Overview of Custom Power Applications

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I. Introduction

Electric power is a form of energy we have come to depend on, so much so, that in many automated product line businesses can not tolerate its loss for even a few tens of milliseconds. With the ever-increasing role of electricity in improving the quality of life, productivity of manufacturing and service industries, and efficient energy use, power electronics will play a significant part. The Power Electronics Building Block (PEBB) concept sponsored by the Office of Naval Research (ONR) has played a key role in accelerating the trend towards reduced cost, losses, weight, volume, and much lower engineering effort to design applications of power electronics. One of the growing power electronics applications is the Power Quality/Custom Power. This paper covers general aspects of the Custom Power applications and a suggested scenario for a Custom Power Park.

II. Custom Power Concept

Custom Power is a concept based on the use of power electronic controllers in the distribution system to supply value-added, reliable, high quality power to its customers. For many customers this is a preferred alternative to the customer improvising utility power by their own means, mostly in a band aid manner with numerous uninterruptible power supplies, as is done now. Many utilities are moving in the direction of value-added Custom Power service to their large customers.

Custom Power means that the customer receives specified power quality from a utility or a service provider or at-the-fence equipment installed by the customer in coordination with the utility, which includes an acceptable combination of the following features:

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- No (or rare) power interruptions.
- Magnitude and duration of voltage reductions within specified limits.
- Magnitude and duration of overvoltages within specified limits.
- Low harmonic voltage.
- Low phase unbalance.
- Acceptance of fluctuating, nonlinear and low power factor loads without significant effect on the terminal voltage.

This can be done on the basis of an individual, large customer, industrial / commercial park or a supply for a high tech community on a wide area basis.

Not all of the solutions call for Custom Power solutions, customers with a few critical loads and small customers would have a few low-power conditioning solutions.

III. Reliability Considerations for Customers

Until recently, voltage reductions (dips) and short term outages were not an issue; the number of cumulative hours of interruptions per year has been the benchmark measure for reliability. Over the last ten years or so, the customers' perception of reliability has been changing, and the pace of change has accelerated. The concept of an outage time of a few cumulative hours per year as being an extremely reliable supply is no longer valid for an increasing number of customers, industrial in particular.

An event of a few cycles interruption, or even of voltage reduction to less than 80%, can cause big problems for industrial customers. With the age of automation, computers, process controls, drives and robotics, a new concept of reliability must be developed. The number of outages and voltage dips and their duration is much more important than the cumulative outage time per year. Hypothetically, if one cumulative hour is made up of 3,600 interruptions of a second duration each, it would be a disaster for any automated industrial customer as compared to one interruption of one hour. In reality a customer may expect more than a hundred events of sags greater than 15% lasting for less than a second.

Studies of cumulative monitoring of events at a large number of distribution substations show that most of the sag events are of short duration of a few cycles and less than 40% voltage reduction and only 1% of events with voltage reduction of less than 80%. With the availability of two independent feeders at the distribution substation, and high-speed solid state transfer switches, a large percentage (70-90%) of the events in figure 2-2 can be eliminated in a much more efficient and economical manner than the customers' own solutions.

Custom Power is intended to protect the customers from interruptions and voltage reductions originating in the utility system as well as those transferred to customers from other customers via the utility system and even internal disturbances.

IV. NEED FOR CUSTOM POWER

The need for the Custom Power concept arises from the fact that:

- Most of the interruptions and voltage reductions occur in the utility system on account of lightning faults on transmission and distribution lines, low frequency dynamic swings of the transmission system, trees touching the wires, equipment failure, switching, etc. Voltage sags may also be a consequence of large load changes affecting customers own equipment or affecting other equipment via the utility system.

- Impulses, switching surges and overvoltages affecting the insulation, would most likely result from lightning strikes and switching events in the transmission and distribution system.

- Temporary overvoltages lasting from several cycles to several seconds would largely result from large load changes, capacitor switching, transformer switching, dynamic stability swings, excessive leading-VARs during light loads, etc. in the utility system.

- Voltage unbalances in a three-phase supply would occur mostly due to large unbalanced loads on a utility's distribution lines and long lines with unbalanced phase impedances.

- Harmonics would most likely be the consequence of high harmonics in the customer load, or the saturation of a utility's transformers. These harmonics would then be amplified by the natural resonances in the utility system and/or the customer system.

There are a number of reasons for the choice of the Custom Power concept for many customers, and on a long term basis for most customers. These reasons are:

- The customers are better served if they receive a comprehensive solution to their power supply problems from the power supply service providers.

- Most of the voltage reductions and interruptions result from events that involve the utility system.

- In general, the total cost of the solutions that involve the utilities' own systems would be much less than the cost of solutions put in place by the individual customers.

- At least from the point of view of reliability, migration to the Custom Power concept seems to be inevitable.

Compared to voltage reductions, overvoltages are less common and do not affect customer productivity unless the overvoltages cause equipment failure. Nevertheless, they represent an issue of safety and life of equipment. Switching in and out capacitors with mechanical switches, or regulating voltage with tap changers, does not provide the coverage needed by, for example, the CBEMA limits. Nor could the existing gapless zinc-oxide arresters ensure overvoltage to less than 1.2 pu for 3 ms as specified in CBEMA curve. Thus, power electronics-based voltage control is essential for modern industry.

V. PRINCIPAL CUSTOM POWER SOLUTION CONCEPTS

Figure 1 shows one-line diagrams of two basic distribution substation solutions based on solid state switching.

One solid state switching solution involves the use of a bus tie switch to share the load between two incoming feeders. These two feeders should preferably come from different transmission substations. However this is often not easy to accomplish and the next best feeder service would be to pick-up the two feeders for different transformers of a transmission substation. The idea is that lightning faults do not affect both feeders, or at least the effect on the two feeders is generally unequal. The bus-tie switch is normally open, and specific loads are assigned to the two feeders via solid state circuit breakers. A fault on one feeder will lead to opening of its circuit breaker. The bus-tie switch will close to serve the loads from the other feeder as soon as the faulty feeder is separated from the loads. This process can be completed in 4-8 ms. There are variations of this concept including one in which the bus-tie switch is normally closed.

Another solid-state switching solution is that of two solid-state transfer switches, one open and the other closed, so that the load is normally connected to one feeder, but is transferred to the other feeder within 4 ms when there is a voltage sag or distortion. If due to some common coupling of the two feeders back in the system, the transfer will result in load connection to the better of the two feeders. In both solid-state switching solutions, the customer will be free from the voltage dips for most if not all of the transmission line fault and switching events. However the cost of transfer switches would be much less than that of circuit breakers.

Figure 2 shows one line diagrams of two approaches to converter-based solutions.

One converter-based solution, known as Statcom, involves a shunt-connected voltage source converter, which basically injects current into the ac system. The dc capacitor voltage, through appropriate sequential switching, is converted to an ac voltage, the difference between the converter generated ac voltage and the system ac voltage results in current flow and corresponding reactive power. DC storage means, such as capacitors, storage batteries, or superconducting magnet, connected through a power electronic interface such as a chopper, can be utilized to supply real power as well and, conversely its capacity can be used to absorb real.

Going beyond that, if the converter's internal frequency is high enough, then it can simultaneously act as an active current harmonic filter. The same converter can be given multiple controls, such as ac bus voltage control by injecting or absorbing reactive and active power, act as an active current harmonics filter, filtering current as ordered to absorb only the harmonics generated by the selected customer loads, and even balance the phases. With large enough storage, it can also serve as a backup power supply.

The other converter-based solution, known as the Dynamic Voltage Restorer (DVR), which, through a series transformer, connects the converter in series with the supply voltage, and injects precise voltage in each phase, which makes the load-side voltage free from voltage dips, overvoltages, distortion and unbalance. DVR rated for injection of $\pm$30% will take care of 90 percent of the dip events and all dynamic overvoltages. It can be designed for 100% injection, in which case the DVR will act as a full backup supply for as long as the storage system can supply active power. The energy storage is connected with an electronic interface to manage the active power required for the voltage compensation. This DVR can also be designed to serve as an active voltage filter, ensuring harmonic free voltage for the customer.

A more elegant approach is to combine the two converters, the Statcom and the DVR, as shown in Figure 3. In this arrangement, the shunt connected Converter can supply and absorb reactive power in order to support the bus voltage, supply and absorb the real power to support the series connected converter, and act as an active current filter. The series-connected converter on the other hand, supports the customer voltage for any deviation, dips and interruptions. The storage comes into play when the shunt connected converter can not supply the power during large dips and interruptions.

VI. TYPES OF LOADS AND POWER QUALITY REQUIREMENTS

In an unregulated environment, electric companies can offer a variety of new value-added electric power products and services in terms of quality and reliability of supply, operation and maintenance of the customers' own electric supply equipment, and also guaranteed performance. Given the variety of customers and their needs and the utilities' options, Custom Power would almost certainly be customized for individual large customers, a group of customers in an industrial park, or an office complex, etc. Additionally, on-site, continuous monitoring of a number of these Custom Power products and services will be necessary. When any value-added service involves liabilities and penalties against the promised service, the monitoring will become somewhat more complex.

The process of agreement itself would call for an evaluation of the sensitivity of the customers' production in relation to the normal service, and how much value added expenditure is justifiable. It is also likely that a high-tech industrial / commercial area would have a normal wide area supply service which is a cut above the normal, and then add further value for the individual customer.

Within the context of the Custom Power Park, one would expect to accommodate:

1) Small to medium size industries and commercial organizations with load requirements in the range of hundreds of KWs up to say about 10 MW.

2) Businesses that need a degree of improvement in the reliability/quality of service.

3) Businesses that are willing to pay a premium in lieu of the investor having to own and manage their power supply conditioning equipment.

Effects of concern on a large variety of equipment include:

- Speed variation of motors/drives.
- Stalling of motors/drives.
- Damage to motors/drives.
- Loss of computer data.
- Misoperation of process control.
- Failure of computers and electronic equipment.
- Communication interference.
- Overload of transformers, switchgear, cables, etc.
- Misposition of robotics tool or machining operation.
- Loss of cooling for a wide range of equipment.
- Loss of lighting, elevators, air conditioning etc.

VII. Types of Custom Power Supply Services in a Custom Power Park

In a Custom Power Park all customers will benefit from a basic supply which is a cut above the normal power supply from a utility. This basic supply can be obtained by provision of two incoming feeders along with Solid State Transfer switches (SSTs) which will reduce the duration of most voltage dips to 4-8ms by rapidly selecting the feeder with the highest voltage. It is also clear that most of the customers generate moderate to high harmonics, and therefore need an active filter service. Thus, the lowest grade supply should involve use of two incoming feeders, SSTs and an active harmonic filter.

As an example, the following loads are assumed for the Custom Power Park. (Figure 4).

	Max Load	PQ Need (explained below)
Semiconductor Chip Co.	10 MW	CP-AAA
Biotech Co.	2 MW	CP-AAA
Computer Hardware Co.	1 MW	CP-A
Software Development Co.	1 MW	CP-AA
Plastics Co.	3 MW	CP-A
Hospital	10 MW	CP-AA + CP-AAA
Data Processing Center	2 MW	CP-AA + CP-AAA
Office Building	2 MW	CP-A
Shopping Mall	2 MW	CP-A + CP-AAA
Total	33 MW peak load	

In addition, there would be small common power needs for parking facilities and driveways.

The key issue is how many grades of power should be available, and how the choices are determined and managed. Consideration of the value to different type of customers suggests that three grades of qualities (CP-A, CP-AA, and CP-AAA) with appropriate value-added premium cost, can serve the need. As a minimum, all customers would receive power CP-A with a quality superior to the regular power. Custom Power Park Control system will play a key role in the real-time and off-line management of services.

Custom Power A (CP-A): This is the basic value-added power at the Park. Its higher quality, compared to the regular power, arises from the fact that the Park has two incoming feeders, which can be designed with improved grounding, insulation and arresters, and better maintenance which reduces the chance of nearby lightening and other faults. With single phase tripping and reclose, the interruptions and major voltage dips are greatly reduced. In addition, the Solid State Transfer Switching ensures that the feeder with superior voltage is selected in less than half a cycle. There will still be voltage dips which are common to both feeders resulting from faults and dynamic swings in the transmission network. Dips from transmission line faults usually last for 4-10 cycles, and occasionally the system swings may cause 20-50 percent dips for about 1 second, and then repeated if the power system is unstable. There is also the possibility that a circuit breakers after clearing the fault will reclose into a fault, and the voltage dip and system oscillations will be repeated. Never the less, improvement over and above the normal power is substantial and may be characterized as follows:

1. 60-80 percent reductions in voltage dips.
2. Rare occurrence of interruptions.
3. Active harmonic filters.

Custom Power AA (CP-AA)*:* Over and above grade CP-A, grade CP-AA receives the benefit of a standby generator which can come up to speed in about 10-20 seconds in case of a power loss.

Custom Power AAA (CP- AAA): Over and above grade CP-AA, grade CP-AAA receives the benefit of DVR, which precisely adds the right amount of voltage including harmonics to the feeder voltage to ensure virtually dip free, interruption free, and harmonic free voltage to the customer.

It is assumed that under emergency conditions (loss of DVR), CP-AAA may degrade to CP-AA. For unavailability of backup power, it would still receive superior quality power and priority customer service attention.

On the left hand side of the CP bus, Figure 4 is shown a distribution bus for Custom Power A and AA. Both receive the same service as long as either of the two feeders is available. If and when both feeders are lost, the circuits of all customers A and AA are disconnected at both ends by their circuit breakers. The differentiating feature between customers A and AA is that when the standby generator is up and running (perhaps 10-20 seconds after the loss of both feeders), the circuit breakers for customers AA are closed to restore power to those customers. This means that customers AA do not lose power for more than 10-20 seconds in the case of loss of both feeders. However the customers A do not receive power until one of the feeders is back in service

The standby generator normally stays off and disconnected from the CP bus. When both feeders are off, the generator is started up immediately, brought up to speed, synchronized and connected to the CP bus. It should take 10-20 seconds for the generator to come on line, and pick up the load of both AA and AAA customers. It is reasonable to assume that CP Control will supervise this fully automated diesel-driven or gas turbine generator of 5-10 MW size. When only one feeder is off, CP Control will alert all the customers and also the utility to confirm that the generator is available, has adequate fuel supply, and to ensure that the utility is extra careful in its system operation., the CP Control can in fact start up the standby generator and bring it online.

Under peak load conditions and/or when one circuit off, the CP Control may even bring the generator up and connected. It can become a co-generator, even if both incoming feeders are intact. Furthermore co-generation may be used as often as economic conditions are favorable for co-generation

In order to ensure that the CP- AAA customers are not deprived of power during the period that the generator is brought up to speed and on line, and to supply them power without dips, distortion and imbalance, a combination of Active Filter, Dynamic Voltage Restorer, and hot standby storage is provided as shown on the right hand side of Figure 4.

In addition, connection to the AAA customers can also be made through solid state current limiting circuit breakers (SSCL). This can ensure that the fault current resulting from faults in the CP-AAA customers own system does not exceed, say, 2 times their peak load for about 1 or 2 seconds before tripping. This will further ensure that other CP-AAA customers are not affected. SSCLs can provide coordination with the downstream protective relays of the CP-AAA customers. These SSCLs also limit over loading on the DVR. Another alternative would be to provide a saperate series converter (DVR) for each customer or a CP super-AAA customer, etc.

The active filter, can filter exactly the amount of harmonics it is ordered to filter. Thus with current measurement on its AAA customer side, it can ensure that the AAA customers' harmonics are filtered. CP Control will supervise such an operation, as well as monitor harmonics from other customers. On the other hand, it can also sum the measured current of select customers, and filter the harmonics of these customers. The overriding considerations will be to ensure that the active filter is not overloaded, harmonic voltage on the CP-bus is not excessive and that the total harmonics entering the feeders is reasonable. Because the harmonics from various customers may cancel each other to some extent, it may be best to order the active filter to minimize harmonic content in the common busbar connection between the two SSTs and the CP bus. As mentioned earlier, practically all customer facilities generate harmonics and need active filter support.

Each customer's waveform is monitored by the CP Control, and all power quality events are captured, logged, and managed for periodic assessment of the service being provided. It is also necessary to evaluate specific events for continued improvement, and collect the information required to resolve disputes, performance-based payments/penalties, etc.

It is obvious that there can be a variety of scenarios for a Custom Power Park. The scenario presented in this paper provides the basis for further discussion.

VIII REFERENCES AND ACKNOWLEDGEMENT

[1] N. G. Hingorani, "Introducing CUSTOM POWER" IEEE Spectrum June 1995.

Author acknowledges the support the support of Terry Ericsen of ONR and David Flamm of SRI for supporting the conceptual definition of the Custom Power Park.

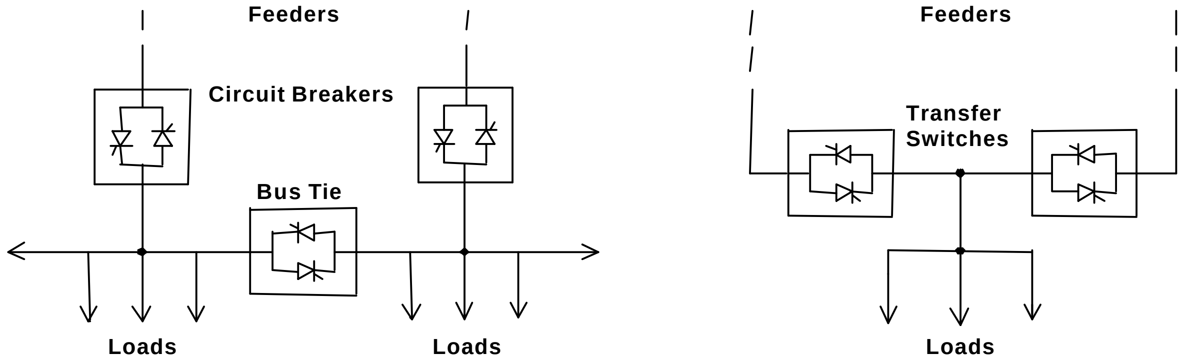


Figure 1. Custom Power based on Feeder Switching

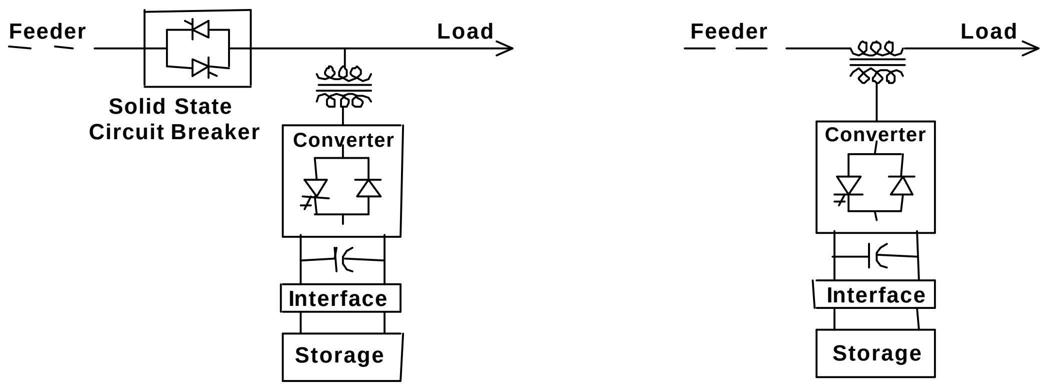


Figure 2. Custom Power based on Voltage Source Converter

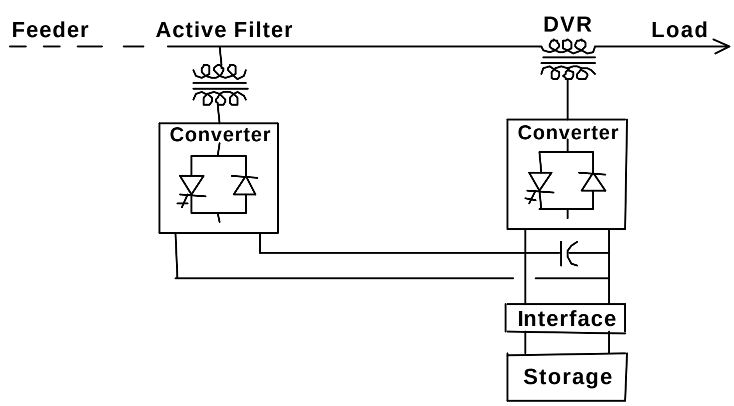
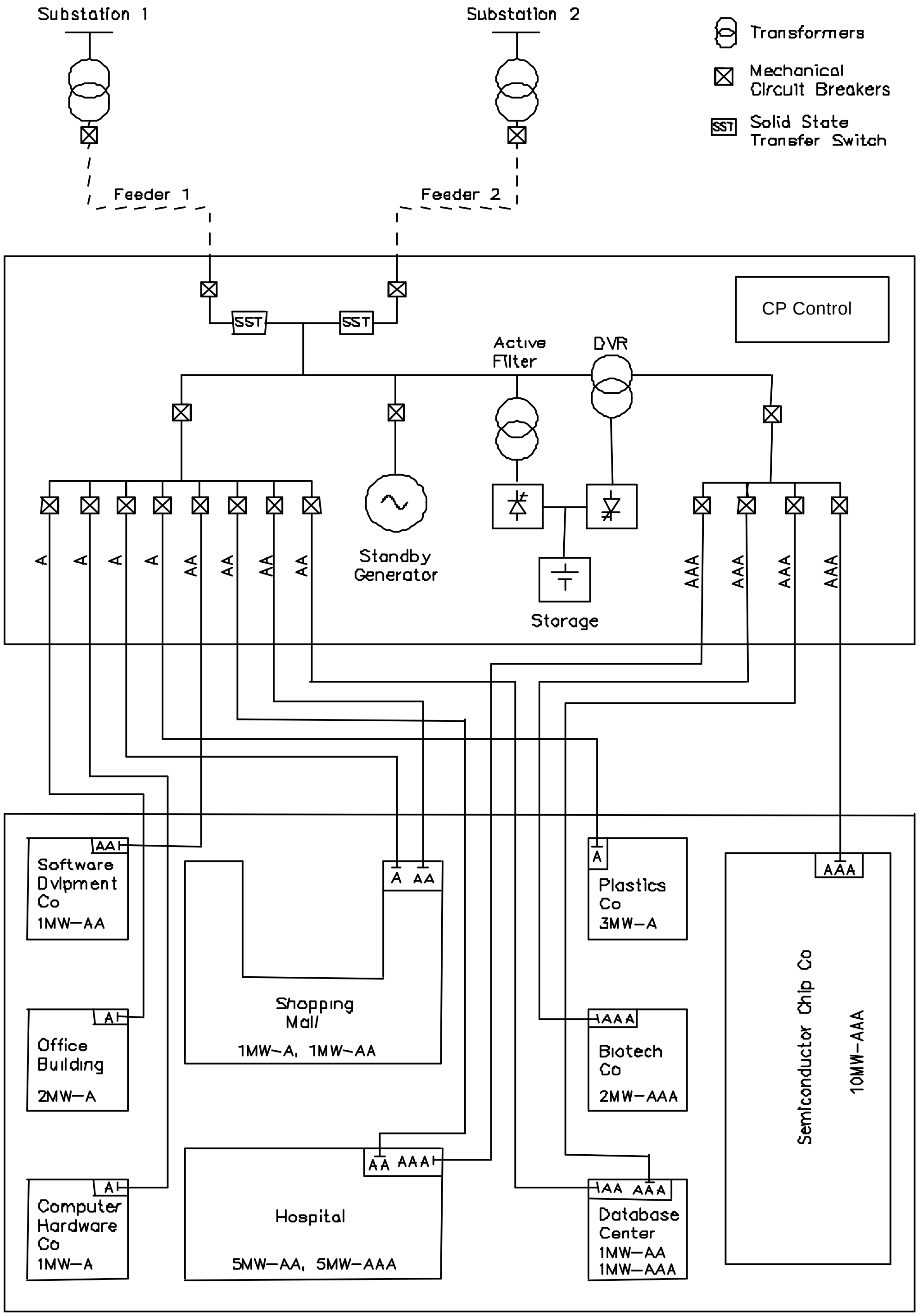


Figure 3. Custom Power based on two Voltage Source Converters and Storage



Custom Power Park Substation

Custom Power Park

Figure 4. Custom Power Park Concept