Power Supply Design with DSPnano

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Overview

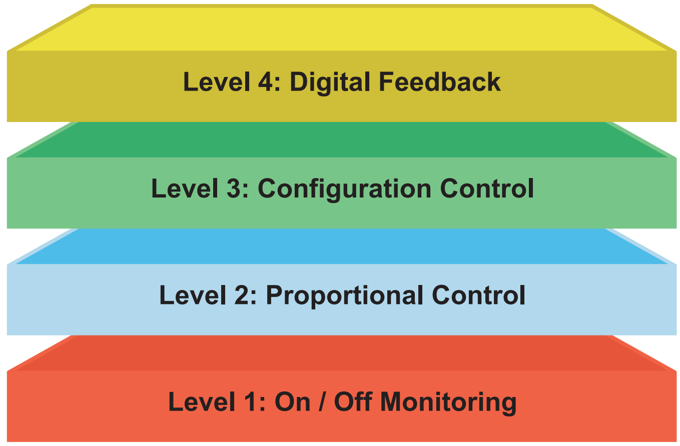


Figure 1: Levels of Switching Mode Power Supply Transformation

Intelligent power supplies are gaining popularity because of a number of concurring needs:

- need for external control
- need for operation monitoring
- need for deterministic behavior
- need to communicate performance information

To fulfill these needs, microcontrollers and digital signal controllers (DSCs) can be used to augment the functionality of traditional power supply designs, or to create radically new designs.

As the level of digital complexity increases in the diagram above from level 1 to level 4, the required computational power increases as does the cost of doing the processing. The power supply designer must look carefully at the requirements for monitoring, external control, determinism, manufacturing ease and digital feedback and design features which will meet these requirements as well as the business goals of the producer. Overall, the designer should be aware that by increasing processor cost many analog components can be eliminated, resulting in a much lower total cost.

This document first describes the types of power supplies that you could implement and which are most desirable or fit best with modern trends in power supply design including:

- reduced weight
- reduced size
- increased efficiency
- increased sequencing
- greater external control
- greater reliability
- improved lower cost manufacturing

After this section will be a section which discusses the various approaches to power supply design and the main strengths and weaknesses of each. Then a discussion of the four main digital power supply architectures will take place. This is followed by a discussion of hardware and software implementation for these supplies.

Types of Switching Power Supplies (SMPS)

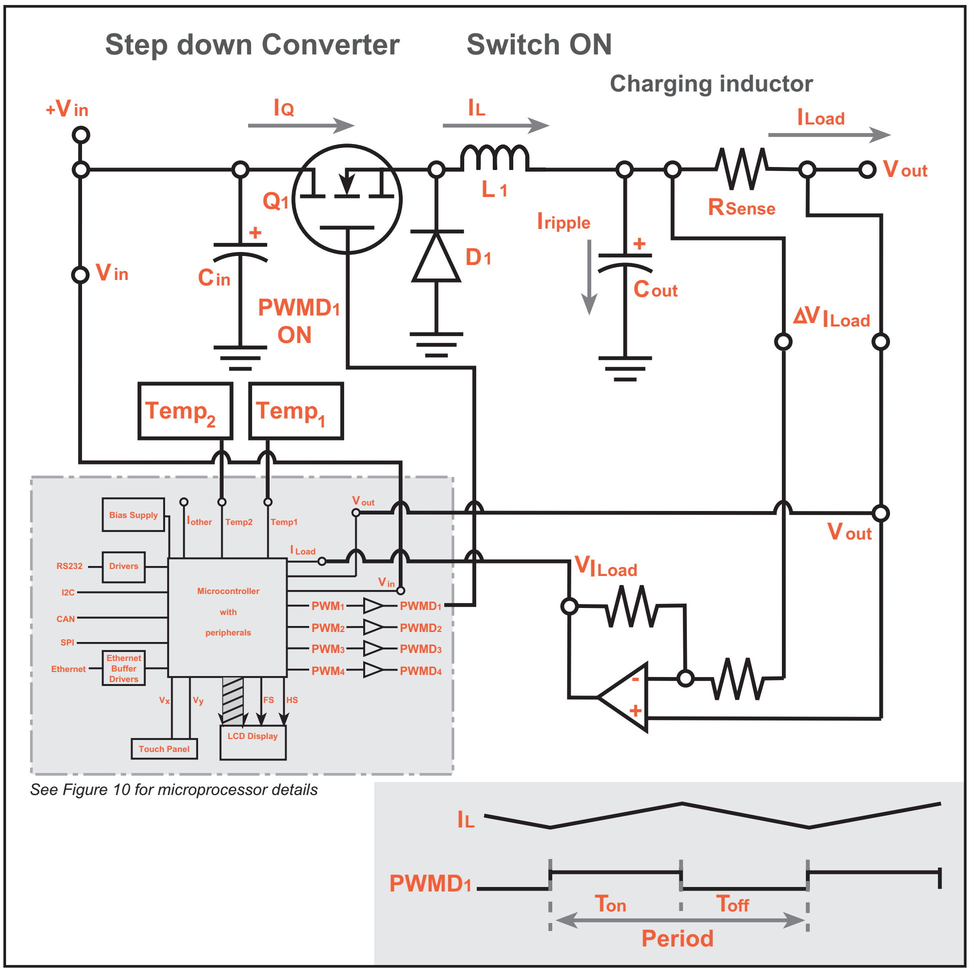
Any of the following topologies of power supplies, either DC to DC or AC to DC can be used with any of the four control schemes discussed above. Furthermore, the trade offs for these supplies are different because the fully digital supply generally offers lower cost with the highest performance. It does represent a step away from the traditional analog design though.

DC-DC Converters

Buck or step down converters are the most common and one with full digital control is shown in figure 2. They operate in continuous mode with constant current flow through inductor. The ratio of input to output voltage is given as:

- Vout = Vin * Duty Cycle
- Duty Cycle = Ton/(Ton + Toff)

Figure 2: Buck DC to DC Converters



Boost or step up converters have more ripple current compared to buck converters and therefore require a larger output capacitor. The ratio of Vout to Vin is given by:

- Vout = Vin / (1-Duty Cycle)

In this case, the Duty Cycle must be less than 0.8 to avoid saturation of the core.

Figure 3:
Boost DC to DC Converters

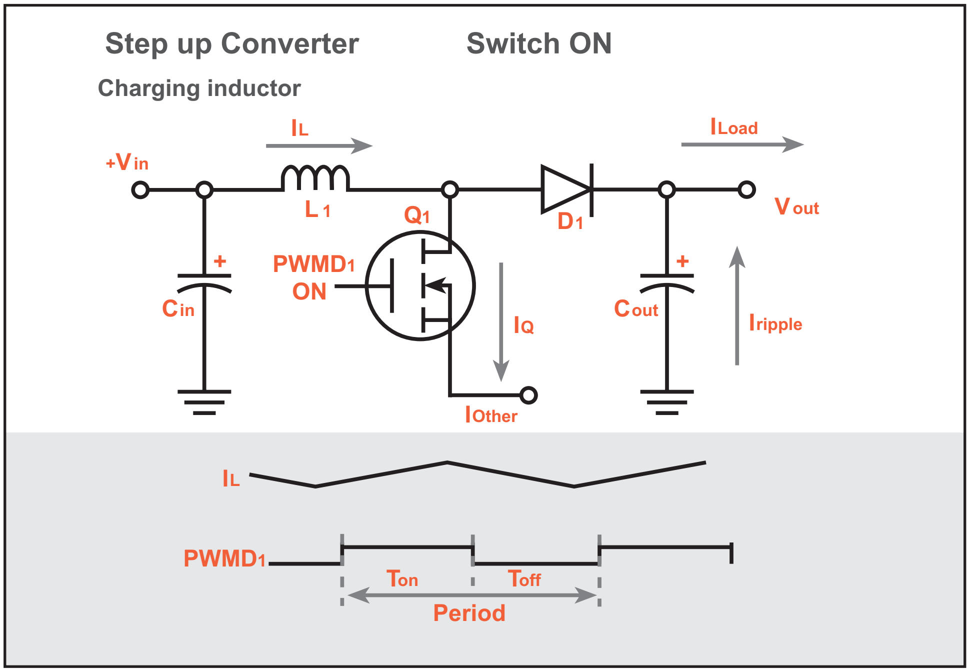


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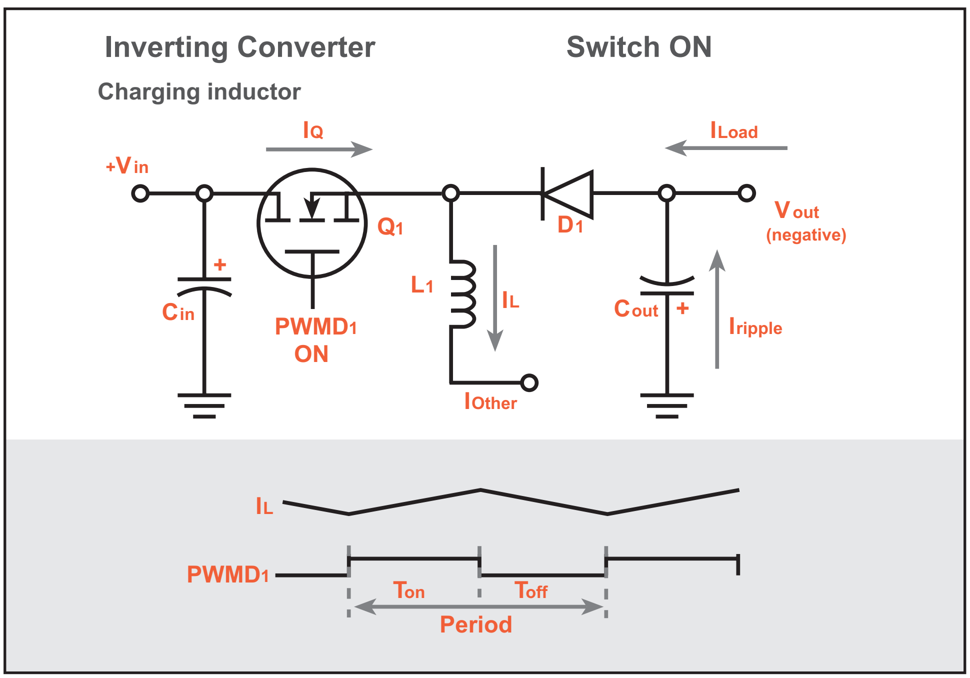
Figure 4:
Buck Boost DC to DC Converters

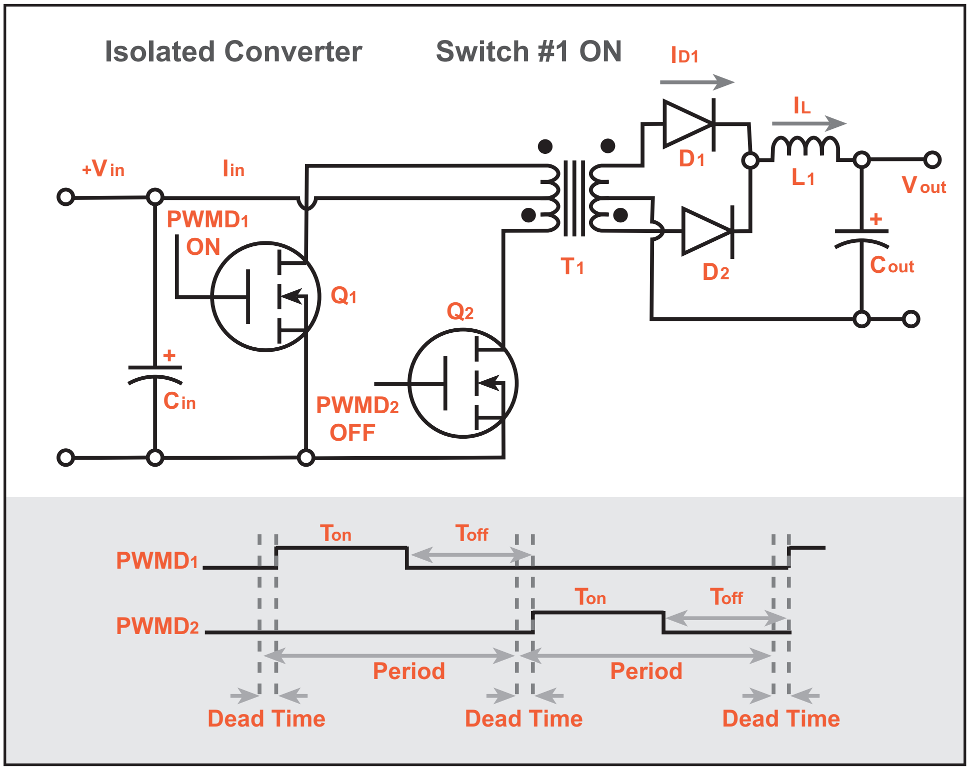


Buck-Boost converters combine both features of a buck converter and a boost converter. In this configuration, a negative output voltage generated. It is capable of handling a wider range of input voltages with a constant output voltage, or a wider set of output voltages with fixed input voltage.

- Vout = -Vin * DutyCycle /(1-DutyCycle)

In this design, inductor current must fall to zero to avoid long term core saturation which makes it a discontinuous mode of operation with a DutyCycle less than 0.8.

Figure 5:
Push Pull DC to DC Converters



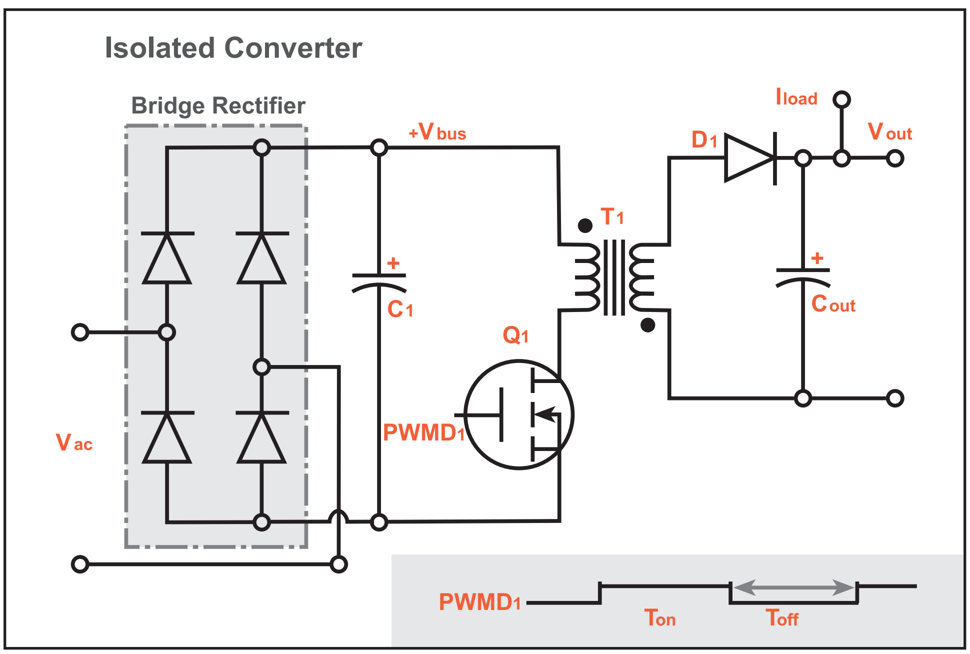
Push-Pull converters allow any input to output voltage ratio with any polarity.

- Vout = Vin * DutyCycle * Ns/Np (secondary winding turns/primary turns)

Transformer provides isolation which is good but the transformer is more costly as well.

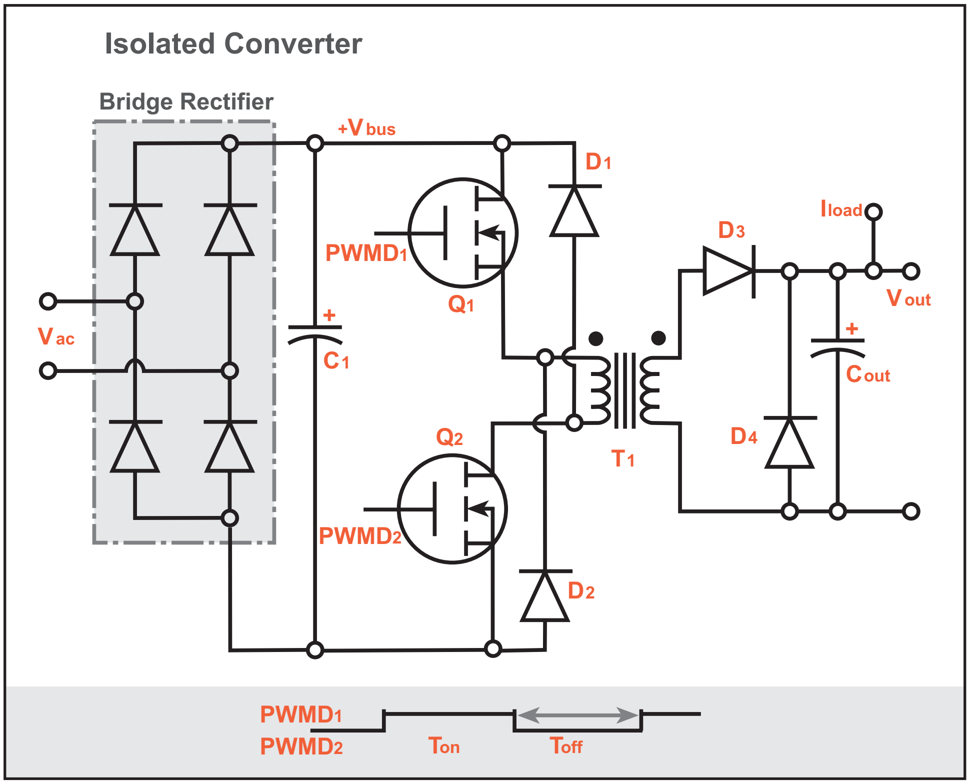
AC-DC Converters

Figure 6:
FlyBack AC to DC Converters



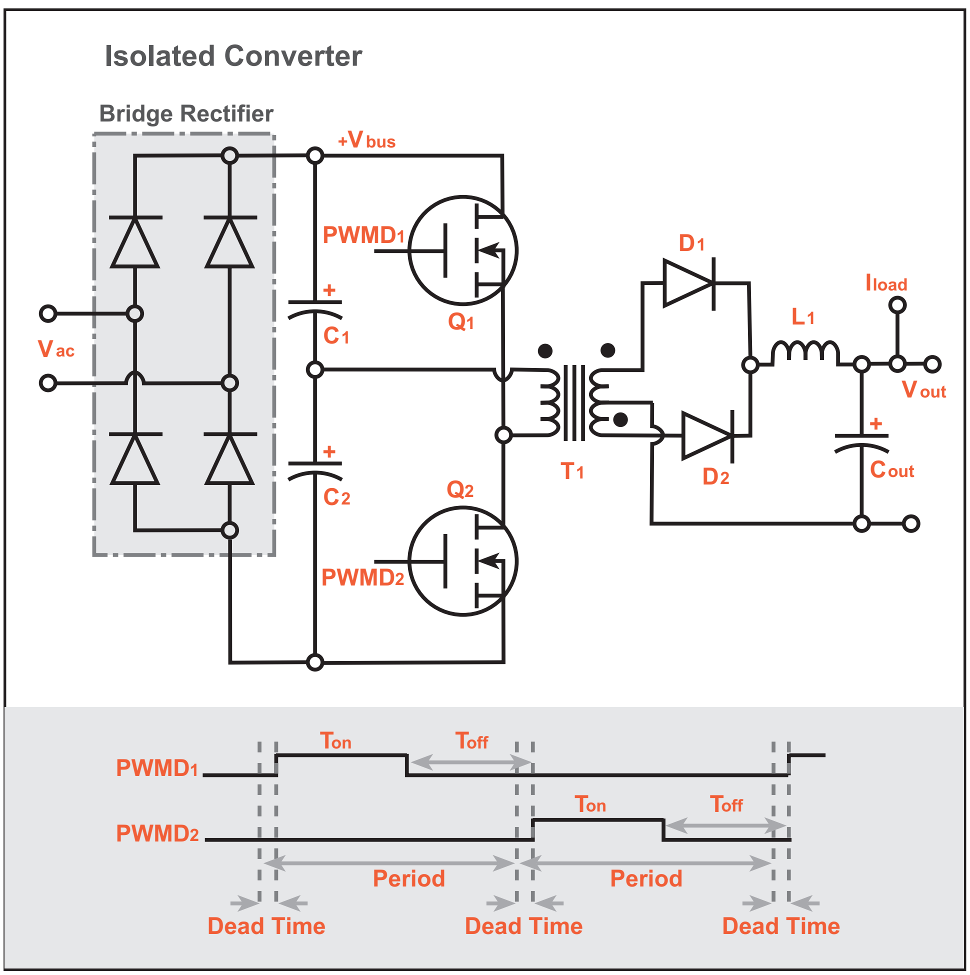
Forward Converters are used in the 100-200W range. The offer great reliability. In the diagram, you see two transistors which are switched together. The transformer is used for both storage and transfer. The efficiency of these units is high (typical SMPS efficiencies are 85% to 95%). Their weakness is that they are sensitive to flux imbalance and generally use current control to deal with this.

Figure 7:
Forward AC to DC
Converters



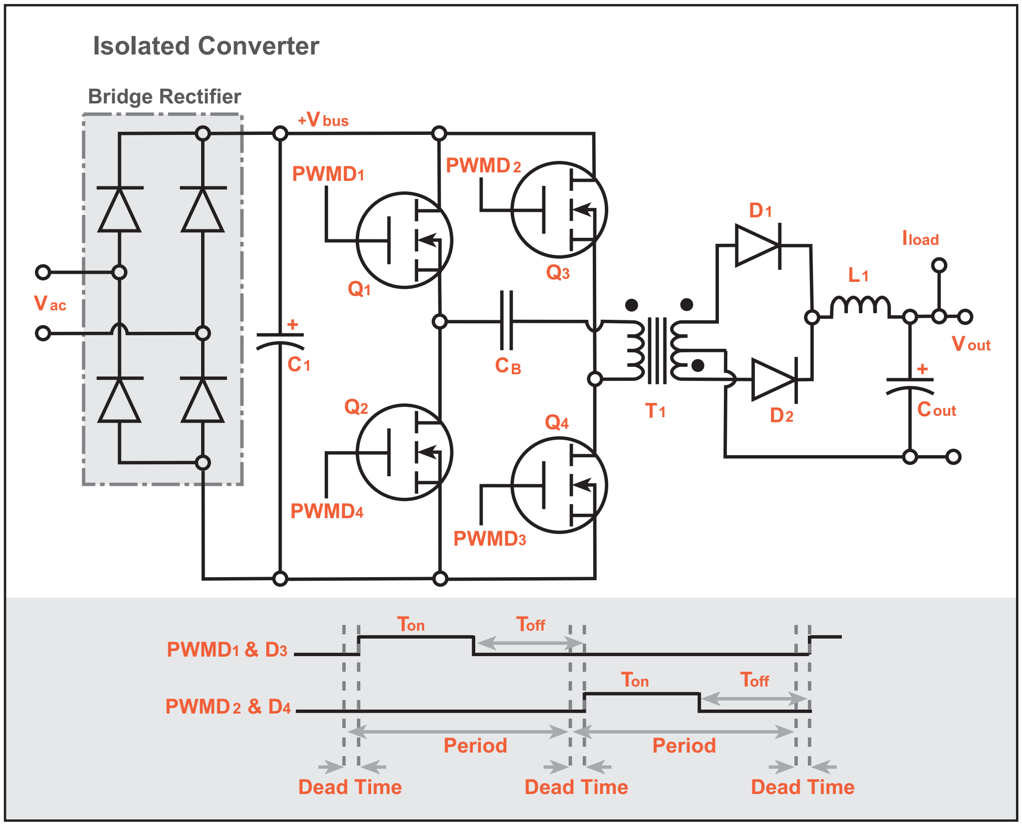
Push Pull converters were traditionally used in the 150-300W but now they are not often used.

Figure 8:
Half Bridge
AC to DC
Converters



Half Bridge converters are used from 150-500W with a full range of duty cycle from zero to 1. With this design smaller cores are possible and flux imbalance is minimized through the addition of two capacitors. They do require dead time to avoid shoot through.

Figure 9: Full Bridge AC to DC Converters



Full Bridge designs are used for larger applications and can be used from 500W to greater than1KW. This design choice offers:

- duty cycles full range
- high core utilization high
- minimal flux imbalance
- reliability

To achieve these features, it needs dead time control and sequential PWM. It is a common design choice.

Level 1: Augmenting Analog Supply

The feature set of an analog SMPS can be augmented with a micro controller or controllers to provide the following additional software based functions:

- Startup sequencing of many supplies
- Soft start control of PWM
- Status monitoring

Typically small micro controllers are used for this purpose (i.e. Pic12).

In this environment, a single loop of control is likely enough. The software is quite simple and detailed software knowledge is not required.

Level 2: Control of Analog Supply

By putting the micro controller into the loop and letting it control the actual supply output allows it to provide PI control of the output. Bigger controllers are used for this and often temperature compensation is included in the controller. A pic 18 or 24 is an example of what might be used.

As the supply gets more sophisticated, a greater need for other features arises too, which allows designers to consider an RTOS based approach for these supplies if a PIC24 was used for example.

Level 3: Reconfiguration

By giving the supply dynamic reconfiguration capabilities, the ability to completely replace or change loop filters for example, it is possible to build supplies with level 1 and 2 features as well as the ability to respond to a range of loads. Operation from zero to full load is possible with a supply like this.

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Processors like the pic24 and dspic 30 are used in these cases.

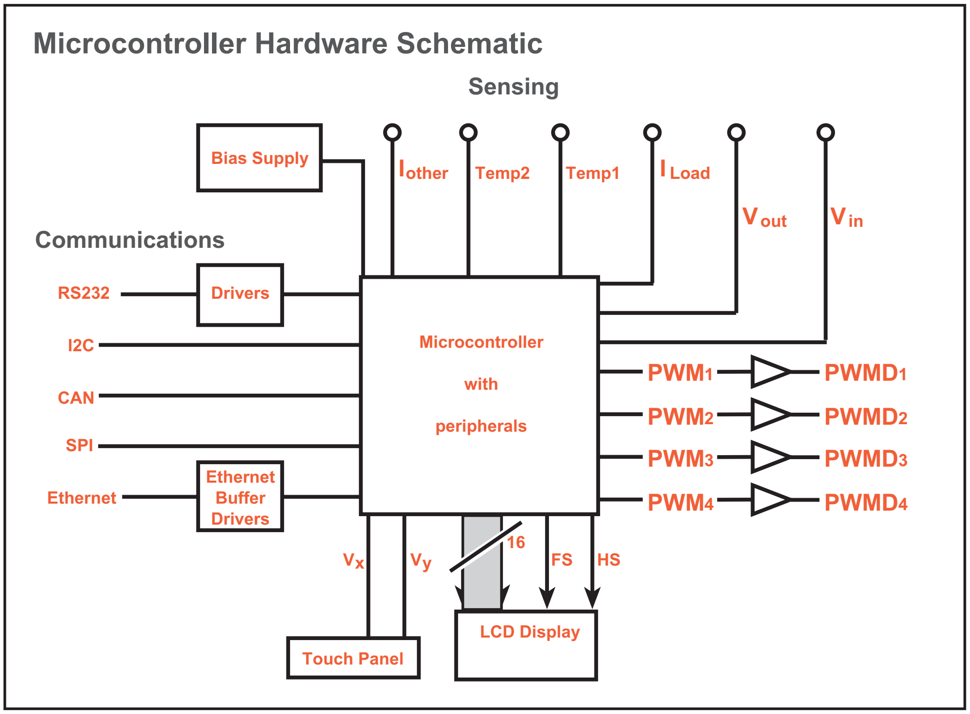
Level 4: Full Digital Supply

A full digital supply is most desirable for fully featured supplies, lean product development reasons and to reduce overall cost, particularly if the loop is slow. In these designs, the micro controller:

- Replaces all analog feedback,
- Supports non linear systems
- Provides all features of level 1, 2, 3 designs,
- Provides programmable loop control based on load
- And offers feed forward mechanisms from a priori information to speed response.

These supplies require higher end digital signal controllers or dsps like dsPIC 30 or 33. The higher the performance demands (or the shorter the loop time), the greater the processing power required is. Note how the signals in Figure 10 (next page) relate to the previous architectual diagrams.

Figure 10: Microcontroller Hardware Architecture



Software Features

For each of these different supply architectures, we have a software architecture that is different and yet the same. Generally, as the level of control goes up and the PWM frequency goes up then the greater the control sophistication and the greater computation is required. At the monitoring end of things, a low end micro controller (i.e. pic12) with interrupt driven response is generally all that is required. At the higher end, a full digital signal controller (i.e. dsPIC) is required to do the fast communication, fast computation and provide the high quality AD converter.

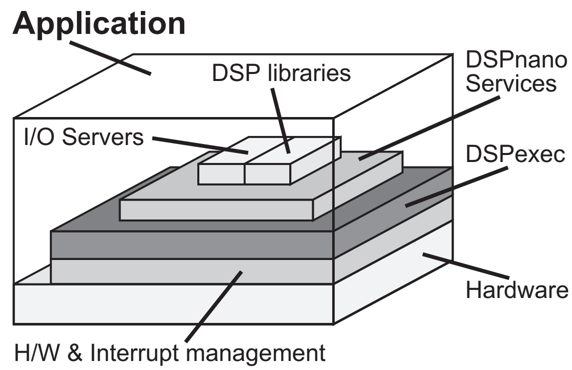
A range of features can be implemented in software for the overall control of the power supply. On lower end controllers it can be done with interrupts and a single loop of control or even just a single loop of control at the very low end. At the higher end, things are greatly simplified with a real-time operating system like DSPnano.

The basic power supply functions can be broken down into several categories:

- Deterministic functions which happen the same way each time (including local front panel).
- Self correcting functions which allow the power supply to compensate for environmental change.
- Remote control and communication functions
- Safety features
- Diagnostics

The details of these functions are given below, but the essence of the approach is to break each function out into multiple threads and then have a modular architecture for the supply that can be reused across projects without significant development or retesting, slashing time to market and eliminating all software risks.

Figure 11: DSPnano Software Architecture



DSPnano Software Architecture supports tiny POSIX implementations with specialized DSP features to ensure minimal time to market and maximum ease of use.

The list of typical functions for the supply are given below. There may be other functions depending on your application. These functions are dependent upon the topology of the supply chosen and the level of digital control required.

- Deterministic Functions
  - Generating a sequence of events
    - soft start
    - start sequencing
    - restart on error
    - LCD display
  - Recognizing events
    - Predicting failures
    - Advanced power down
    - Data logging
    - Retry limits
    - Touch panel input
- Remote control functions
  - Output voltage
  - Current limit
  - Shutdown sequencing
  - Coordinated actions for multiple supplies
- Remote reporting functions
  - Current, voltage, temperature
  - Calculated values like efficiency, power and power factor
- Self correcting functions
  - Temperature compensation of voltage reference
  - Calibrated output value
  - Temperature driven current limits
  - Current driven feedback selection (hysteresis limits)
- Safety Features
  - Watch dog timer
  - Brown out control
  - Low voltage detection
  - Oscillator fault
  - Diagnostics

Software Features

Continued

Some proponents of supply control software would advocate that the functions listed above be interrupt driven and one main loop be used to provide the remainder of the functions. We would recommend a more systems oriented approach that is better suited to lean product development, allowing many similar supplies to be built quickly and easily at lower cost with higher quality.

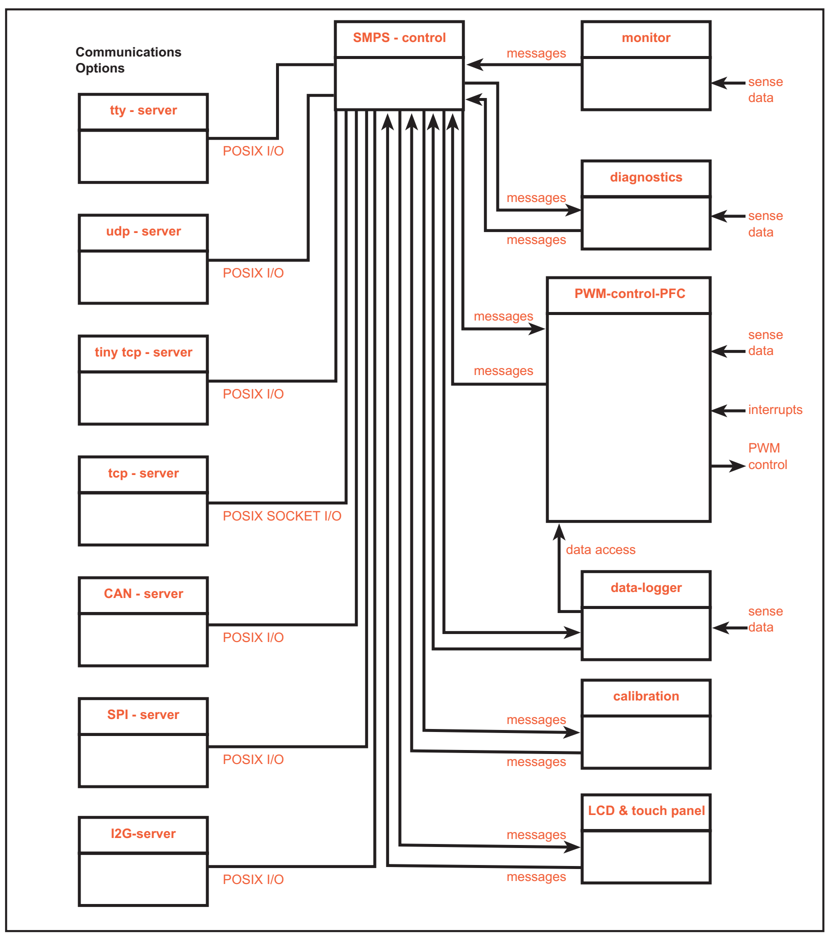
RTOS Based Software Architecture

An RTOS has a few major advantages that make it superior for power supply product development, particularly if you are developing multiple supplies for different purposes. The main advantages are:

- modular approach which eliminates retesting and rework
- independent off the shelf communication servers
- off the shelf timer support
- integrated development tools
- synchronization ability
- nested interrupt capability
- resource management
- standards based to eliminate training

With this RTOS approach, threads can be developed to provide specific features. For example, all diagnostics could be provided in one thread and only used for those designs which have the space and need for these diagnostics. The overall architecture of DSPnano which provides these features is shown in figure 11 and the software architecture is provided in figure 12.

Figure 12: Power Supply Software Architecture



RTOS Based Software Architecture

Continued

The other main advantage of the thread based approach is that it supports nested interrupts without special coding and allows most of the functionality to be moved from the interrupt service routines into the threads where resources can be more easily be controlled. The net result is a better time response of the system.

In such a system, the main piece of the control is done by a PID loop implemented in a thread which monitors voltage and maybe current in some applications and computes new PWM parameters. Depending on the power supply this thread will control the configuration of the PWM outputs to drive the various transistors and/or gate drivers in the design. Different conditional compilation or completely different selectable threads can be used to provide a broad set of configurations to the power supply designer as off the shelf modules.

Various state machines, self correcting features, advanced power down and soft start features could be included with this thread to provide a diverse set of features. The limitations of such a system are small, allowing complete reconfiguration by the designer to meet a broad spectrum of power supply topologies and features discussed herein.

Another selectable thread will be the I/O module. A broad set of off the shelf I/O is available and by using an RTOS based design the user could easily select between uart, spi, tcp/ip/ethernet, usb, can and i2c without changes to their application program. All would be done with minimal resource requirements and standard I/O interfaces.

Another additional and optional thread could be an LCD display. Standard high level C calls could be used to open the device, write to the display and close the device. Status updates could be provided. Additional features could provide touch sensitive operation and menu systems for user interaction.
With a full range of communication possible with this supply and other supplies. Startup sequencing becomes a matter of timely communication between the various supplies using one of the standard I/O servers or another mechanism that the designer chooses.

Other modular thread based features include data logging, predictive maintenance and failure, power factor correction, and power and efficiency calculations. Of course, all related information can be easily communicated to other supplies and overall controllers in the system – one of the biggest benefits of an integrated power supply system.

Also diagnostics and safety features can be added both within modules and in separate threads. This allows the designer to easily configure supplies to make a range of features available easily with full line pricing. Because features are almost entirely software based, simply adding memory (depending on the feature) and changing a configuration is enough to extend the design and provide greater benefits to the customers.

References:

1.Microchip Technologies Inc., Introduction to Switch Mode Power Supplies, Bill Hutchings 2006

2.RoweBots Research Inc. DSPnano RTOS Version 2, Tutorial Guide 2007

Summary

Switch mode power supply has changed dramatically over the past decade. Today, advanced fully digital power supplies with tiny real-time operating systems like DSPnano offer the most modular, lean product development based approach to supply design and maintenance. Modular features eliminate testing, and fit with full line supply development with software based features rather than hardware based features.

