Using Advanced Power Electronics And Concepts To Develop A 2200 Kva Rotary Battery-Less UPS.

Gene Weaver[1]

I. Introduction

A commonality exists between high technology concepts, components and their end products. Products such as jet aircraft, missiles, spacecraft and stations in space. Initially, one may think that they can be categorized as Government owned, costly, and high tech. Beneath all of this however, and largely unseen is that each of these is comprised of components that make up the whole. The development of the components that created the entire product or system became the "enabling technologies" along with a whole lot of "out of the box" thinking. Bits and pieces that came together to create an F-16, Saturn missile, a reusable spacecraft or a station in space.

Companies that are high technology, producing power electronics components that come together to form the end product built by others include SatCon Technologies Corporation. They are component and or technology driven companies that sustain a profitable thriving business with associated high visibility primarily through the courtesy of the U.S.Government. However, over time and taking a long hard look at the private sector, as was the case with SatCon Technologies Corporation, the decision was made to move from a product/component driven Company to a market driven company. The decision made was to develop, through an evolutionary internal process, completed in the shortest possible time, end products to fill market needs as identified through market research. To maximize their basic power electronics as the enabling technology and thus identify a product to fill a product gap in a major revenue producing market. The market selected was power quality and reliability. The product to be developed was a rotary, batteryless UPS in the multi mega watt range to satisfy the need for high load kVA power problem/anomaly mitigation equipment.

II. Power Quality & Reliability

Power quality and reliability come under the power protection umbrella. The differences are that Power Quality means how well the utility performs in delivering utility grade power while Power Reliability is the continuing availability of that power. Power Quality has a number of definitions, such as: "The interaction of electrical power with electrical equipment, where the electrical power is considered to be of good quality if the equipment operates correctly without being stressed." Note – the operative word is "stressed." However, reliability is the real key. The utility delivers utility grade power at 99.9%. That is equivalent to outages to the tune of 8.7 hours a year! That might be OK for Freddie Krueger's house on Elm Street but disastrous for a typical mission critical data center. A facility where required reliability is at 7 to 9 nines, or:

- 99.99999 = 3 seconds annually
- 99.9999999 = .03 seconds annually
- Possibly - 99. To infinity = totally transparent to the load

So, the question was "can we get there from here – is it achievable?" The answer was yes. The need was to go back to those enabling technologies and borrow from them. Take and make use of whatever was needed to achieve the highest reliability goals. To think out of the box by mixing marketing with R&D, engineering and manufacturing. Timing was critical since the product must be brought to market in a timely manner. There was no closing of a window of opportunity to worry about since the concern was to open it wider and get a fair share. A fast start would be required along with forgeting about the N.I.H. (Not Invented Here) factor.

[1] SATCON POWER SYSTEMS DIVISION, SATCON TECHNOLOGY CORPORATION, CAMBRIDGE, MA. Email: GENE.WEAVER@SATCON.COM

III. <u>**The Drivers**</u>

It would take people, time and money to develop such a product. There were many issues that needed to be addressed about the market. One of these and perhaps one of the most important is where is the market today and where is it going. It was determined that the Power Quality and Power Reliability market has a number of drivers. Among the most recognizable and arguably most important are:

- E Commerce
- Deregulation
- Process Industries
- Data Centers

<u>Data Centers</u> – It is a fact that today, most all data centers, or about 99%, have power protection usually in the form of a UPS. Based upon this, data centers must have known something that every one else did not. So, what did they know and when did they know it. The obvious is that they came to life recognizing that the equipment they housed was among the most sensitive in the world. A voltage drop below 59.6Hz or a one-quarter cycle outage – about 4 MS will cause most computers to drop out. This could not be tolerated especially in a mission critical center. In about 1996, the Technical Center of the Americas, considered to be the first of many “Internet hotels” at Miami, installed power protection/conditioning equipment. They had building costs at $562/ft2 with 53% or $300/ft2 spent on UPS. There were many more to that numbered into the hundreds and each of these had requirements for large load UPS.

So, what happened? According to the August 1, 2001 edition of USA Today “The technology got carried away and overbuilt everything – especially the data centers. It was part of an exaggerated dot com economy.” However, the Internet isn’t going away. Accordingly, the economy is today (April, 2002) on the rebound. We may not see as many centers as before but they are still being built and each one will mandate power protection and high reliability.

<u>**Process Industries**</u> **–** In major contrast to the data centers, process industries (pi’s) in America are estimated at less than 10% with power protection. Over the years the pi’s have accepted losses due to electrical anomalies as “a cost of doing business.” Or, “roof leaks, but it’s not raining today so we’ll fix it tomorrow.” Recent studies show that these outage costs or losses are annually in the $50 to $60 *billion* range. Add to this power anomalies in the $6 to $8 *billion* range. The numbers are BIG! The reason is the fact that process industries are huge consumers of electrical power. All utilities categorize their customers as Residential, Commercial and Industrial. At the majority of utilities, the industrial customers comprise the least number BUT represent the largest electrical loads.

Lost productivity for these industrial customers does have an impact. Recently in California for example, losses were at $15 billion, and without the impact of the rolling blackouts. Of the top three impacted states, Texas was second at $10 billion with New York a close third at $9 Billion. It is not reasonable to consider this as *a cost of doing business.* The process industries will become the major users of power quality power protection equipment – especially once they find that the losses are totally unnecessary. Acceptance of these losses as a “cost of doing business” is not part of rational thinking. The initial cost of a large load UPS is a capital expenditure. However, under a lease arrangement, for example the cost can be expensed. In addition, a Life Cycle Cost (LCC) analysis will most often demonstrate that rotary, batteryless UPS ownership is cost effective over the long term. Especially as entire facility protection is becoming the norm. In the past only the critical loads were protected such as the R&D or test lab. Today, the entire facility is protected since all facets of facility operation are considered critical. Lighting for the stairwells are just as important as the test lab.

<u>Deregulation</u> **–** Regardless of deregulation, utilities will continue to provide utility grade power at 99.9%. The benefit of deregulation was to create a highly competitive environment for the sale of electricity. In some cases this did occur, especially in Europe. Here in the US the outcome so far has been mixed, however a benefit was derived in the form of the ESCO – Energy Services Company. There are two sides to every meter, the utility side and the customer side. On the utility side the utility, especially the IOU’s (Investor Owned Utilities) are bound by PUC (Public Utility Commission) policy. The other two utility categories of Municipalities and COOPs/rural electric’s can set their own policy as to what side of the meter they are on and they usually choose

their side. ESCO's on the other hand work on the customer side. They are usually part of an IOU. They are broadly defined as "companies that assist utility users, both electricity and natural gas, in the reduction of their overall utility costs." There are "For profit utility-affiliated ESCO's" and "Independent non-utility affiliated ESCO's." Both types can work to provide power quality solutions that would include UPS.

Utilities non-responsive to customer problems with or without ESCO's may seek alternative solutions. One of these is to disconnect from the grid. This is risky, however with large load high reliability UPS in an N+1 or N+? arrangement, the customer can feel secure in having the power needed without the grid. Other alternatives include peak shaving (to get a lower rate) cogeneration using CHP (Combined Heat and Power) and/or Distributed Generation (DG) where primary power generation is at the site with the utility as back up. Each of these has been driven by deregulation and is gaining momentum, especially for large load systems. The future of the grid is dependent upon one or more of the above. It is not going away and neither is deregulation. As a consequence, utility power will not improve, there fore UPS and power protection systems will continue to be required and probably at an increasing rate.

E Commerce – The Internet is here to stay. The demise of more than 800 highflying dot-coms were not enough to scuttle the USS E Commerce. The unemployment rate soared of course, but the situation is now relatively calm and dot-coms are beginning to increase once again. This of course specifically takes the form of the *mission critical data center* that is packed full of file servers versus main frames supporting primarily the dot-coms of E Commerce. Also known as COLO's (Cooperative Locations), these facilities advertise "high security requirements" (retinal scans to enter) and power quality/reliability capability levels usually at 8 or 9 nines as discussed above. This becomes a requirement when we realize that microprocessor for example, will malfunction or drop out in $1/240^{th}$ of a second or one quarter cycle – 4 ms. Consequently protection in the "high nines" is critical to prevent this from happening.

The major issue here pertains to the loads – watts per square foot. It started at about 50 to 75 watts per square foot. COLO's initially fo9r example, were averaging 100,000 sq. ft and entire facility protection was needed or about 5 to 7.5 mW. As E Commerce grew COLO power requirements increased as did UPS protection requirements. At 200 watts per square foot for example, 20 megawatts are required. Obviously the least number of UPS to achieve this total loading would be the most efficient way to proceed. Since interior COLO space is expensive and is dedicated to file servers, power protection systems such as UPS have to be placed outside. This would also eliminate the cost for additional air conditioning. Rotary systems fall into the "placed outdoors with no air conditioning required" category. Since E Commerce had a dependency upon facilities such as the Mission Critical Data Center, these would once again be useful and drive the need for more sites. As a consequence it was axiomatic to equate this with the need for total facility protection. If the process stopped at 200 watts per square foot would new facilities be built at 300 watts + per square foot? Assuming this scenario, larger load kVA systems would be needed – the larger the load UPS, the fewer UPS' required.

IV. The Protective Device – Or, How Do We Get There From Here? – It was agreed that a sizeable and growing major market for large load UPS systems existed. The market drivers were still in place, active and were growing. At issue was the identification of the necessary enabling system technologies to be incorporated into the device. Major design considerations began to emerge:

- Energy storage – batteries or flywheel
- Power electronics – Out of the box and innovative
- Static or rotary – Wave shaping or power generation

And,

1. Robust – able to tolerate hostile environments
2. Outside placement – no AC required
3. KISS – able – no complex pumps or exotic gases (Keep It Simple, Stupid)
4. COTS – open market availability

5. Batteries? – probably not
6. Loads – multi mega watt

Enabling technologies sampling:

- Flywheel storage – US Navy program development
- Wound rotor induction motor – Chrysler EV program
- Bi-directional inverter – military EV programs
- Power controllers – frequency & amplitude controllers for the Government

Sample Specs:

- 60/50 cycle
- 3 phase
- 3 or 4 wire
- Low & Medium voltage – 480 & 4160+
- Slow speed solid steel flywheel @ 12 seconds
- Wound rotor IMG @ 15% load replaces full size double conversion system
- Efficiency @ 96% minimum
- Integrated high speed industrial engine – diesel or NG

V. Features

System features incorporate elements such as operation, design, efficiency and application. System operation would be generally similar to other large load rotary UPS with major differences such as using a rotor wound IMG, scaled down bi-directional inverter and delayed engine start. The system would soft start and parallel to the grid at a flywheel speed of 1980 rpm. IMG would operate as an unloaded motor supplying VARS to the load for PF correction if required. Upon detection of grid out of tolerance the flywheel would provide 12 seconds of ride through from 1980 rpm super synchronous to 1620 rpm sub synchronous. During this period the flywheel's kinetic energy would provide power for the bi-directional inverter to electronically advance and retard a now energized IMG rotor maintaining 60 Hz to the load. The transfer from loss of utility to the flywheel to perform this function would be seamless to the load. The engine would receive a start signal after an initial 2-second delay. This would allow for utility recloser if it occurs and avoid nuisance starting of the engine. The Cummins engine would start in 6 seconds or less. When the engine speed matches the clutch speed, the clutch would engage the engine and the engine would replace the loss of utility power. The engine would become a continuos power source as long as fuel is available.

Essential design features would focus on batteryless, skid mounted, outdoor placement and medium voltage capability. Batteryless became a requirement to compete in the large kVA load market. The battery replacement is the stored kinetic energy in the flywheel. However, flywheels can become technically complex based upon speed and composition. High-speed flywheels for example, at 10,000 to 40,000+ rpm require containment and containment testing. The slow speed flywheels do not. A 4140 solid steel flywheel turning at 1980 rpm is safe from stress fractures or cracking. It will also operate in ambient since the slow speed did not produce any friction or resistance of any consequence, hence an exotic gas, at partial or full or vacuum is not required. Vacuum pumps can become a single point of failure.

The skid mount configuration was designed primarily for outdoor placement. The skid or sled is transportable. It should be mounted on a concrete pad placed outdoors and covered with a sound attenuated or weatherproof enclosure or both.

Medium voltage from 4160 V up to 30kV was available. These higher voltages were rarely offered with UPS and could become a sales feature unique to this system. Utilities liked the idea of medium voltage since it could be installed to accept loads directly from the sub station.

The topology would be a horizontal configuration with all rotating components, i.e., flywheel, IMG, clutch and engine, integrally mounted on one skid. The engine radiator could be skid mounted or remote mounted as required by the customer. All of the solid state electronics to support and control the system would be mounted in separate NEMA cabinets. These cabinets could be placed adjacent to the skid or remote at a distance of up to 200 feet. Paralleling of units can be accommodated without the use of extensive switchgear. This is based upon the operating characteristics of the bi-directional controller that does not require each unit in parallel to be synchronized at 1800 rpm.

VI. <u>Application</u>

As discussed above and determined through the initial market research, application would be all markets that have large kVA load requirements. Such as;

- Mission critical and other data centers – High nines reliability
- Process industries – Losses from anomalies
- Telecom – Battery bank replacement
- Communications – Radio, TV, large antennae, etc
- Government – Military, FAA, Noah etc.

The system would provide the combination of generated power with the flexibility and speed of power electronics control. A bi-directional controller to advance and retard the ING rotor to maintain 60 Hz to the load would be introduced. System application would include load size parameters maximizing at 2200 kVA down to 300 kVA. This would encompass the broad spectrum of "large load size" UPS. It would also recognize application requirements for smaller critical loads as well as larger essential loads. These larger loads would include the entire facility protection if required.

Flexibility in design would extent to users who did not want an integrated engine for extended outage protection where 10 to 12 seconds would be satisfactory. Since flywheel stored kinetic energy is a linear function, the 12 seconds at full load is extended at any reduced loading. For example, 12 seconds at 2200 kVA becomes 24 seconds at 1100 kVA. Applications where manual shut down can be effected quickly can take advantage of the lower cost, reduced maintenance engine-less system.

Large and small system loads suppliers share a number of common burdens from an applications standpoint. Some of these are;

- Make provision for as many nines of reliability as possible
- Make use of state of the art technology
- Use only technology that has been proven reliable
- Design for a high MTBF – elimination of single points of failure
- Be innovative and think out of the box
- However, no need to reinvent the wheel if you do not want to
- Cost effective – at inception & over the life cycle – 20 years for rotary

Keep in mind that application becomes the most critical element in the entire product process – unless applications can be created. Application in this case becomes *the* answer or solution to a need.

VII. <u>Conclusion</u>

This product was developed;

1. To provide a solution or answer to a need as identified through market research
2. To move the company in a new direction by going from component/technology driven to product/market driven
3. To develop the product as a repackage/upscale from already available, tried and proven enabling technologies – repackage, not redesign

4. To build a better Mouse Trap
5. To use market research to find the Mice

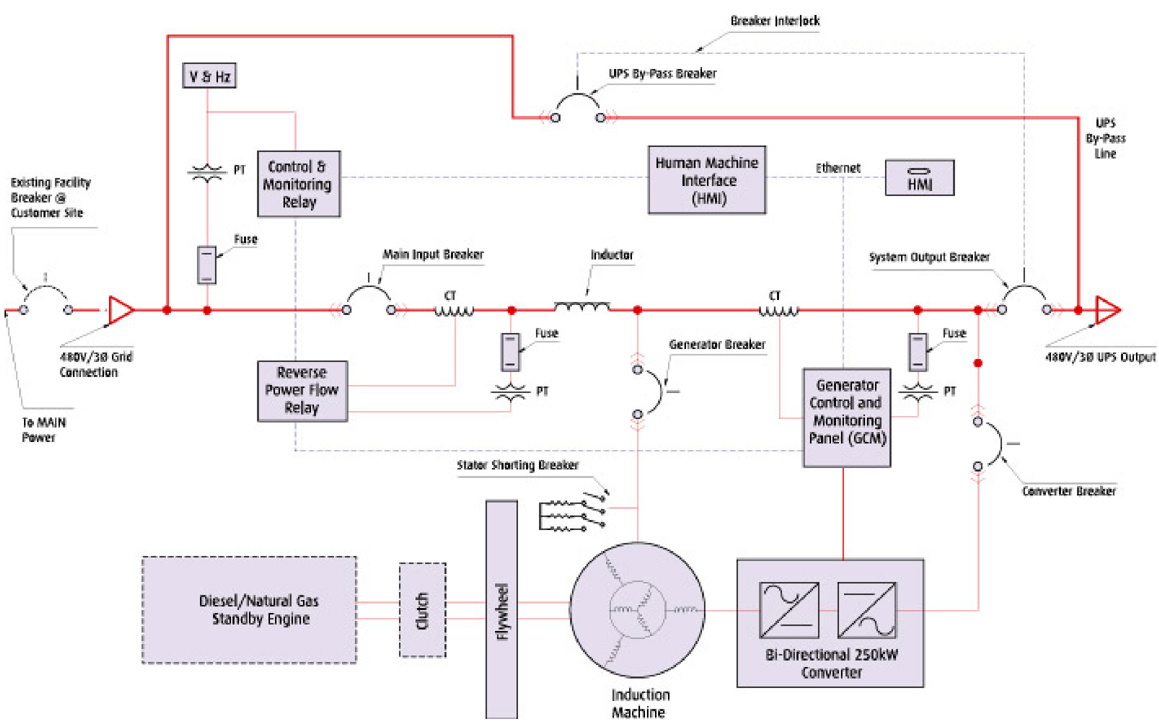
The result has been the build, test and commercialization of a new product. A product for energy storage to provide power protection and power quality/reliability and become a total turn key integrator. Prospective customers asked for only one number to call as a problem-solving system. The market also saw the need to maximize the load rating as high as possible – 2200kVA/1760kW.

A vast array of enabling technologies was examined to avoid a “clean sheet” costly and time-consuming redesign effort. This included an internal search to answer if it could be done once the problem parameters were identified. The response was positive with a view toward examining and accepting already tried alternatives and discarding the ubiquitous “not invented here syndrome.

The product became StarSine, a 2200kVA/1760kW (maximum) rotary, batteryless, flywheel UPS with 12 seconds of ride through to mitigate all utility anomalies including an integrated industrial engine for extended ride through available as a total turn key system. It is designed and built by the Power Systems Division of SatCon Technology Corporation and available through the Power Quality Group of the Power Systems Division.

Project initiated in September 2000. First of two units at 315kVA/250kW available and ready for test as of March 13, 2002. Testing of the first of two 2200 kVA units to begin in June, 2002. An aggressive Beta site selection program is underway. Initial placement as “critical power protection” is expected to give way to “essential power protection.” A comprehensive test program designed with the assistance of outside high kVA rated UPS systems placement specialists will focus on both critical and essential customer load profiles. Customer witness testing is stongly encouraged in providing a product that will perform to specifications and resolve all quality power problems.

SINGLE LINE DIAGRAM – 2200KVA/1760KW ROTARY BATTERYLESS UPS



SIDE VIEW – 2200KVA/1760KW ROTARY BATTERYLESS UPS