to 21.4TWh in 2010 and reaching 35.8TWh in 2020, assuming there is no adoption of ‘green network technologies’.

The nature of wide-area communications networks involves massive amounts of parallel processing to simultaneously route arbitrary numbers of subscribers and widely varying network traffic levels; and naturally, business and consumers of these services expect almost flawless communications across global networks. As a result, datacom and telecom processing racks will house multiple instances of similar circuit boards - some of which are redundant elements to guard against hardware failures. Each board makes use of leading-edge logic components to meet network throughput and response time requirements, while also maximizing channel count per unit area.

**Intermediate Bus Architecture (IBA)**

Today, the power architecture increasingly being used in the ICT industry is the Intermediate Bus Architecture (IBA), which was adopted as the standard in 2003. The IBA model differs from the classic Distributed Power Architecture (DPA), which typically comprised a number of isolated DC/DC converters on each board that down-convert the -48 VDC line to values that suit the load circuitry, daisy-chaining additional regulators for expediency. While the DPA model may still suit some small-scale applications running from the 24 VDC sources that are popular in some industrial sectors, issues arise with efficiently down-converting -48 VDC to logic supply levels of 3.3 VDC or less in one step. Also, isolated DC/DC converters are intrinsically more expensive and less efficient than non-isolated ones.

The IBA now dominates in telecoms and many other applications that demand high availability, such as MicroTCA where its telecom-developed roots also serve well for small-scale and high-reliability systems such as industrial process control instrumentation. The architecture uses Intermediate Bus Converters (IBCs) to convert a traditional 48 VDC distribution-level power line used in data/telecoms to a typically static 12 VDC. This first ‘down-conversion’ 12V level feeds a number of non-isolated DC/DC Point-of-Load (POL) regulators, which supply the final load voltages at IC logic supply levels of 3V or below (see figure 1).
The use of two down-conversion stages offers the opportunity to achieve optimal balance between the intermediate bus voltage that supplies the POLs and the load currents supplied by the POLs at any particular time. This is absolutely crucial for maximizing power-conversion efficiency at the system level. The choice of 12 VDC was made to ensure high enough voltage to deliver all the power required by the board, or load, in times of high network data traffic. However, this approach becomes highly inefficient when there is low traffic demand.

**Dynamic Bus Voltage**

The Dynamic Bus Voltage is an evolution of the Intermediate Bus Architecture - it provides the ability to dynamically adjust the power envelope to meet load conditions. It achieves this by adjusting the previously fixed 12 VDC intermediate bus voltage via the use of advanced digital power control and optimized hardware - the Advanced Bus Converter - combined with an energy-optimizer series of algorithms. This can lead to a reduction in both energy consumption and power dissipation, which in turn contributes to a reduction in required cooling.

The concept of adjusting the intermediate bus voltage to suit the load requirement was actually first explored in the mid-1990s by using an electronic potentiometer to control an analog DC/DC converter’s output voltage adjustment pin (see figure 2). However, the technology never reached commercial development due to the complexity of accurately optimizing the bus voltage, but it was the trigger for further research into digital power management and control.
Intended for non-static loads, DBV implies the need for tightly coupled supervisory measurement and control and intelligent devices that can operate autonomously or as part of a network. While it is possible to implement these requirements using analog technology, it comes at significant expense in terms of PCB area and component count. Taking the case of a buck converter for example, a digital version substitutes an ADC, numeric reference, adder, and digital filter for the error-amplifier, ramp generator, comparator and latch that the analog system uses to modulate the PWM stream. Internally, the part routes binary information between its circuit elements to perform functions that range from housekeeping tasks to correcting the duty cycle of its PWM stream to maintain accurate output voltage regulation.

In addition, it also becomes cost effective to include a measurement and control system together with a communications interface alongside the DC/DC controller, when implemented in an advanced mixed-signal process technology. Adopting industry-standard PMBus™ protocols enables a simple serial interface to communicate with compatible board-level devices using a standard command language that is specifically designed for power control applications.
The advent of readily available and commercially produced digital power-converter modules allows systems architects to slash implementation complexity while supporting applications that range from standalone to sophisticated systems, each being able to monitor and fine tune their performance in real time – including the value of their intermediate bus voltage.

**DBV in Practice**

The advanced digital converter offers on-the-fly programmability and quickly responds to commands that span simple output-voltage adjustments to complex operations such as trimming the values of the digital filter that characterizes control-loop responses. Using simple PMBus commands to perform complex measurement and control functions, the embedded facilities within a digital controller IC vastly simplify the implementation of applications such as dynamic bus control.

Implementing dynamic bus control in telecoms equipment requires the writing of application code to supervise the system: making judgments regarding when to increase or decrease the intermediate bus voltage with rising and falling load levels. Refining algorithms to make reliable decisions take some effort, as it is can be difficult to visualize the complex series of interactions created by a combination of IBCs and POL regulators.

Before considering the implementation of DBV technology, it is important to validate the potential energy savings by modeling a typical system and verifying that the model is both accurate and reliable in a real application. The starting point involves exercising each IBC and POL in a system over at least the range of input voltages and output currents that it will experience in the end application and recording the power losses that result at each step. Plotting these parameters against one another creates a three-dimensional graphical overview of each device’s performance over the chosen measurement area (see figure 3).
Consisting of the test results at each step, the array of data points that build the graph is also useful as input data for simulation. Evaluating the test results for each IBC and POL using the least-squares-fit approach builds a polynomial model of the corresponding device, which the Simulink environment can import and manipulate. Ericsson has built computer models of systems to explore the performance of alternative control strategies in maximizing the power savings delivered by dynamic bus voltage control, while also ensuring that the system remains unconditionally stable.

One strategy starts by running an algorithm that derives a baseline power loss value. The first control cycle then starts, monitoring relative power loss (see figure 4) until reaching a threshold value that triggers an optimization sequence.

\[ P_{loss} = P_{Load_{HS}} + P_{Load_{LS}} + P_{L_{ESR}} + P_{ripple_{LS}} \]
\[ + P_{ripple_{HS}} + P_{ESR} + P_{switch} \]

This complex algorithm performs numerous iterations but ultimately drives the intermediate bus voltage to a value that minimizes power loss for the present conditions, whereupon the sequence closes. The cycle repeats to minimize power losses within constraints that include hysteresis to ensure stable triggering conditions for the optimization sequence, while also ensuring that the bus voltage does not fall below a level that maintains regulation for the load current profile.

A test system comprising an Advanced Intermediate Bus Converter supplying two 20A and four 40A digital POLs illustrates the efficiency improvement potential that results from dynamically adjusting the intermediate bus level compared with a fixed 12 VDC level. Improvements are estimated at between 3 and 10%, depending on the average load per operation (see figure 5).
Simulation to Application

Simulation and verification demonstrate the potential for saving energy by adjusting the intermediate bus voltage to match load conditions. Although running an onboard energy optimization algorithm is a smart solution for small systems, it may not always be the most appropriate approach for large and complex systems, such as datacenters or radio base stations. However, the concept is impossible to ignore in large systems as the amount of energy saved by DBV adjustment broadly scales with system size.

The question is simply how best to assess and implement the technology in these circumstances. As data traffic levels have a profound effect on power consumption, one promising approach derives DBV levels from traffic flow statistics. In this case, controlling the bus voltage relies on lookup tables that reflect operational scenarios; the basic premise is to reduce the bus voltage with a fall in traffic and raise it again with increased volumes.

As is often the case with these types of approaches, systems architects construct models that help to verify the accuracy of the profiles under consideration while they are compiling the lookup tables, and run a number of iterations that follow the below sequence:
1. Simulate the power consumption that different load conditions create
2. Verify the simulation with hardware tests
3. Validate the simulation model or adjust it to optimize the profile

When the sequence is qualified, the profile is uploaded to the scenario library within a Board Power Manager, which controls the board’s bus voltage, among other possible tasks. Tests then run under best- and worst-case conditions before final implementation.

**Operational Sequence**

Each application will require its own scenarios, but as a simple example outlined below are the operational sequences that can apply in this case study:

- Reference Scenario
  - Compare data traffic with scenario
  - Validate scenario
  - Adjust bus voltage to situation
  - Sense data traffic and compare with traffic in the network’s neighboring cells
  - Anticipate data traffic migrating from cell A to cell B
  - Adjust bus voltage
  - Sense and detect abnormal events
  - (If Yes) Adjust bus voltage to priority High
  - (If No) Adjust to local traffic scenario
  - Repeat the sequence

This sequence continually adjusts the intermediate bus voltage to the optimal level, yet always delivers maximum power as a priority, in case of abnormal events or upon a specific user command.

**Profile Examples**

The following illustrates the value of the intermediate bus voltage relative to the influence that data traffic volumes exert on the power required by the equipment. The first profile corresponds to a normal traffic condition profile, taking into account residential, transit, and business operating hours before returning to lower traffic volumes (see figure 6). The second profile includes an event that demands high volumes of data traffic for a limited period (see figure 7).
Lower power consumption is achieved by adjusting the intermediate bus voltage to suit load.
conditions. In what is known as the ‘power cascading effect,’ every Watt saved at the board level results in an average saving of 2 to 3W at the system level. This ratio depends upon many factors, but is confirmed by users and power experts (see figure 8).

Figure 8 - Power Cascading Effect

A New Era in Energy Optimization

Digital power control and management enables easy dynamic optimization of the voltage delivered by a master DC/DC converter to a series of POL regulators, directly enabling reduced power consumption. Complementing the high efficiency offered by digital core controllers, the ability to optimize converter performance on-the-fly and adjust the intermediate bus voltage to match load conditions are just two of the wide range of opportunities made possible by digital power technology. The dynamic bus voltage is now a reality that represents the arrival of a new era of energy optimization in ICT applications.

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