CogniPower is committed to building better, more efficient power products by re-examining accepted wisdom regarding power converters in the light of new control technology, improved components, new semiconductor process technologies, and changing economics driven by energy cost and availability.

Our robust and growing patent portfolio will be the basis for fundamental improvements in how effectively and efficiently power is transformed and used, in other words, "***power smarter***."

History

Spun off from Lawson Labs Inc. ("LLI") in 2009, CogniPower is an independent company specializing in power conversion and power management technology. CogniPower was established to develop a new, more efficient, and agile approach to power conversion which was initially envisioned by LLI. The collaboration with LLI leverages LLI's 30 years' experience designing and producing high-performance electronic instrumentation. CogniPower has developed industry-changing technology that can dramatically improve the performance and efficiency of power converters, while reducing their size and cost.

Because power conversion is a requirement of almost any device that produces, stores, or consumes electricity, CogniPower's technology can increase efficiency and reduce costs across many industries. Between generation and final use, power is converted many times; consequently, the benefits of CogniPower technology can multiply. The superior agility and flexibility of CogniPower's technology enables equipment to run faster and more reliably, and to waste less energy as heat.

Our technology, embodied in our patents and patents pending, can do more than incrementally improve the performance and efficiency of power converters. Even larger efficiency gains can be achieved by eliminating entire stages of power conversion. This transformative technology can be used to cut wasted power by half in some applications, and can provide substantial performance benefits in powering almost any electronic equipment.

Markets: AC/DC Converters

AC/DC converters are the most common form of power converters. CogniPower offers three patented technologies for different power ranges of AC/DC converters.

The first category is power supplies under 65 watts, which are generally simple flyback converters. A mobile device charger is a typical application. CogniPower holds patents covering superior control of this category of power converter that provide extremely low standby power and high efficiency at low loads. International standards bodies are increasingly tightening these requirements while conventional chargers are nearing their practical efficiency limits. While the amount of power saved by any one charger over its life may be small, in the aggregate, billions of inefficient chargers in daily use waste huge amounts of energy.

The second category is for AC/DC converters up to about 200 watts that require Power Factor Correction (PFC). These include supplies for laptops, flat-screen displays, and office equipment. CogniPower's Compound Converter topology is a proven success for lowering cost, shrinking size, improving efficiency, and achieving better PFC performance for power converters in this category. The key to this patented technology is blending the PFC stage with the output regulation stage. An entire transformer is eliminated in the process. The largest source of increased efficiency in the Compound Converter is that the majority of power moves through only a single stage of power conversion, providing a 25% efficiency advantage at the start, even before other improvements.

The third category is AC/DC conversion over about 100 watts, when the forward converter topology is preferred. CogniPower has modified the Compound Converter architecture to work in the forward converter topology, and it offers the same set of advantages for PFC, size, cost, and efficiency. These higher power converters are particularly well suited for the latest generation of GaN advanced power switches.

In all three cases, CogniPower power converter control loops can run faster than conventional controls. That allows the use of physically smaller transformers and filter capacitors. In some situations, failure-prone electrolytic capacitors can be entirely eliminated at those higher switching frequencies. Transient response is uniformly excellent. Again, in all cases, most of the control intelligence resides on the isolated side of the power converter where it is available for convenient interfacing with digital controls.

Markets: GaN Switching

Power switching semiconductors have improved dramatically over the last twenty years, but the switch drivers that operate them have lagged behind. By now, switch drivers have become a limiting factor holding back further improvements in switched mode power applications, especially for HEMT switches. CogniPower has developed proprietary technology to enable faster switching.

CogniPower switch drivers reduce switching losses by providing higher peak gate drive currents than conventional switch drivers. Faster edge rates require exemplary control of circuit parasitics, particularly inductance, to limit overshoot and to control radiated interference (EMI). The totem pole switch with drivers that we have demonstrated used the previous generation of silicon switches. It had only 150 pH of stray inductance, which allowed the totem pole to handle one kW at several MHz while remaining cool to the touch. This demo system takes advantage of gate capacitance to help speed up switch operation. In the normal case, gate capacitance only slows operation. The benefits of more precise switching extend beyond reduced switching losses.

Faster transitions combined with tighter timing control enable the reduction of totem pole switch dead time. That, in turn, both eliminates the need for wasteful snubbers and reduces voltage stress. Efficient delivery of gate charge reduces heat generation. Well controlled output waveforms eliminate the need for oversized switches, which are otherwise needed to survive voltage spikes and ringing. All of the above contribute to increasing efficiency and reducing operating temperatures. Lower operating temperatures reduce the cooling load and increase reliability. Additional bonuses: size, cost, and EMI are also reduced.

Newer HEMT switches in low-inductance packaging are capable of operating 10 to 50 times faster than silicon FETs. Our switch drivers can support those speeds. Power converters operating at higher frequencies use physically smaller inductors and filter capacitors, saving cost and space. As power converters continue to shrink, the effects of stray inductance and capacitance are reduced, producing even more ideal behavior. In some cases, electrolytic capacitors can be entirely eliminated, and with them goes a major source of failures.

One more thing is required to make faster power converters practical: faster controls. CogniPower's Predictive Energy Balancing controls can operate at over 20 MHz, more than fast enough to take best advantage of today's fastest HEMT switches. Ask us about high frequency magnetics and engineered broadband filters to complete your high speed power converter designs.

Markets: Renewable Energy

CogniPower has developed new technology for efficient power conversion that closely follows the underlying physics. The result is a generalized, flexible set of controls that are intrinsically stable over a very wide range of operating conditions. In contrast, conventional power converter controls are conditionally stable, and are tuned for a particular application operating under a limited set of circumstances. When faced with a new set of requirements, they require a comprehensive re-analysis in order to achieve acceptable levels of stability. Their behavior is always a trade-off between agility and stability. These concerns limit the performance of power converters, especially for applications like renewable energy, where the range of operating conditions tends to vary much more than for line-powered devices. Because power

converters employing CogniPower's unconditionally stable controls don't need to compromise between performance and stability, they can accommodate operating conditions which have proven impractical for those attempting to use conventional power management methods.

CogniPower converters can offer an extra degree of control, for example, allowing AC to AC conversion for wind generators, or panel-by-panel maximum power point tracking for solar panels. Often wind generators suffer accelerated wear due to vibration. The customary way to deal with vibration is to use oversized bearings. Extra weight high off the ground requires extra structural strength in the tower, further increasing installed cost. Some of the force causing the damaging vibrations is created by the generation of the electricity itself. However, CogniPower power converters can be modulated to damp vibration while still producing the desired output, given a local capacitor for short-term energy storage. The input current waveform shape could even be adjusted dynamically to minimize vibration under prevailing conditions. The result will be maximum reliability and service life with lower initial cost.

CogniPower controls run seamlessly from near zero load to maximum load. That enables excellent low-load efficiency while avoiding the complications and disruptions caused by the normal approach, which is switching in and out of a burst mode. CogniPower's smoother operation can help turbines generate power economically in lighter winds, or can extend the productive day for solar panels. Smoother operation also reduces stresses and improves reliability.

Markets: Electric Vehicles

Electric Vehicles (EVs) and Hybrids (HEVs) are an application where the agility, bidirectionality and universality of CogniPower's switched mode power controls are particularly valuable. Electric Vehicles require the ability to move AC or DC power to or from multiple sources based on driver inputs that can change quickly and unpredictably. Usually, a number of unidirectional power converters each do part of the job. However, harnessing multiple power converters to work in concert is challenging because they tend to interact in complex, and sometimes contrary, ways.

CogniPower controls' distinctive design allows a single power converter to do the job of two conventional converters. Advantages include not only improved performance and efficiency, but also smaller size and lighter weight. Those reductions offer double value by increasing the performance and range of the vehicle. When a single, bidirectional CogniPower converter replaces multiple conventional converters, the increase in efficiency means less waste heat to remove, and this simplifies design and increases reliability.

Because EVs rely on emerging technology, there are few unalterable aspects of power train design. Therefore, a new battery technology may become practical at any time. New switching semiconductor technologies like GaN and SiC are increasingly attractive. CogniPower flexible power switching technology will adapt more easily to the evolving requirements of an EV power system. Conventional converters can stand in the way of incorporating improved technology.

EV chargers are another area that can benefit from CogniPower technology. Our Compound Converter topology enables smoother, more efficient charging. Again, the largest single advantage is gained by removing an entire stage of power conversion when compared to conventional chargers. And again, removing that extra power stage reduces size, cost and complexity. Also, an extra degree of control allows for maintaining more optimal conditions for the battery during charging. That added controllability both maximizes vehicle range, and, maximizes the service life of the battery system.

CogniPower has seventeen issued patents and eight pending patents covering the underlying technologies required.

Markets: LED Lighting

Low wattage, unisolated LED lighting is a cost-driven technology. Several CogniPower patents cover techniques for simply and directly converting AC input voltage to a regulated voltage or current suitable for LED lighting. These extremely simple techniques take advantage of improved controls to eliminate the need for extra magnetics and switching devices. The efficiency gained, and the removal of unneeded components, reduce the amount

of waste heat, which allows higher wattage lighting to run without exposed heat sinks. That enables simpler, less expensive, unisolated circuitry to serve for higher wattage applications.

For higher wattage lighting that does require isolation, Power Factor Correction is also needed. CogniPower's Compound Converter topology is a proven success for lowering cost, shrinking size, improving efficiency, and achieving better PFC performance. The key to this simpler topology is blending the PFC stage with the output regulation stage. An entire transformer is eliminated in the process. The largest source of increased efficiency in the Compound Converter is that the majority of power moves through only a single stage of power conversion, providing a 25% efficiency advantage.

Heat is the enemy of reliability in LED lighting. A 25% efficiency improvement makes a huge difference in the amount of cooling needed to maintain safe operating temperatures. Also, CogniPower control loops can run faster than conventional controls. That allows the use of physically smaller magnetics and filter capacitors. Failure-prone electrolytic capacitors can be entirely eliminated at higher switching frequencies.

The agility and flexibility of our control mechanisms allows a greater range of input voltages, output currents, dimming ratios, and more flexibility in the number of LEDs that can be placed in series. For more sophisticated systems, the digital nature of our controls makes them convenient for intelligent feedback for the regulation of color and intensity and to accommodate LED manufacturing differences, aging effects and temperature changes.

CogniPower Patents - Summary Technical Description

Updated March, 2016

1. **Patent 7642758,** filed 11/6/2006 in the Patent and Trademark office in Washington, D.C.; issued 1/5/2010. **Power Conversion Regulator with Predictive Energy Balancing**. An international patent application in the European Union, **EP1920532**, is in the process of issuing. A Korean patent issued as **10-1333218** on 11/20/2013.

The first patent application covers predictive energy balancing for switched mode power converter (SMPC) control. The principle of energy prediction is covered in the broadest possible terms in the allowed claims. In essence, the inductor is energized until it holds enough energy to balance the energy deficit at the load. The regulation decision, made during an individual control cycle, is based on the predicted state at the end of that control cycle. In so doing, the filter pole created by the output filter capacitor is effectively removed from the feedback loop. That removes the tendency toward oscillation shown by conventional controls, and eliminates the need to compromise between stability and responsiveness. Controllers according to this invention can be built as analog or digital circuitry. The main advantage enabled by prediction is intrinsic stability, which leads to superior agility, flexibility, transient response, efficiency, and reliability. The broadest claims were allowed in the first issued patent. We refiled for the disallowed claims and they issued in their entirety as **patent 7965064** on June 21, 2011.

2. **Patent 7492221**, filed 11/6/2006 in the Patent and Trademark Office, Washington, D.C.; issued 2/17/2009. **Power Conversion Regulator with Exponentiating Feedback Loop**

This patent covers analogous improvements in analog circuits. It applies to analog power regulators and to amplifiers, in general. These devices can be made faster and more stable without increasing their cost by using exponential feedback. Shaping feedback to match the energy equations instead of according to linear voltage differences allows faster settling at a given gain. Using this technique, amplifier compensation becomes a much easier task. In addition to three-terminal regulators, power amplifiers, buffers and drivers can be improved using this technique. The principle is general and the claims are broad.

3. **Patent 7786709**, filed 3/5/07 in the Patent and Trademark Office in Washington, D.C.; issued 8/31/10. **Bi-polar Bi-directional Energy Balancing Power-Conversion Engine.**

The third patent includes a number of related inventions. It was split by the Patent Office into five patents. The broadest 15 claims are included in the first issued patent. The first divisional of the four split patents issued as **Patent 8698462** on 4/15/2014. A continuation for the rest of the IP has been filed as **14/185144**. This group of patents covers means to build and control bi-directional, bipolar SMPCs. These define a new product category. Also covered here are several novel topologies for better SMPCs, and novel control strategies, some not requiring prediction. This work was done in anticipation of possible future attempts to circumvent the advantages protected in the first CogniPower patent. Other claims in this patent cover improved SMPC circuit protection methods, improved ways to control SMPCs that cross from discontinuous to continuous mode, adaptive control techniques that increase efficiency, and means for using recirculation in a switched inductor to aid regulation. Some of these novel converters can recover reactive energy from the load in order to achieve even greater efficiency.

4. Patent 8004344, filed 12/15/08 in the Patent and Trademark Office in Washington, D.C.; issued 8/23/2011. **Gate Charge Retaining Switch**

The fourth patent covers improved controls for the switches used in SMPCs. Faster, more precise control of switches is possible using the novel technique covered here. The bistable nature of a FET or IGBT is used to aid in faster switching with more precise timing. The gate of a power switch can be allowed to float for a brief period before being switched to the other state. Taking advantage of that bistability during the crucial periods enables lower latency and faster switch transitions, enabling higher efficiency. These improved switch controls can be used to advantage in any power switching application. We have built and tested five generations of these devices. The most basic claims were found to have been anticipated in the prior art, but claims covering important details required for implementation were granted.

5. Patent 8134347 B2, filed 1/24/2008 in the Patent and Trademark Office in Washington, D.C.; issued 3/13/2012. **Apparatus and Method for Recycling the Energy from Load Capacitance**

This patent covers the basic principle of recovering reactive energy from a load when cycling power. Its main application is seen to be computer power supplies, though the technique could eventually migrate to almost any power converter. The basis for energy savings here is that circuitry need only be fully powered for the actual time that it is performing useful work. With capacitive energy recovery, circuitry can be turned off or powered at a minimum level for state preservation without unproductively dissipating the energy stored in filter and load capacitance.

Inrush currents are high during power-up because filter and load capacitance needs to be charged, and a significant amount of energy is required. The normal way to deal with inrush currents is to slowly ramp voltage at power-up. That requirement limits the possibilities for saving energy by powering-up on demand, and powering-down during idle periods. Instead, a POL converter with local storage can supply energy at power-up to charge filter and load

capacitance quickly from its local storage reservoir. At power-down, such a POL converter can draw that filter and load capacitive energy back into local storage. Circuitry that is now left ON constantly, but is only sometimes used, could be efficiently powered up and down as needed. Substantial amounts of power can be saved in the process. At the cost of the ability to handle higher peak currents, much lower average power can be achieved. The small additional POL cost can be mitigated by reducing the size of heat sinks and fans.

6. Patent 8698540, filed 4/3/08 in the Patent and Trademark Office in Washington, D.C.; issued 4/15/2014. **DC Common Mode Level Shifter**

The sixth patent application covers CogniPower's improved method of monitoring current in SMPCs. The technique allows fast and accurate measurement of current even in the difficult electrical environment found inside SMPCs. The same principle can be applied to amplifiers, particularly those that must tolerate extreme voltages. Other applications include high-energy physics, power generation and smart grid monitoring. CogniPower's CP10 Current Probe is based on this patent. The underlying principle is to use a commutated common mode choke to level-shift a small differential signal in the presence of large, fast-slewing common mode voltages. The special value of this method is that its common mode rejection increases with common mode frequency, while conventional differential amplifiers rapidly loose CMR at higher frequencies.

The use of a common mode choke as a level shifter has many unexplored applications. One application that we have explored is for driving high-side switches. Patent 8, below, covers that particular case.

7. Patent 8570008 filed 11/18/10 in the Patent and Trademark Office in Washington, D.C.; issued October 29, 2013. **ENERGY PREDICTIVE BUCK CONVERTER**

This patent covers simple ways to add predictive energy balancing control to conventional buck converters. These controllers can be based on volt-time product, eliminating the need for fast and accurate current sensing. Predictive controls can recover more smoothly from disruptions and avoid the tendency toward destructive runaway.

8. Patent 8823420 filed 11/23/10 in the Patent and Trademark Office in Washington, D.C.; issued September 2, 2014, **SWITCH WITH COMMON-MODE CHOKE**; publication date, May 26, 2011

This application application has been allowed, and the issue fees have been paid. It combines Patents 4 and 6 to make a new class of switch driver. This method of driving a FET or IGBT switch allows superior timing, in particular, for the high side switch in a totem pole. It is faster and more precise than prior art methods. Dead time can be held to a few nS without the need for closed-loop adaptive dead time control. CogniPower's APEC 2010 Presentation describes this method in detail.

9. Patent 8552697 filed 1/28/11 in the Patent and Trademark Office in Washington, D.C.**;** Issued October 10, 2013. **UNIVERSAL SINGLE-STAGE POWER CONVERTER WITH PFC CAPABILITY**

This patent shows how extensions of the first and third patents can be used to move power efficiently between multiple ports by making choices on a cycle by cycle basis. The minimum topology requires six switches and includes an input port, an output port and a storage port. Because the current in a switched inductor cannot change instantaneously, to be completely opportunistic, a power converter must be able to perform any energy transfer with any magnitude and polarity of switched inductor current flowing at the start of a chopping cycle. The addition of a few extra switches enables complete flexibility. Once such a set of rules is in place, energy need only move from the best source to the best destination during any given cycle, with no limitations imposed by previous behavior or past assumptions.

Another benefit of such a structure and set of controls is that multiple control loops can be closed through the same switched inductor using time multiplexing. In the power factor correction (PFC) case, the input current is regulated independently of the output voltage. A slower, non-critical loop controls the average energy moved into or out of storage. One cycle's worth of energy for storage capacity is sufficient for PFC applications. By incorporating larger storage capacity, UPS functionality is achieved.

A conventional AC to DC system would include a bridge rectifier, a boost PFC converter, a buck converter, and an additional switching stage to incorporate the storage. All of the above can be replaced with a single stage converter according to this invention, using only one switched inductor, and fewer switching elements than the usual combination of conventional stages. Since the inefficiencies of series-connected power stages multiply, employing only a single power conversion stage provides substantial efficiency gains.

10. Patent 9036376 filed 11/14/11 in the Patent and Trademark Office in Washington, D.C.**; COMPOUND POWER CONVERTER for EFFICIENT POWER FACTOR CORRECTION; EU Patent EP2748918**. EU issue date, March 4, 2015. US issue date, May 19, 2015.

These are the enabling patents for a new topology family of PFC switched mode power converters. Conventionally, converters for these applications use two stages of power conversion in series. The compound converter moves power through only one stage of power conversion where possible, and uses a second supplemental power conversion stage when necessary and/or desirable. This topology offers advantages for regulation, efficiency, flexibility, size and cost. It lends itself to more efficient Power Factor Correction, to uninterruptible power supply applications, and to applications requiring redundancy for reliability. This topology adapts to multi-output supplies, bipolar supplies, to AC-AC conversion and to power amplifiers. Applications include laptop-style AC-DC converters, LED lighting, and bus converters. While disruptive in some ways, this patent is directed at drop-in replacement power supplies for AC-to-DC conversion. Recently, we have found

applications for this technology in DC/DC converters that benefit from input current regulation.

11. Patent 8493893 B2 filed 12/29/11 in the Patent and Trademark Office in Washington, D.C.**; SINGLE-TRANSFORMER FULL-DUPLEX DIGITAL ISOLATOR;** issued July 23, 2013

A new method for sending bidirectional digital information through a single transformer isolator is described. This technique was developed for IGBT switch drivers where status information must be sent back across an isolation barrier from the IGBT to the controller. Existing products can send information in both directions, but not at the same time. The conventional method requires "collision avoidance" logic and forces blind periods when information can not be transmitted. This new method allows data to pass simultaneously in opposite directions through the same transformer. Commercial digital isolators for the purpose use two transformers, one for each direction of data flow. By eliminating one transformer, coupling capacitance across the isolation barrier is minimized. Size and cost also benefit.

12. Patent 9071152 filed 7/3/12 in the Patent and Trademark Office in Washington, D.C.**; POWER CONVERTER with DEMAND PULSE ISOLATION;** issued May 19, 2015

This patent describes a new form of AC-DC converter control particularly suited for wall adapters or battery chargers. It is adapted for low cost, small size, and better efficiency. Improved feedback for regulation does not require an optocoupler. Filter capacitors can be much smaller than those needed in conventional converters, allowing the use of ceramic capacitors instead of bulky electrolytic capacitors or expensive tantalum capacitors. Unloaded wall adapter power consumption has been reduced to just a few milliwatts. The same control approach provides benefits in much higher power supplies, as well.

13. Patent Application US2014/011206 filed 1/14/13 in the Patent and Trademark Office in Washington, D.C.**; FLYBACK AMPLIFIER with DIRECT FEEDBACK**; **WIPO WO/2014/110474,** publication date, July 17, 2014

Bidirectional Predictive Energy Balancing Flyback Converters suited for power amplifiers and audio amplifiers are described here. These are Predictive Energy Balancing power converters reduced to their simplest form. Topologies that have been of little value in the past become capable when equipped with agile controls. One particular target application is a cell phone audio amplifier for piezo speakers. AC motor drive is another application. The first 10 claims of this application have been ruled allowable.

14. Patent Application 14/598582 filed 2/18/14 in the Patent and Trademark Office in Washington, D.C.**; EFFICIENT INDUCTORLESS AC/DC CONVERTER**. This patent is in the process of issuing.

This patent application shows an inductorless AC/DC technique capable of 98% efficiency. It is well suited for producing a mains side regulated power supply in isolated AC/DC converters. That supply might power control circuitry and switch drive circuits. This technique could also be valuable for LED lighting applications, as well as for other low power applications where cost is paramount.

15. Patent Application 14/711869 filed 7/28/14 in the Patent and Trademark Office in Washington, D.C.**; AC INPUT POWER CONVERTER WITH MULTI-FUNCTIONAL INDUCTOR**. International applications are pending.

This patent application shows a family of new topologies for single-stage power converters with PFC. Output is well-regulated DC or AC. Outputs can be bipolar and/or bidirectional. The uniting principle is an extension of the Compound Converter, #10 above, and can also take advantage of elements of #1, 2, 9, 12, & 13. These topologies are simple, yet flexible. More function is obtained from fewer circuit elements for better efficiency and lower cost. Forward and blended Forward/Flyback forms are scalable to arbitrarily high power levels.

16. Provisional Patent Application filed 7/1/15 in the Patent and Trademark Office in Washington, D.C.**; FAST SETTLING CIRCUIT FOR DRIVING REACTIVE LOADS** (unpublished)

This patent application covers a new technique to speed the settling of amplifiers and buffers driving capacitive or inductive loads.

As of March 2015 there are 16 patents issued, 2 issuing and with 7 more pending.

The intellectual property described here is owned by CogniPower, LLC.

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