A New Digital “Powerdigm:”
Digital Power Conditioning Systems
for Commercial/Industrial Facilities

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Executive Summary

Momentary power interruptions cost U.S. businesses at least $60 billion annually. Methods of protecting against these interruptions, including uninterruptible power supplies (UPSs), are energy inefficient, impose high capital and maintenance costs, and are outside the core competency of most commercial and industrial users. Many digital loads are also sensitive to temporary voltage sags. Static var compensation (SVC), which is often used to address these sags, does not respond fast enough to provide effective protection for sensitive digital loads. This white paper describes the primary recommended attributes of an alternative to UPSs and SVC to provide high-reliability, high-quality power. It also describes potential applications, summarizes one commercial offering in this area, and highlights sample implementations of this technology. The sample commercial system is an optimal, efficient solution for protecting digital loads against power interruptions and voltage dips, and is available as a value-added service with no need to purchase, lease, operate, or maintain equipment. The solution represents a paradigm shift in how power can be managed to protect sensitive, critical, or high energy consuming loads – a “powerdigm” shift. The intended audiences for this paper include commercial and industrial companies that seek to better protect their electric equipment, devices, and systems from momentary power interruptions and voltage sags, as well as electric utility managers who can consider offering an optimal digital power conditioning service to their customers.

The Challenge: The High Cost of High Quality Power

Momentary power interruptions – very short interruptions of electric power – are a major challenge for many sensitive and critical electric loads. Equipment in data centers and microprocessor-controlled manufacturing facilities are two examples of electric loads that can be damaged and/or disrupted by these power interruptions – with consequent high costs. According to preliminary results of a Lawrence Berkeley National Laboratory (LBNL) national assessment, momentary power interruptions cost U.S. businesses approximately $60 billion annually. These costs represent more than one-half of total outage costs (including sustained outages) in the United States [1]. To put this into perspective, the cost rivals some of the most destructive hurricanes to impact the U.S.; according to the National Oceanic and Atmospheric Administration (NOAA), the cost of Hurricane Sandy for example was more than $70 billion [2].

The LBNL preliminary results also indicate an upward trend in total outage costs since their earlier study in 2006 [1]. This is likely due to the increasing use of microprocessor-based manufacturing systems, growth in data centers, and growth in other sensitive loads that require high-reliability, high-quality electric power. For example, according to another 2016 LBNL report, annual U.S. data center energy consumption increased by 90% from 2000-2005, increased by another 24% from 2005-2010, and continued to rise in this decade [3].

Protecting against these momentary power interruptions is also quite costly. Many industrial companies use uninterruptible power supplies (UPSs) to "condition" their power in an effort to avoid the effects of these power interruptions. However, many of these legacy UPSs suffer from large electrical losses as they perform their protection function; the efficiency of some in-service UPSs is as low as 75 percent. This introduces very high operating costs, especially in energy intensive industries such as semiconductor fabrication, aluminum smelting, petrochemical processing, pulp and paper manufacturing, and many others. These UPSs also pose other disadvantages, including high capital cost, high maintenance costs, and high disposal costs at end of life (i.e., battery disposal). The latter also poses adverse environmental impacts. Of equal importance, acquisition, operation, and maintenance of UPSs is not typically within the core competency of many businesses.

Many digital loads are also sensitive to temporary voltage sags. Static var compensation (SVC), which is often used to address these sags, does not respond fast enough to provide effective protection for sensitive digital loads.

As a result of these considerations, some forward-thinking organizations are considering outsourcing their power conditioning needs, in addition to other services they currently outsource, such as information technology (IT), security, information storage, internet access, telephone and videoconferencing, and many others. Such outsourcing to focus on business core competency is increasingly important to maintain global competitiveness.

The Opportunity: Attributes of an Optimal Power Conditioning Solution

As an alternative to UPSs, sophisticated power electronics systems for power conditioning are now tested and commercially available. However, not all such systems are created equal. One recommended attribute of such a system is its development in close collaboration with semiconductor chip manufacturers. (Processing chips are at the heart of these power conditioning solutions.) This is important to ensure that the power electronics chips are uniform, precise, manufacturable, high-yield, reliable, and affordable. The power conditioning solution itself should be:

- Affordable
- Efficient (low losses)
- Compact, lightweight, with require a small footprint
- Easy to install and use, and reliable in operation
- Flexible, modular, and scalable as electricity user needs grow
- Available as a value-added service, where the user need not purchase, lease, operate, or maintain the equipment
- Alternatively available for purchase or lease, if desired
- Thoroughly tested in field conditions
- Available as a generic service or product, not a one-of-a-kind solution that must be tailored to each installation
- Environmentally friendly

Potential Applications of an Optimal Solution

Potential applications for these enhanced solutions include the following:

- Electricity users' sensitive loads (e.g., data centers, manufacturing assembly lines, and others), with high costs of interruption (aka outage costs), such as loss of revenue, loss of customer satisfaction, fines due to inability to meet contractual obligations or regulatory requirements, etc.
- Electricity users' critical loads (e.g., healthcare systems, critical telecommunications, and other critical services) that cannot be interrupted due to their critical need to continue operations (i.e., due to societal requirements such as disaster recovery)
- Electricity users' loads that consume a large amount of electricity (e.g., semiconductor fabrication, aluminum smelting, petrochemical processing, pulp and paper manufacturing, and many others) to take advantage of the solution's much higher efficiency

Potential Benefits of an Optimal Solution

Electricity user benefits of optimal power conditioning systems include the following:

- Lower electricity costs (due to reduced electric losses)
- Ability to convert a capital/operating cost (CAPEX) to a purely operating cost (OPEX, at lower equivalent annual cost) via a value-added service
- Lower maintenance costs
- Avoided electricity outages costs, such as lost production and damaged equipment
- Reduced facility insurance costs
- Enhanced flexibility and reliably compared to existing, conventional solutions
- Environmental benefits that enhance corporate community relations and public relations

Electric utilities that offer these optimal solutions to their commercial and industrial customers can realize the following benefits:

- Enhanced customer satisfaction
- Revenue opportunities by offering various power reliability/quality options to electric customers
- Environmental stewardship that benefits utility customers and the public

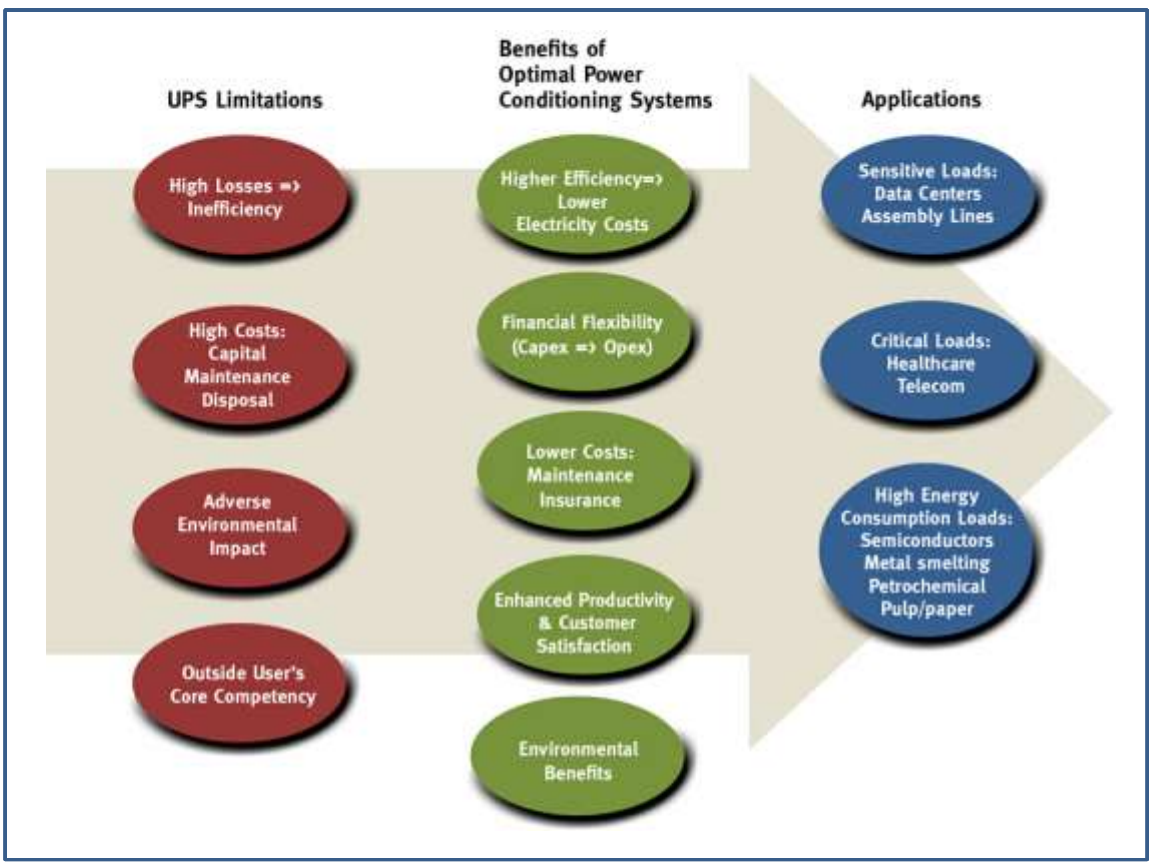

Figure 1. UPS limitations, benefits of optimal power conditioning systems, and applications

Incorporation of a "Macroprocessor"

To address the need for an optimum digital power conditioning solution, Silicon Power Corporation (SPCO) has developed and tested "macroprocessor" technology. Over a 20-year period, SPCO closely collaborated with integrated circuit (IC) manufacturers to achieve the breakthroughs needed. This macroprocessor provides the underlying technology for SPCO devices that can provide effective digital power conditioning.

The macroprocessor processes power in much the same way as the common microprocessor, but at orders of magnitude higher power levels. While the traditional microprocessor operates at voltages on the order of 5 V and a few milliamps (at a power level of less than 1 watt), the macroprocessor operates at voltages of greater than 5000 V and 2000 A (at a power level on the order of 10 MW). This represents a seven order of magnitude increase in power flow.

Hence, the macroprocessor technology effectively enables the digital control of large amounts of power by utilizing modified IC technology to accommodate higher voltages and currents. This control of power occurs in these macroprocessor systems in a timeframe of approximately 4 milliseconds (1/4 of a cycle). This sub-cycle operation is faster than the Computer and Business Equipment Manufacturers Association (CBEMA) power quality standard of 16 milliseconds (one cycle). This means that devices with this disruptive macroprocessor technology can switch power fast enough to protect digital loads from the effects of momentary power interruptions. By contrast, today's electromechanical-based switches, in wide use in the electric power industry, can switch power in 75-150 milliseconds (5-10 cycles) – far too slow to enable protection against these interruptions.

SPCO's work with IC manufacturers to develop and perfect the macroprocessor-modified IC technology over the last two decades leveraged many of the same techniques used earlier to perfect 4-layer microprocessor chips, including the following:

- **Shrinking cell dimensions** – A standard gate turn-off (GTO) thyristor contains "cells" each about 400 microns apart with a cell density of 50 cells per square centimeter. SPCO has developed a high-density GTO that contains cells about 5 microns apart with a cell density of 50,000-100,000 cells per square centimeter. This represents an increase in cell density by a factor of 2000.
- **Novel device packaging techniques** – SPCO emulated microprocessor technology evolution in the efficient electronic packaging of the device. SPCO invented a package that can handle cathode and gate currents an order of magnitude higher than those of a standard GTO.
- **Higher yield** – The industry standard yield for conventional power semiconductor devices is 65-70 percent. Over several years of in-depth research and development, SPCO has attained a consistent yield of approximately 98 percent.
- **Enhanced performance** – SPCO thyristor-based devices outperform the previous state-of- the-art for high power thyristors. They increase surge current densities by a factor of 10, increase speed (di/dt) by a factor of 100, and turn on with so little loss that they can operate in soft-turnoff circuits at resonant frequencies above 100 kHz.

Applications of the Macroprocessor

The following applications of the macroprocessor are possible for medium-voltage class (2.4-68 kV, 200-4000 amps) distribution systems (see Figure 2):

- The **static transfer switch (STS)** enables instantaneous transfer of power from a preferred source to an alternate source, allowing seamless power transfer for sensitive or critical loads.
- The **disconnect switch (DS)** instantaneously disconnects the power source to quickly isolate the power grid and eliminate cascading effects.
- The **fault current limiter (FCL)** instantaneously limits fault current to enable load growth without significant investment in upstream protection equipment.
- The **static compensator (STATCOM)** instantaneously controls power flow and improves the transient of the power grid.
- The **smart power interface (SPI)** instantaneously and harmoniously integrates distributed resources into the power grid.

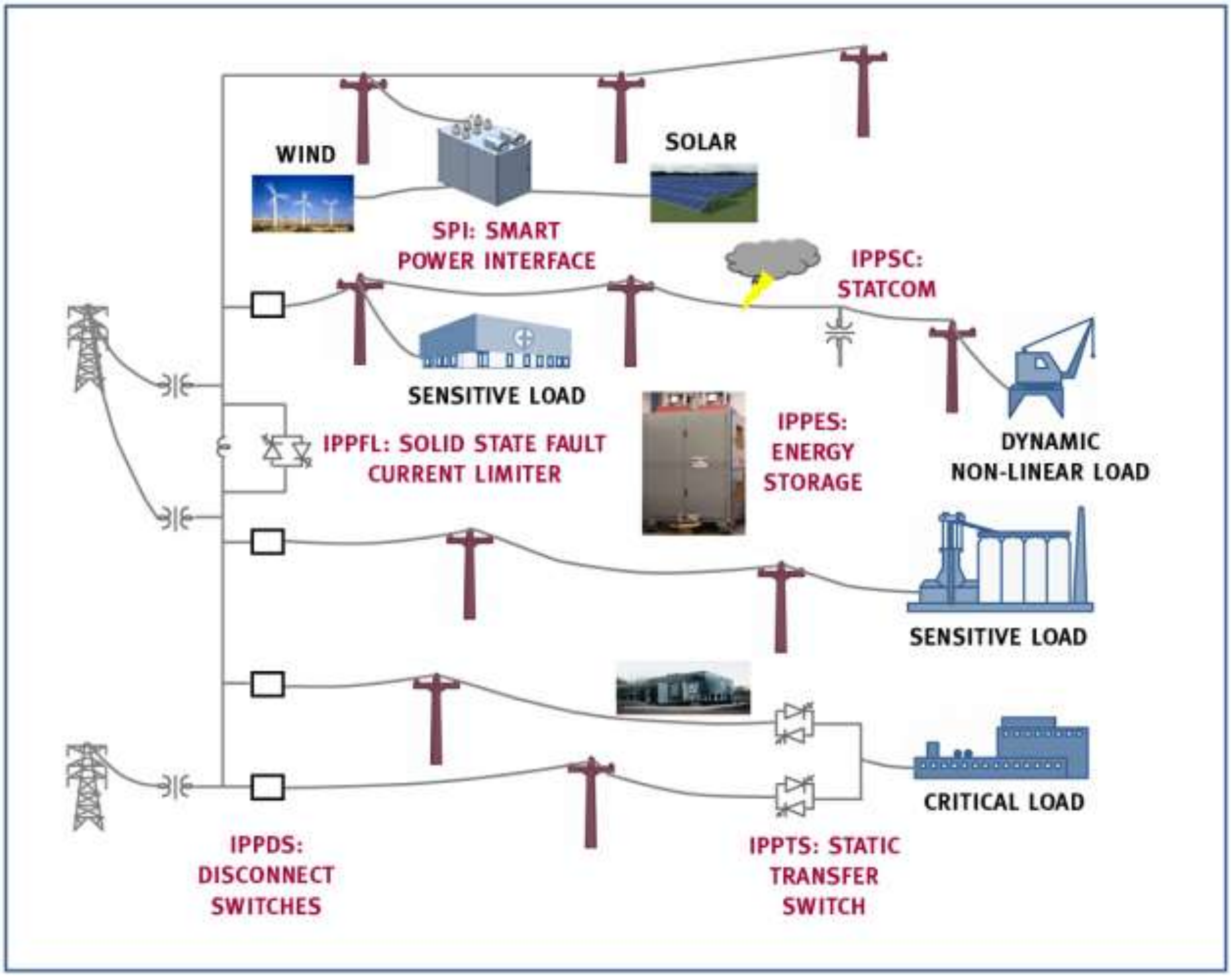

Figure 2. Macroprocessor applications in medium-voltage class distribution systems

Static Transfer Switch (STS)

One example of a state-of-the-art power conditioning system is SPCO's solid-state sub-cycle static transfer switch (STS). Incorporating the macroprocessor technology described above, this device can ensure high nine's power quality for mission critical applications (see Figure 3).

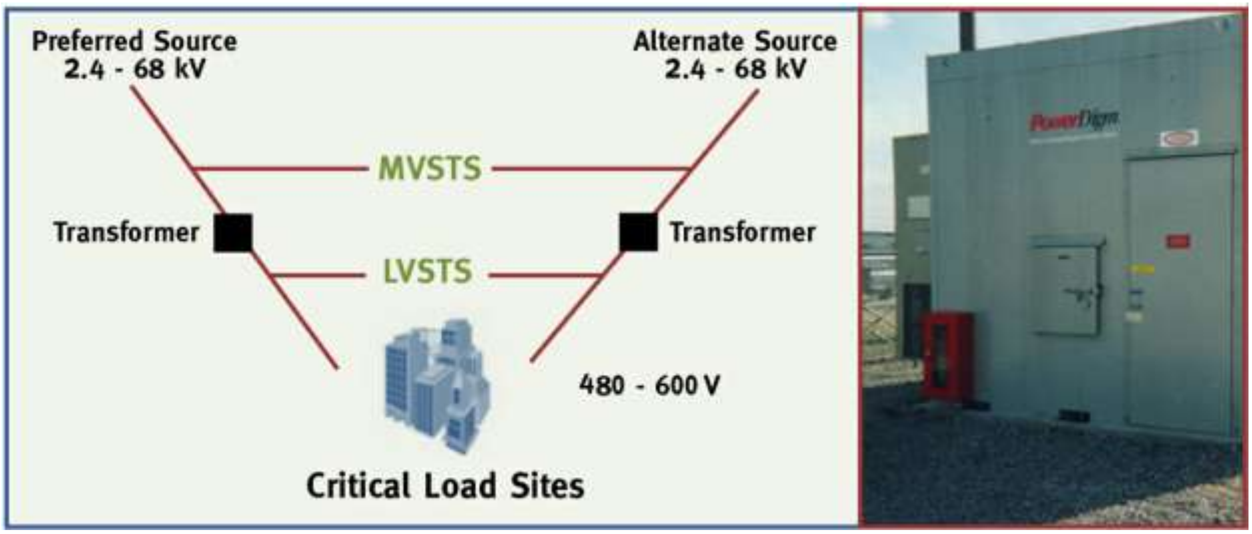

Figure 3. SPCO's static transfer switch (STS) rapidly switches utility service to the critical load from a source/feeder affected by an interruption to an alternate source.

At existing facilities, because the STS is compliant with UPS systems, the device has immediately remediated plant and data center lost downtime, operational interruptions, lost productivity, and product damage. Typical return on investment (ROI) for the STS is less than two years. In new projects, the STS provides a lower lifecycle cost alternative to UPS systems, without the growing and substantially complex environmental costs (e.g., no need for batteries or SF_6), periodic maintenance concerns, and comparatively short service life of UPSs. Compared to a backup diesel generator, the STS provides much faster response and transfer from one power source to a secondary source.

SPCO designed its STS for medium voltages from 2.4 kV to 68 kV and currents from 400 A to 4000 A. When these systems detect a disturbance, they transfer the load from one source to another with sub-millisecond/sub-cycle reaction times. During a voltage sag, the STS transfers from one source to the other

STS Case Study: International Airport

A new international airport located in Calgary, Canada required uninterrupted power for luggage conveyor belts, automated walkways, and information technology (IT) systems within the airport. To meet this need, Silicon Power Corporation (SPCO) installed a 25-kV, 600-ampere static transfer switch (STS) in 2017.

The STS monitors the power quality of two distinct and redundant feeders to the airport, and provides fast transfer from the utility preferred source to the utility alternate source in the event of a momentary interruption or disruption in power quality. This effectively protects the specified airport systems and keeps them online in the event of a disturbance.

within ¼ of a cycle. The complete STS system consists of three-phase, properly series/paralleled solid-state thyristor ac switches, sensors (current transformers and potential transformers), SPCO's proprietary controller, disconnect breakers, and bypass breakers. SPCO connects a static switch to each source, and the third static switch operates as a tie switch. The outputs of the switches connect to each other and furnish power to two load buses

The SPCO controller executes all automated STS operational functions. The controller also provides an external status and control interface to supervisory control and data acquisition (SCADA) systems via a Modbus TCP interface. The bypass and isolation breakers facilitate maintenance, repairs, electrical tests, and emergency shutdowns without disturbing the loads.

STS Case Studies

Following are case studies of SPCO's implementation of the STS:

Case Study: Pharmaceutical Research Facility

A new research campus for Novartis Pharmaceuticals Corporation located in Shanghai, China required clean, uninterruptible power for its animal research facility. To meet this need, SPCO installed a 10-kV, 1250-ampere, split-bus STS in 2014.

In addition to providing fast transfer based on utility power quality events, this installation also addressed the challenges posed by a large local installed base of on-site generation. The local utility prohibited the export of power from the customer site to the grid, which could occur in the event of a high impedance fault due to on-site generation on the nearby utility grid. To prevent this inadvertent power export, SPCO's STS detects reverse current, which enables the STS to immediately transfer the load to an alternate utility power source that is not affected by the fault.

Automotive Components Assembly Line

A Visteon (Ford Motor Company) automotive components plant in Detroit was experiencing numerous electrical incidents – 17 in one year alone – that were affecting Ford's primary downstream automobile assembly lines. Because of this crippling loss of production time, the utility (Detroit Edison) negotiated a special manufacturer's contract with Ford. The contract stipulated that any interruptions in power supply to the components plant would require monetary compensation from Detroit Edison to offset Ford's estimated losses. To help the utility avoid compensation payments, SPCO installed an STS at the substation serving the manufacturing plant. In the first year of service, the switch operated at 96.6% availability and averted ten disturbances. This saved the utility $360,000 in compensation penalties as stipulated in the contract.

Hazardous Waste Incinerator

At a large-scale hazardous liquid waste incinerator plant in Kentucky, even slight power quality problems could cause shutdowns of certain systems. More important than loss of production time was the need to ensure plant operation within U.S. Environmental Protection Agency (EPA) requirements. Operated 24 hours a day and constantly monitored by EPA, plant violations could incur sanctions or fines exceeding $50,000 per event. The local utility worked with the plant to determine the power quality level needed to maintain proper plant operation, and evaluated available service levels. Previously, the utility had successfully improved power quality at another plant using an SPCO STS. After further evaluation, the utility determined that a second 15-kV feeder and STS was the best alternative for improving power quality. Hence, the utility and plant agreed to a specific multi-year rate structure that included the second feeder and STS, which was soon placed in service.

For More Information

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About Silicon Power Corporation

Silicon Power Corporation, founded in 1994 and headquartered in Malvern, PA is a globally recognized technology developer and solutions provider in the design, development, testing, and manufacturing of high-power semiconductor devices, high-power pulsed-power modules and, high-power utility-applicable systems.