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Taking Energy Efficiency to the Next Level

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Energy efficiency as a design goal opens new market opportunities; the omnipresent microcontroller has evolved to hit the green button and system cost targets simultaneously.

The time has come for environmental consciousness. Global warming, rising energy prices, and unacceptable thermal footprints have evolved from topics of conversation to causes for action. More than ever before, consumers are paying attention to energy ratings and showing a strong interest in alternative technologies such as hybrid vehicles, "green" white goods and LED lighting.

In a "from the top down" approach, governments around the world are tightening electronic design criteria by enacting ever more stringent regulations -- turning what used to be "nice to have" features into design imperatives.

In addition to the ultimate prize of a more inhabitable planet, the green movement is also creating a cornucopia of electronic design opportunities in nascent applications such as solar and wind power, hybrid vehicles, and LED lighting. But green also means radically improving the efficiency of familiar applications such as motors, white goods, and appliances.

This paper focuses on energy efficiency advancements in three innovative areas: solar micro-inverters, LED street lighting, and battery management for hybrid automobiles.

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1 Real-time Control Brings Efficiency to Cost-sensitive Applications

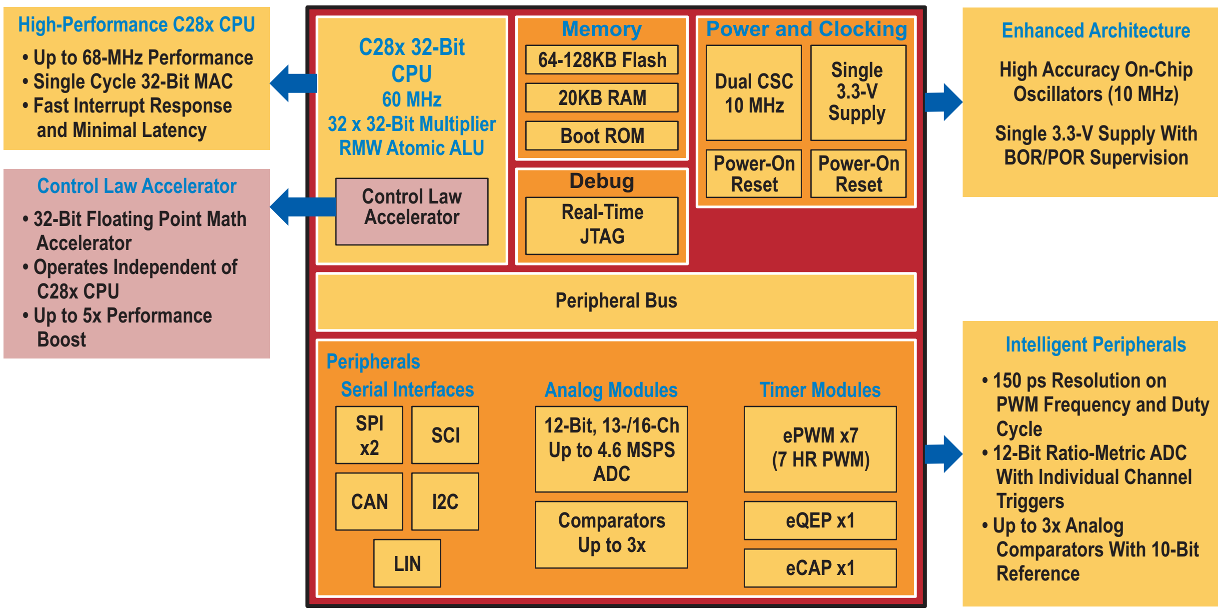
TMS320C2000™ microcontrollers have realized market success in bringing energy efficiency to a wide range of industrial and white-goods design by executing sophisticated algorithms such as field-oriented control of three-phase ac motor at reasonable cost. TI’s TMS320F2802x/F2803x Piccolo™ microcontrollers take energy efficiency to the next level by raising the level of integration while simultaneously reducing both the chip and system bill-of-materials (BOM) cost.

Piccolo devices retain the powerful the 32-bit TMS320C28x™ central processing unit (CPU), which makes computation-intensive control algorithms more efficient. Peripherals such as the enhanced pulse width modulator (ePWM) support the industry's highest resolution with frequency and duty cycle resolution down to 150 pico seconds. The on-chip, 12-bit ADC operates up to 4.6 MSPS and includes powerful triggering mechanisms. TMS320F2802x devices scale up to 64K bytes of embedded Flash and 12K bytes of RAM and are available in 38-pin TSSOP or 48-pin LQFP packages.

TMS320F2803x devices offer 60-MHz performance plus a new control law accelerator (CLA), a 32-bit floating-point,software-programmable math accelerator that operates independently of the C28x™ CPU. The CLA is designed to run complex, high-speed control algorithms allowing the main CPU to handle I/O and feedback loop metrics resulting in up to five times increased performance for some real-time control applications.

The combination of 32-bit performance, enhanced peripherals and small package size allows designers to add real-time control and system management with a single Piccolo microcontroller.

Figure 1. TMS320F2803x Block Diagram



2 Solar - Powering the future

Solar panels offer the opportunity to tap into a limitless energy source and contribute to national energy self-sufficiency. The solar inverter is a critical component of an entire solar energy system. It performs the conversion of the variable dc output of the PV cells into a clean sinusoidal 50-Hz or 60-Hz voltage source suitable for supplying the commercial electrical grid or local electrical network.

Impressive progress has been made to date improving the materials that convert solar energy to electrical power. Equally important, however, are the challenges of maximizing the efficiency of the overall system.

2.1 The Challenge

Solar energy systems must transform a highly variable dc power source – the sun may be obscured by clouds, shadows or weather conditions – into a well-regulated ac source that will not play havoc with sensitive electronic equipment. Improving the dc-to-ac energy cycle is a critical design opportunity for optimizing efficiency.

Real-time microcontrollers effectively execute the very precise algorithms required to charge the battery of the system and provide power to the electrical grid without power losses – thus executing the system at its maximum power point. The drive of the main bridge of the dc/ac is performed by highly flexible pulse-width modulator (PWM) peripherals of the controller.

There are also several use scenarios that require sophisticated control. Fault projection must be built in, for example, to guard against events such as brown outs and blackouts on the public electricity grid. When batteries are incorporated in the system, additional dc-dc or ac-dc conversion is necessary for battery charging and efficient battery management and monitoring are also required.

The algorithmic capability in particular is a tall order for an inexpensive controller because in addition to typical control functions, it requires the chip to deliver very high-performance computing power. Texas Instruments' 32-bit real-time microcontrollers in the TMS320C2000™ platform offer the microcontrollers for a wide range of solar applications. For more information, see: http://focus.ti.com/docs/solution/folders/print/349.html.

2.2 Micro-inverters

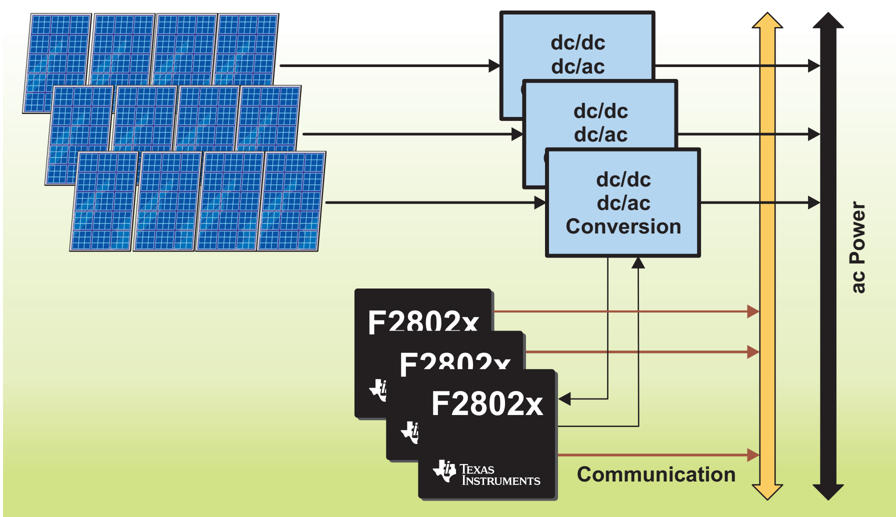
A relatively new option for optimizing solar system efficiency is to use a micro-inverter for each individual solar panel, instead of using a single inverter for the entire system. The chief benefit of the micro-inverter topology is that the system will continue to convert energy even when one inverter malfunctions.

Each panel having its own micro-inverter has other important benefits as well, including the ability to adjust conversion parameters on each panel using a high resolution PWM. Clouds, shadows and other environmental conditions can vary the output of individual panels. Equipping each panel with its own micro-inverter allows the system to accommodate its changing load, which provides optimal conversion efficiency for both the individual panels and the entire system.

Micro-inverter architectures also enable simpler wiring, which translates into lower installation costs. Panel and system monitoring is also improved. Large solar panel farms, in particular, require subsystems to communicate with each other to keep loads in balance and plan in advance how much power will be available and what to do with it. On-chip peripherals (SPI, UART, etc) simplify interfacing with other micro-inverters in the solar array.

Although solar power has taken center stage, power generation from wind turbines will also contribute to the alternative energy mix. This technology has many of the same electronic control challenges as solar and can enjoy many of the same benefits of technological advancements that the solar industry has seen.

Figure 2. Efficient Power Conversion for Solar Micro-inverters



2.3 Managing Cost

Cost is a concern whenever an architectural change is considered. To meet system price targets, having a controller for each panel means the silicon must be cost competitive, in a relatively small form factor, but still capable of handling the full range of control, communication, and computational tasks simultaneously. Integrating the right mix of control peripherals on-chip as well as key analog integration is essential to keeping system cost low. High-performance is also critical in order to execute the algorithms that have been developed to optimize efficiency at every step of the conversion, system monitoring, and storage process.

3 LEDs Light the Way

Just as solar panels are challenging conventional power generation technologies for the good of the planet, LEDs provide a promising alternative to compete with today's dominant incandescent and fluorescent technologies. LED technology provides brighter lamps that are also more energy efficient and have a longer life than either incandescent or fluorescent lamps.

According to a 2008 study prepared by Robert Grow, Director of Government Relations for the Greater Washington Board of Trade, the ten largest metropolitan areas in the U.S. could reduce annual carbon dioxide emissions by 1.2 million metric tons – the equivalent of taking 212,000 vehicles off the road – and save $90 million a year by switching to more efficient lighting such as LED or intelligent streetlight networks for their roads.

However, as with any application, there are a few design issues to be resolved. LEDs run on dc power and from a design perspective they're more than a little temperamental. Light output of LEDs is proportional to the current going through them, which means the control system must be able to provide constant current within tight tolerances.

On the other hand, the voltage drop of LEDs varies with temperature. This coupled with the fact that they need a constant current to avoid self-destruction has created a problem called "thermal runaway." When transistor junction temperature increases, current at a given voltage increases and this adds heat to the junction. If nothing limits the current, the junction will fail. The death spiral can accelerate quickly so definitive, sensitive control is needed, which typically requires sensing of the temperature and real-time adjustment of the supply voltage.

Since LEDs are by nature small, many must be assembled to make a single lamp. Most topologies use strings of LEDs in series. The control system must deal with individual bulb failure so as not to disable the entire system. And since LEDs need a dc supply, the control system must be cost effectively integrated with the ac/dc conversion stage.

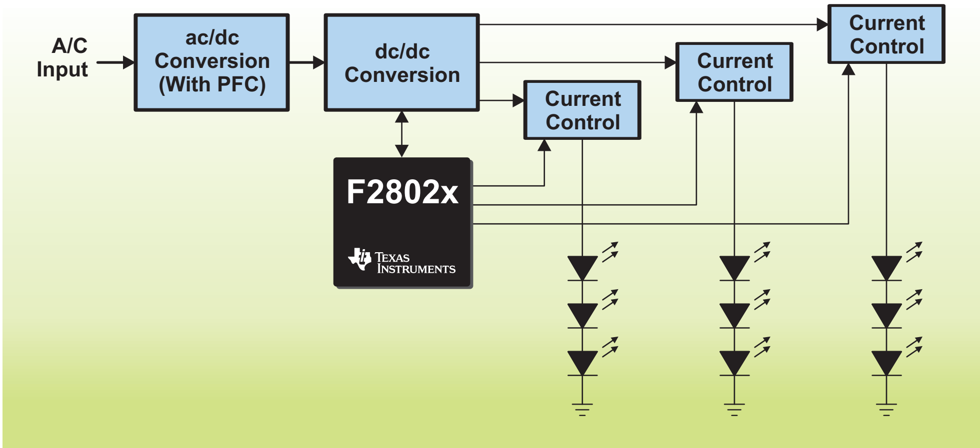
For applications such as street lighting and building lighting, multiple light sources often must be controlled in a coordinated way to produce illumination to the right spots or generate the desired lighting effect at the right time. Therefore, the control for each individual lighting unit must be able to communicate with another unit or the central control and monitoring station.

Design trifecta: To accomplish the design trifecta of tight, real-time current control, communication, and ac/dc conversion cost effectively, a single controller doing all the work would be preferred.

Piccolo microcontrollers also offer the performance and integration to implement power line communications (PLC) for street light networks that allow cities to pinpoint power outages and centrally manage and adjust lighting based on time of day, traffic or weather conditions. TMS320F2802x/F2803x microcontrollers' control optimized peripheral set and its high-performance 32-bit core can accurately and simultaneously control the power stage and the LED lighting.

The high-performance 32-bit TMS320C28x core contributes by running several complex control loops in real time. The high-resolution PWMs -- 150 pico-seconds resolution -- and a multichannel,12-bit ADC achieve precise lighting control. These robust peripherals also allow Piccolo microcontrollers to run low data rate PLC protocols. On-chip communication peripherals offer several options for communicating with the external system.

Figure 3. Intelligent Digital Control in One MCU for Commercial LED Lighting



4 Battery-management

Renewable energy generation from solar and wind often include short-term energy storage in batteries. Batteries are also critical to up-and-coming applications such as hybrid vehicles and uninterruptible power systems (UPS). Maximizing efficiency in charge/discharge cycles and other conversion characteristics will help make green power generation economically competitive and, in the case of UPS and hybrids, waste a smaller percentage of generated energy when it is consumed.

UPS systems have many of the characteristics of battery-based systems. There are several topologies -- and the most energy efficient option requires the highest level of control. Online UPS, in which the power supply constantly supplies ac power to the load, is emerging as a superior source of clean ac power compared to earlier "offline" systems that would only switch on when a power loss was detected.

4.1 Triple Conversion Cycle

One of the most common online topologies is the triple conversion cycle in which (1) ac is converted to dc, which (2) charges batteries which (3) drive a dc-to-ac converter. This delivers clean output ac power regardless of variations in the input and eliminates the need to switch to backup power and all of the transient problems that go along with hot plugging.

Triple conversion requires three power stages, however, and in a conventional design each stage had its own control system and analog controller. Since the system must monitor for potential outages and decide when to switch to backup power, most UPS systems include a supervisory microcontroller. Online UPS systems occupy the high end of the UPS market so they must provide reliable, clean ac output regardless of conditions such as temperature and age. As a result, triple conversion UPS systems tend to be difficult to design and expensive to build.

The drawbacks of conventional designs can be avoided by using digital control in which a controller, analog peripherals, and serial communications peripherals are integrated into a single chip such as those in TI's C2000™ microcontroller platform. This reduces parts count, complexity, and cost, of course, but these are not the most compelling reasons for adopting digital control for UPS systems.

4.2 32-bit Intelligence

By adding 32-bit computational intelligence, digital control gives the system the ability to detect and compensate for drift, aging, and temperature of components. This results in more accurate control in a wide variety of situations, which in turn, makes the system more energy efficient over its lifetime.

The C2000 microcontroller platform’s 32-bit, real-time computational intelligence is powerful enough to implement the advanced digital techniques such as voltage ripple notch filtering that delivers superior power factor correction (PFC) performance than an analog system. Because a single CPU can control the entire system, digital control also delivers better dynamic response at a system level. Finally, UPS reliability is enhanced because the system can be designed with advanced failure prediction that responds to problems before they happen.

Piccolo microcontrollers extend the benefits even further by offering more memory and peripheral options at a reduced cost. In addition to the F2802x/F2803x features and peripherals previously mentioned, F2803x devices offer 64-128KB embedded Flash, 64-pin and 80-pin configurations and CAN, LIN, and AECQ100 qualification for automotive applications.

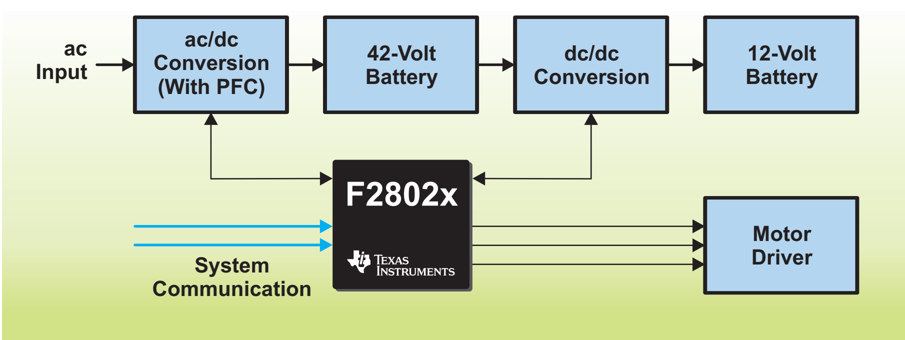
4.3 Hybrid Vehicles

Although the battery technology of hybrid vehicles is typically implemented on a much larger scale than most UPS systems, the control challenges are much the same: ac-to-dc and dc-to-ac conversion; battery charging; and, the ability to accommodate power delivered from the internal combustion engine, which is working in tandem with the electric motor. Accurate control of the motor and battery are essential to delivering fully on the promise of hybrid vehicles, which is better fuel economy, lower carbon emissions, and a greener transportation economy.

Hybrids and all-electric vehicles, UPS systems, industrial motors, white goods and even some handheld appliances can be designed to be more efficient with microcontrollers from TI's C2000 microcontrollers. In addition to its 32-bit real-time computing power, the Piccolo microcontroller series delivers a spectrum of features that enable digital control to be realized easily and cost effectively. To support multi-stage control, the microcontrollers integrate multiple independent PWM peripherals that allow it to control the ac/dc conversion stage, battery charging stage, and dc/ac stage.

The PWM peripherals deliver a maximum resolution of 150 ps. An on-chip 12-bit, 16-channel ADC samples at up to 4.6 mega samples per second. Together, the PWM and ADC peripherals enable the design of very accurate UPS systems. Communication peripherals such as SPI, I2C, and UART give C2000 microcontrollers the ability to communicate inside and outside of the complex, multi-part systems. On-chip flash and RAM memories allow for large program code and variable storage space to support the software needed for triple conversion system control.

Figure 4. Enabling Cost-effective Advanced Electrical Architectures for Hybrid Vehicles



5 Conclusion

The world is going green and this means new challenges and opportunities for designers who think innovatively and execute cost effectively. New applications such as hybrid vehicles, solar and wind power, and LED lighting attract the spotlight but increasing the power efficiencies of motors, battery management systems, and converters will be equally rewarded by the marketplace. Texas Instruments is doing its part to enable energy-efficient designs of the future with a wide selection of products led by its C2000™ microcontroller family and the associated Piccolo microcontrollers that take energy efficient design to the next level by offering 32-bit real-time control in a microcontroller package and price.

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