# Power Quality Solutions

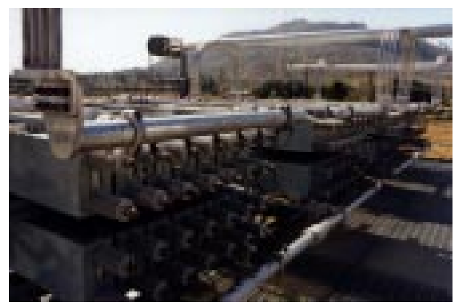


ABB Power T&D Company
Power Systems Division

# POWER QUALITY SOLUTIONS

Optimization is a key word in today's business environment. To an energy provider or large electric power consumer it means achieving the most from an existing power system. The systems described in this brochure provide exactly that, power system optimization.

For the electric power supplier it may mean serving larger distribution loads without expanding transmission service or providing a greater level of power quality to attract high-tech loads. To an electric power consumer, optimization of an existing power system can increase productivity, decrease utility charges, and often improve equipment reliability. Ultimately, optimization improves the competitiveness of a facility or entire business.

The first step in optimizing any system is monitoring and evaluating existing equipment, operating procedures, and frequent problems. ABB can assist with a power system study and evaluation to fully optimize the power supply. Of course, ABB also has an extensive offering of equipment and systems that can optimize a power system for existing and future requirements.

These systems from ABB are largely based upon high-power electronics. ABB is a world leader in power electronics and has developed these systems from experience with 1000+ MW HVDC converter stations, Static VAr Compensators, and large adjustable speed drives supplied to electric utilities and industrial customers for over 30 years.

# Power Quality Solutions



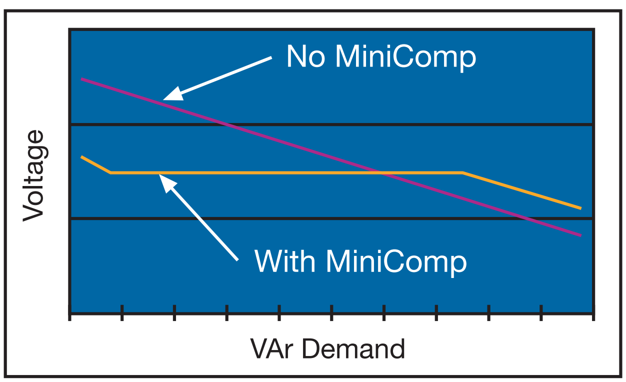


ABB

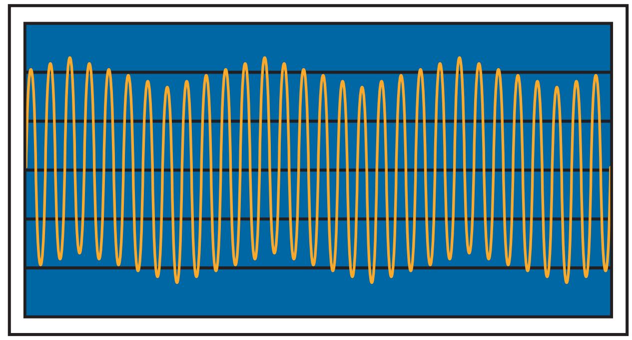
A large inductive load, such as a motor, that is frequently loaded and unloaded, can cause periodic variations in the system voltage. This may result in irritation to others on a distribution system from flickering electric lamps or malfunctioning electronic loads.

A MiniComp provides voltage compensation by providing a rapidly variable source of reactive power. Periodic voltage variations, or voltage flicker, is a function of the change in power requirement and the stiffness of the upstream power system (available short circuit MVA – $S_{SC}$). The change in power consumed by the load is a combination of the reactive power (MVAr=Q) and the real power (MW=P). The change in voltage can be estimated with the following function:

$$\Delta V = \Delta Q / S_{SC} + (\Delta P / S_{SC}) \times (R/X)$$




The MiniComp supplies reactive power close to the load, thereby reducing the reactive power supplied by the power system. MiniComp output is adjusted on a cycle-by-cycle basis, which is normally faster than the demands of an electro-mechanical load. The net result is a significant reduction in voltage flicker. Often, the application of a MiniComp can enable a weak power system to deliver 2 to 5 times more power than a similar system without a MiniComp Alternatives are generally reducing production or increasing the voltage service with a new substation, both less than optimal alternatives.



Voltage Flicker: The periodic variation in RMS voltage, causing annoying "flicker" in electric lamps.

A MiniComp can provide from 1 to 20 MVAr of controllable reactive power. The MiniComp rating (in MVAr) can be estimated by multiplying, the difference between existing and acceptable voltage fluctuations by the system short circuit capacity in MVA at the point of common connection.

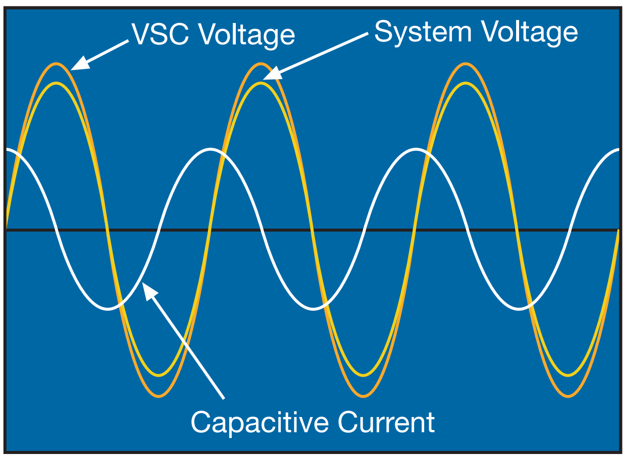
$$\text{Rating} = (\text{Existing } \%\Delta V - \text{Acceptable } \%\Delta V) \times S_{SC}$$

Two MiniComp configurations are available. For applications from 1 to 4 MVAr, a voltage source converter (VSC) is used as a variable source of reactive power. Applications from 4 to 20 MVAr use a thyristor controlled reactor (TCR) to control reactive power output. Both configurations can utilize fixed or switched capacitors to achieve the required level of compensation.

## Common Applications:

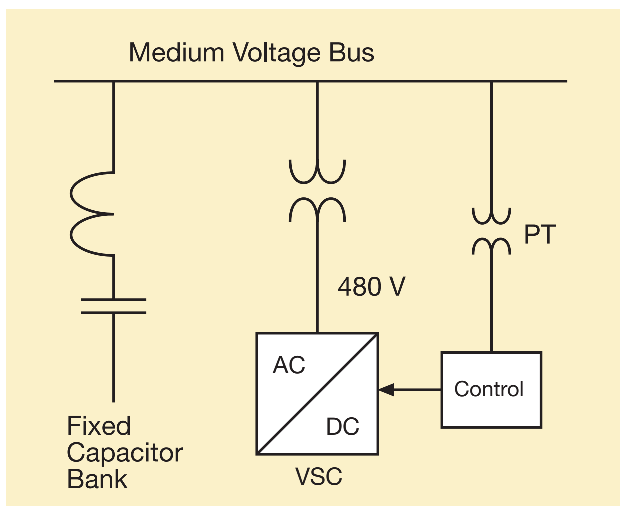
- Starting Large Pumps (Pipelines)
- Mining Shovels & Hoists
- Wood Chippers
- Welding Operations
- Car Crushers & Shredders
- Saw Mills
- Rolling Mills
- Induction Furnaces
- Paper Mills
- Ship Unloading Cranes
- Ski Lifts
- Air Separation Plants
- Cold Starting Power Plants
- Wind Farms

For applications requiring a controllable compensation range of 1 to 4 MVAr, a power electronic voltage source converter (VSC) is used as a source of reactive power. The VSC generates an AC voltage in phase with the system voltage, but of variable magnitude. Reactive power is generated or absorbed with the power system by varying inverter voltage magnitude.




Outdoor enclosure for controls and power electronic converter

VSC output is 480 V and is coupled to a medium voltage system (4.16 to 34.5 kV) with a transformer. The controllable range of the VSC is normally offset with a fixed capacitor bank, directly connected to themedium voltage bus. For example, a ±2 MVAr VSC with 2 MVAr capacitor bank has a net operating range of 0 to 4 MVAr. The master control system monitors the system voltage and varies the VSC output accordingly. The controls respond in less than 1/2 cycle. MiniComp controls can also switch a fixed capacitor bank during light load or over-voltage conditions. A VSC MiniComp can maintain a constant bus voltage in applications wher VAr demand causes voltage drops up to 40%.




Typical bus configuration for a MiniComp using a VSC

## Hardware:

±1 or ±2 MVAr VSC
1 or 2 MVAr Capacitor Bank
Interfacing transformer (5 to 35 kV)
Master control system

## Physical Arrangements:

Indoor or outdoor enclosures
Outdoor, pad mounted
Outdoor walk-in or non-walk-in
Approximate footprint = 10’ x 37’
All components air-cooled
A/C included for VSC & controls
Interconnection optional

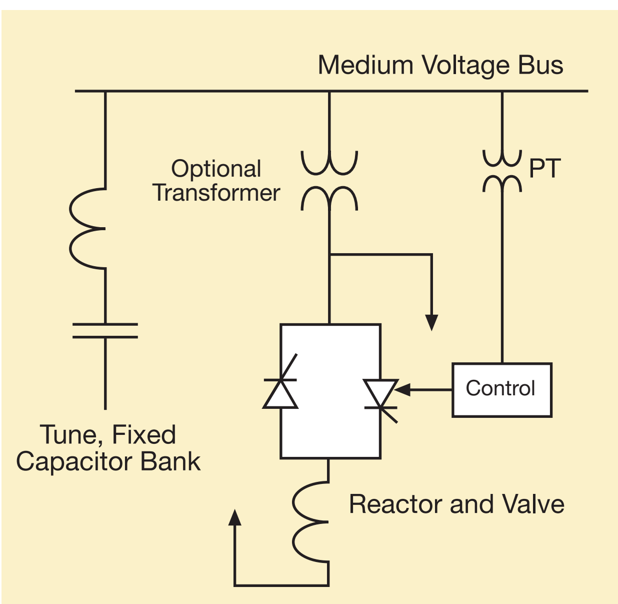
## TCR Configuration

MiniComp solutions requiring 4 to 20 MVAr of compensation use a thyristor controlled reactor (TCR) and fixed capacitor bank. The capacitors provide a constant level of compensation and the TCR provides vernier control of the net compensation. During high VAr demand, such as motor starting, TCR current is reduced. As VAr demand decreases, TCR current increases. A TCR MiniComp can maintain constant voltage or power factor for up to 30% voltage correction.

Capacitors used with a TCR are tuned to filter harmonics, generally the 5th and 7th. Tuning is required as TCR operation generates harmonics. The tuning points are also designed to accommodate existing sources of harmonics, such as variable speed drives in a paper mill.

Water cooled thyristor valve 13.8 kV, 600A

Typical one-line diagram of a MiniComp using a TCR




### Hardware:

4 to 20 MVAr TCR
Tuned Capacitor Bank
Transformer (as needed)
Master control system

### Physical Arrangements:

| | Air Cooled TCR | TCR |
|---|---|---|
| Rating (MVAr) | Up to 6.5 | Up to 20 |
| Voltage (kV) | 1.2 | 1.2 to 13.8 |
| Enclosure | NEMA 3R | NEMA 3R |

Capacitors and reactors are normally located in an outdoor substation. Valves can be applied at any system voltage with application of a transformer. Space requirements can vary from 5000 ft.$^2$ to 40,000 ft.$^2$ depending on MVAr and voltage ratings.

The controls used in both VSC and TCR configurations can be adapted and upgraded to reduce the up-front cost or accommodate a future system uprate. Both of the options listed below can be stand-alone installations or combined with a VSC or TCR.

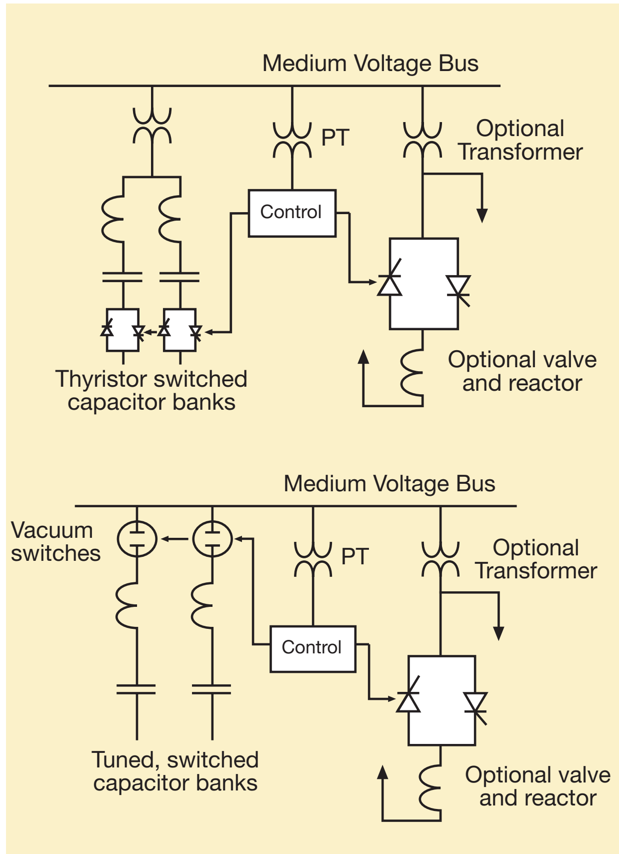
## Thyristor Switched Capacitors

Thyristor switched capacitors (TSC) offer VAr compensation in steps. TSC modules combined with an existing TCR or VSC MiniComp extends the unit's vernier operating range. A TSC module offers soft charging to avoid inrush and zero net-voltage switching minimizing transients. A TSC has no mechanical limitations on switching operations.

## Mechanically Switched Capacitors

Mechanically (vacuum) switched capacitors can be used as an alternative to thyristors if an application requires 10 or fewer switching operations per day. Mechanically switched capacitors can be controlled by a MiniComp controller and thus reduce the rating of a TCR while providing vernier control over an extended VAr range. This arrangement is an extremely economic solution for (infrequent) line-starting of large motors on a weak system.

Thyristor or mechanically switched capacitors can be used alone or with a TCR to reduce the TCR rating

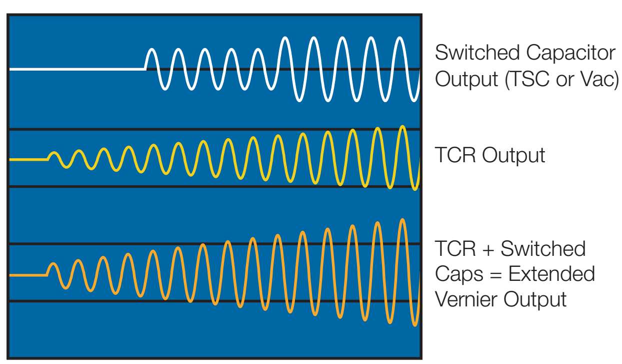



## Hardware:

- 1.2 MVAr, 800V TSC
- Up to 5 TSC steps per control system
- Transformer (as needed)
- Tuning reactors (as needed)
- 1 to 10 MVA for Vacuum switched
- 600A, 5 to 35 kV Vacuum switches

## Physical Arrangements:

- Air Cooled
- Indoor or NEMA 3R enclosure
- Oil or dry-type transformer
- Switches Controlled by MiniComp

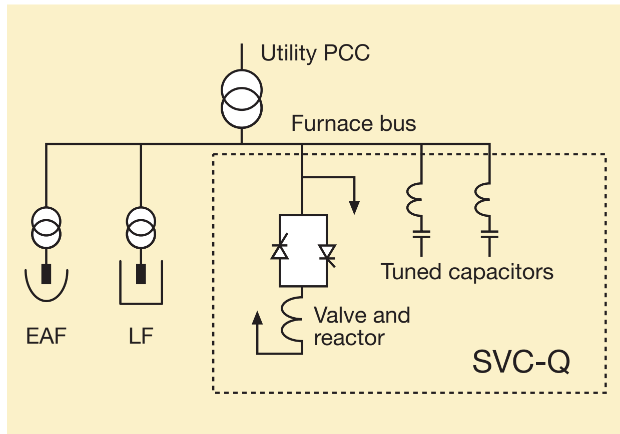


# SVC-Q

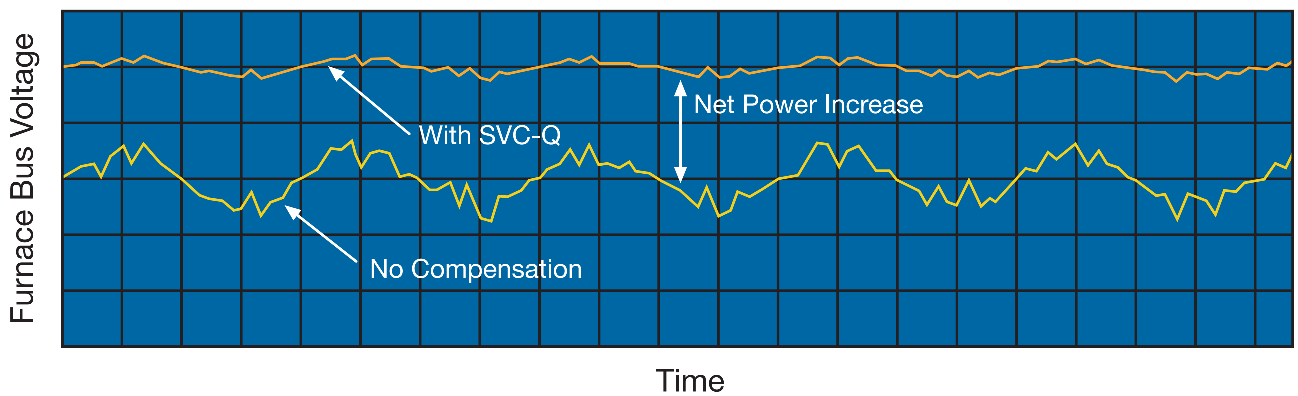
SVC-Q offers benefits similar to the MiniComp, but for applications requiring ratings greater than 20 MVAr. The most common sites for SVC-Q are electric arc furnaces (EAF) and large rolling mills. Typically SVC-Q can increase production from 10% to 15% and reduce operating costs.

To achieve optimum performance, an arc furnace requires a stable and steady voltage supply. SVC-Q compensates for the random variations in reactive power demand from an EAF. The net result is an improvement in EAF utilization.

SVC-Q uses a thyristor controlled reactor (TCR) and fixed capacitor banks. The capacitors are often split into two or more branches to achieve the proper tuning characteristics.




Possible EAF-bus configuration with SVC-Q




## Reactive power compensation with SVC-Q can provide the following benefits:

### Higher furnace-busbar voltage:
Shorter melt times
Reduced energy losses
Extended electrode life
Extended ladle lining life

### Improved power factor:
Lower utility penalties
Use existing electrical equipment more effectively

### Voltage stabilization and harmonics reduction:
Minimize disturbances in nearby electrical equipment
Reduce misoperation of protective devices
Extend motor life by reducing negative sequence currents

0 to 44 MVAr, 10.5 kV SVC Light

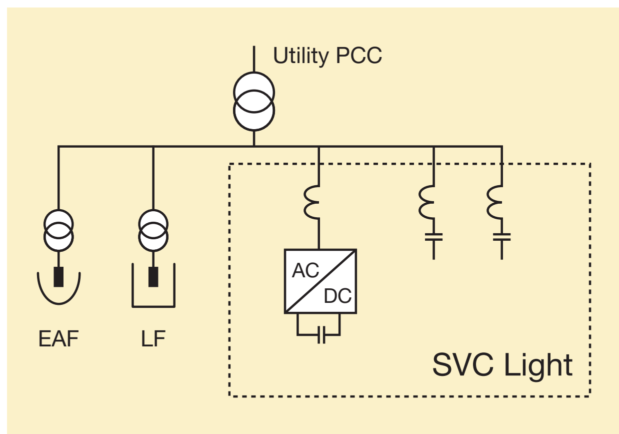
SVC Light is the premium method of electric arc furnace (EAF) compensation. SVC Light uses a voltage source converter (VSC) as a variable source of reactive power. A capacitor bank is normally applied with the VSC to offset the net operating range.

Insulated gate bi-polar transistors (IGBT) are the power electronic devices used in SVC Light. Several IGBTs are series connected to form a valve. An SVC Light system uses 12 valves configured as a three-level converter.

The valve design enables the converter output to be 10 kV or greater. With this operating voltage, the converter can be directly connected to the furnace bus with standard air-core reactors.

IGBTs are also used to enable a converter switching frequency greater than 1 kHz. With this switching frequency, SVC Light can alter its reactive power output in less than 1/4 of a cycle. A traditional SVC can respond within 1/2 of a cycle. With a faster response, SVC Light can often provide more than twice the flicker suppression of a conventional SVC.

SVC Light offers benefits to both utilities and steel producers. Utilities can maximize the use of existing transmission lines, while reducing customer complaints caused by flicker. For steel producers, SVC Light offers increased production benefits like SVC-Q. Furthermore, steel producers now have additional choices in selecting a greenfield EAF location. A new mill site can be selected on the basis of attributes such as qualified workforce, transportation infrastructure, and low cost electricity, rather than adequate electrical transmission capacity.




Possible EAF-bus configuration with SVC Light converter and capacitors

## AC Furnace

$S_{SC}$/EAF Rating > 80 No Compensation

80 > $S_{SC}$/EAF Rating > 40 SVC-Q

$S_{SC}$/EAF Rating < 40 SVC Light

## DC Furnace

$S_{SC}$/EAF Rating > 60 No Compensation

60 > $S_{SC}$/EAF Rating > 30 SVC-Q

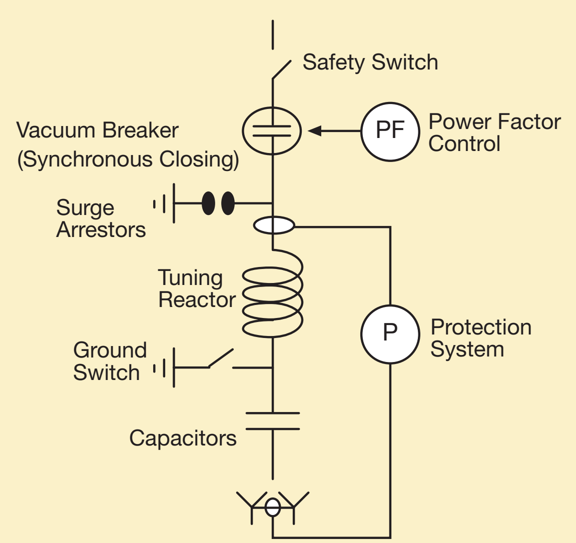
$S_{SC}$/EAF Rating < 30 SVC Light

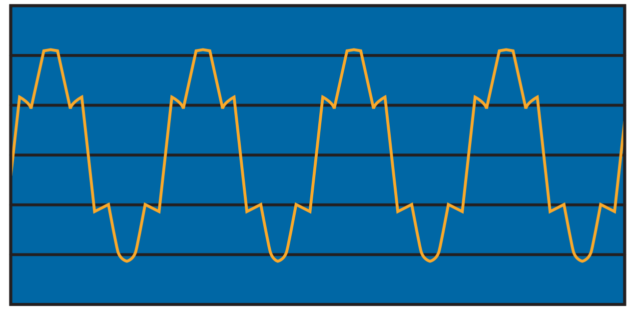
The type of compensation needed for a particular EAF site can be estimated from the table above. Short circuit capacity ($S_{SC}$) and EAF rating are both in MVA.

# Harmonic Filters

Non-linear loads such as variable speed drives (VSDs), rectifiers, or other electronic loads can cause harmonic currents to flow in the power system. Harmonics are often associated with overheating transformers, capacitor bank failures, nuisance protective relay trips, or consistent operational problems with sensitive loads close to the harmonics source.

In addition to causing harmonic distortion in the system voltage, non-linear loads often operate with a poor power factor. This can result in utility penalties and voltage depressions on a weak system.



Harmonic Distortion: Non-linear loads can distort system voltage from a sinusoid causing overheated transformers and other problems.

To improve power factor on a non-linear load and reduce utility surcharges, capacitor systems must include a tuning reactor. Untuned power factor correction capacitors can actually amplify a harmonic by creating a resonant condition.

Tuned capacitors provide a low impedance path for harmonic currents generated by non-linear loads. This reduces distortion in the voltage waveform, alleviating most or all of the other problems associated with harmonic distortion.

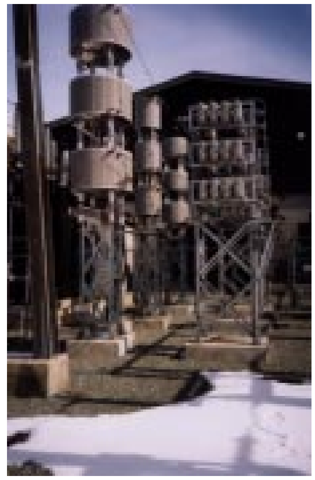
ABB can provide filter system services from analysis to commissioning. Upon identification of a harmonics or power factor problem, ABB can assist with expertise in electrical and civil design, component selection, testing, and commissioning.

The first step in applying a filter system is determining the effective MVAr rating. The MVAr requirement is largely an economic calculation, based on utility power factor penalty charges and equipment VAr demand.

## Physical Arrangements:

Indoor or outdoor designs
Single or double-wye designs
Footprint dependent on voltage and MVAr ratings
All components air-cooled

Once the MVAr rating has been calculated, specific harmonics present need to be quantified. ABB's experience with industrial harmonics is applied to design the filters to so that maximum harmonic distortion is reduced to IEEE 519 harmonic standards.


Live Open-Rack

### Industrial applications include:

- Steel Mills
- Electro-chemical rectifiers
- Aluminum and copper smelters
- Pulp and Paper
- Traction
- Foundries
- Solid state drives


Metal Enclosed

Harmonic filters from ABB are available with internally or externally fused capacitors. Internally fused capacitors are more compact and inherently more reliable than externally fused cans.

Harmonic filters from ABB are available in a variety of packages. A live-open-rack arrangement is a low-cost option for an outdoor installation behind a substation fence. A pole-mount design is also available for applications up to 1200 kVAr. Metal enclosed filters are forced air cooled and can be installed indoors in a NEMA 1 enclosure or outdoors in a NEMA 3R structure. The SIKAP filter design from ABB does not require forced air cooling and is an option for outdoor installations with safety, space, or aesthetic limitations.


"SIKAP" Design

Some options for filter designs are listed below. However, additional options can be provided by ABB to meet specific requirements. ABB can also offer performance guarantees on a technical or economic basis.

### Standard Hardware:

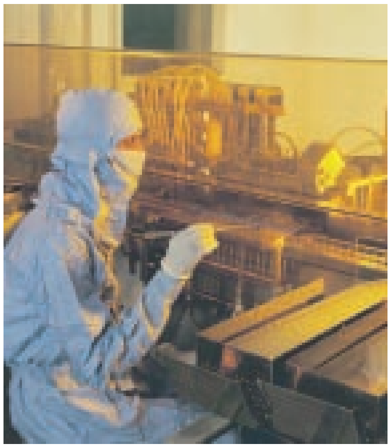
0.5 to 20 MVAr tuned capacitance
4.16 to 46 kV capacitors
Controls and NEMA 4 Cabinet

### Optional Hardware:

High-pass resistor
Ground switch
Disconnect switch
Phase imbalance protection

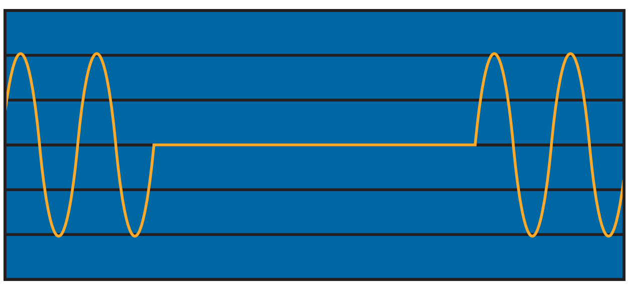
# Outage & Voltage Sag Protection

## DUPS, DVR, S-DVR

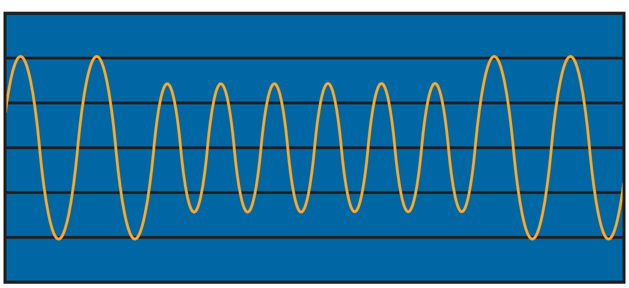


The DUPS, DVR, and S-DVR protect a sensitive load from events that originate on the utility system.  Faults on the utility grid cause voltage sags or even outages at an end user's facility. These events can interrupt automated or sensitive processes resulting in costly downtime.

These systems are presented from most comprehensive to the lowest cost per load MVA.  Ultimately, economics is the driver for these types of solutions. The avoided costs associated with a process interruption, in a given length of time, must be greater than the power quality equipment cost.



Outage: The loss of utility voltage for a sustained period.



Voltage Sag: A net reduction in RMS voltage for a period of cycles.

To optimize application of a DUPS, DVR, or S-DVR, a power system engineering study is required.  The study should examine the upstream power system and consider the root cause of any voltage sags or outages.  Sag and outage data such as the depth and duration of each event, is also important.  Finally, the sensitivity of in-plant equipment is also needed.

With this information, a voltage boost level can be calculated as the difference between typical sag depth and equipment sensitivity.  If energy storage is used with the solution of choice, typical event duration is used to calculate the energy storage capacity rating.

A DUPS is the ultimate protection for an entire facility from utility outages, voltage sags, and swells. The DUPS is a second energy supply, connected in shunt with the main power supply.

Water cooled IGCT converter.
1 of 2 identical converters used in applications up to 5MW.

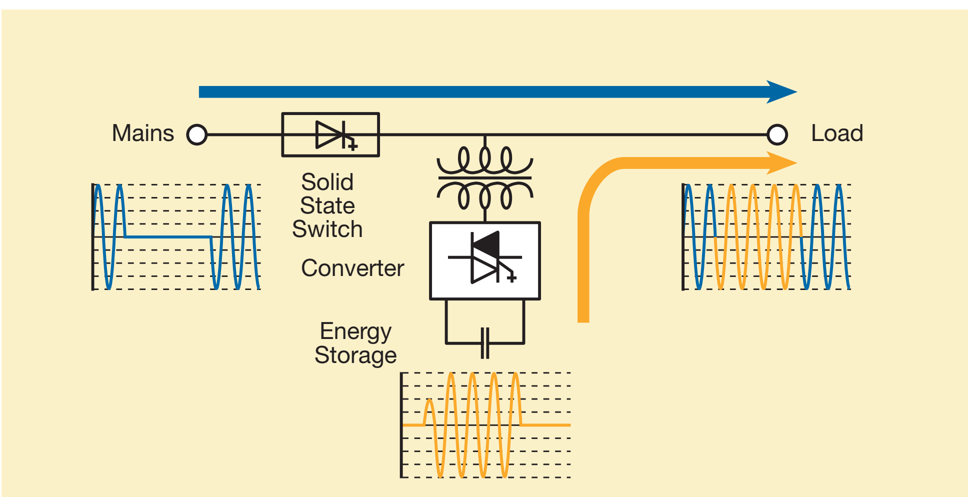
### Typical Applications:

- Hospitals
- Radar installations
- Data centers
- Financial institutions
- Semiconductor plants

The DUPS uses an IGCT-based DC-to-AC power electronic converter. DUPS converters using IGCT devices can be built with ratings ranging from 1 MVA to as large as 100 MVA while exhibiting superior efficiencies as compared to other devices.

A DUPS is designed to have a minimum one minute ride-through. Additional energy storage can be provided as needed. Batteries are normally used as the energy storage medium. Alternatives such as superconducting magnets, flywheels, and fuel cells can be used as well. The DUPS control can also be designed to start backup diesel or gas generators in the event of a long-term outage.

If the system voltage varies from an acceptable range, the DUPS disconnects the load from the system and supplies power from a stand-by source. Operation time including detection, disconnect, and re-supply is less than 5 to 6 milliseconds.




DUPS Operation During an Outage

### Hardware:

1 to 100 MVA converter
Solid state disconnect switch
1 minute or greater ride-through
Interfacing transformer (5 to 35 kV)
Master (PSR) control system

### Physical Arrangements:

All indoor equipment
Minimum 1000 ft.$^2$ footprint
Water cooled power electronics

# Dynamic Voltage Restorer

**DVR**

The DVR is similar to a DUPS. However, the DVR protects a sensitive load from from momentary voltage dips, or sags, but not outages. Outages do occur, however, the predominant power quality cause of industrial process interruptions is voltage sags. The DVR is a series connected system that generates the "missing" voltage during a sag.

## Typical Applications:

- **Semiconductor plants**
- **Automotive manufacturing**
- **Plastic extrusion processes**
- **Paper Mills**
- **Automated manufacturing lines**

By compensating in this manner, significant reductions in converter and energy storage ratings are achieved.

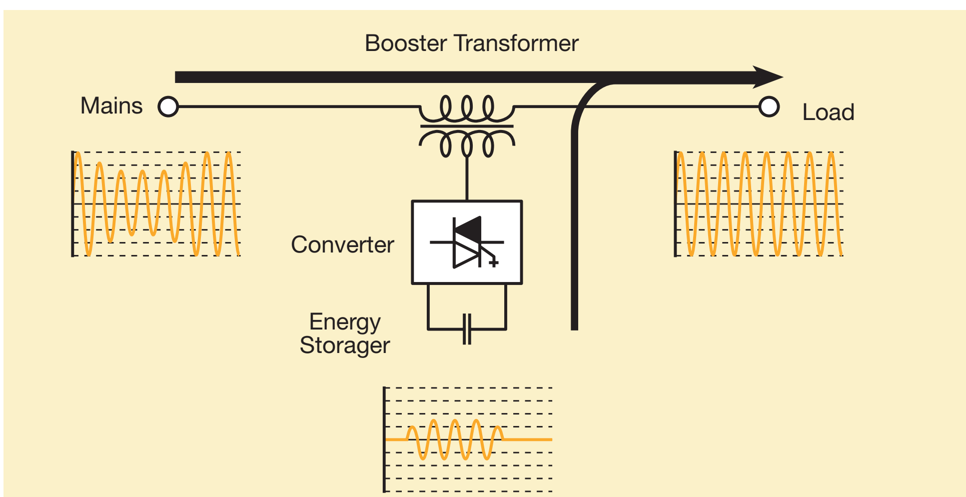
The actual converter and energy storage ratings are determined by boost and ride-through requirements.

The DVR converter provides less than 1/4 cycle response time and can compensate for voltage phase shift, a phenomenon that often accompanies voltage sags.

Voltage boost usually ranges from 25% to 50%, depending on sag and protected equipment characteristics. Ride-through time is a function of energy storage and normally ranges from 10 to 30 cycles. Capacitors are normally used for energy storage, though other means can be applied.

The DVR also uses an IGCT converter. This converter is readily scalable to protect loads up to 100 MVA and provide 50% voltage boost. Depending upon converter rating and external environmental conditions, DVR power electronics may be air or water cooled.

DVR Operation
During a Voltage Sag




## Physical Arrangements:

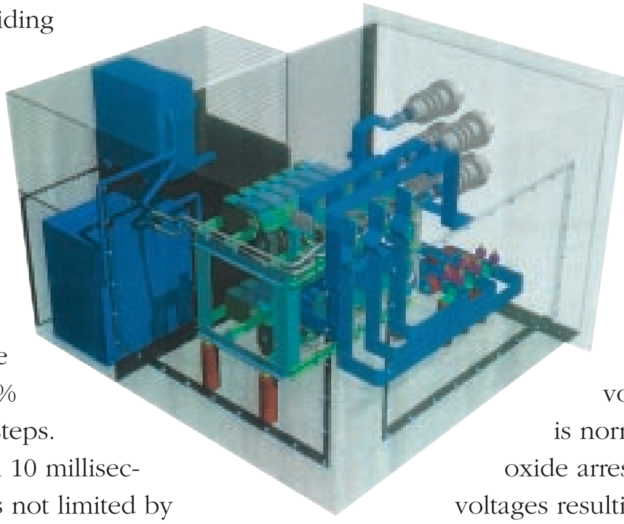
Indoor or containerized
Minimum 400 ft.$^2$ footprint
Air or water cooled power electronics

## Hardware:

2 to 50 MVA converter
(4 to 100 MVA of protected load)
Energy storage for 20 cycle
or greater ride-through
Booster transformer
Master (PSR) Control System

# Step-Dynamic Voltage Regulator

## S-DVR



An alternate means of providing voltage boost during a sag is with a tap-changing transformer. The S-DVR provides voltage boost with thyristor switches that rapidly change taps on a specialized transformer.

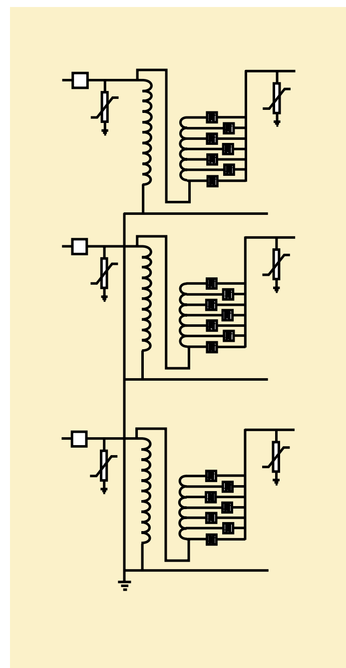
The regulation range can be as wide as 50% boost to 10% buck, usually in 3% or 5% steps. Tap changing occurs within 10 milliseconds and tap changer life is not limited by the number of operations. There are no moving parts in the current path.

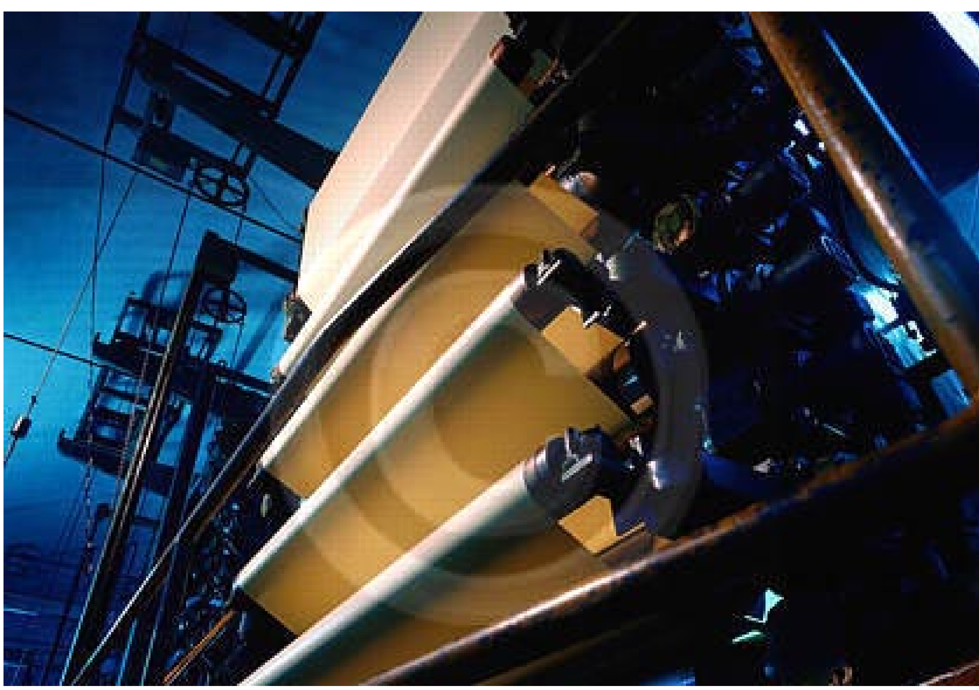
The S-DVR does not use energy storage when providing voltage boost and can therefore boost indefinitely, if required. Existing upstream breakers require coordination as the S-DVR can draw up to twice the rated current when providing voltage boost. Also, the S-DVR is normally equipped with metal-oxide arresters to limit transient overvoltages resulting immediately after the return of nominal voltage after a sag condition.

**Typical Applications:**

- Semiconductor plants
- Automotive manufacturing
- Plastic extrusion processes
- Paper Mills
- Petro-chemical plants
- Pharmaceutical
- Automated manufacturing lines

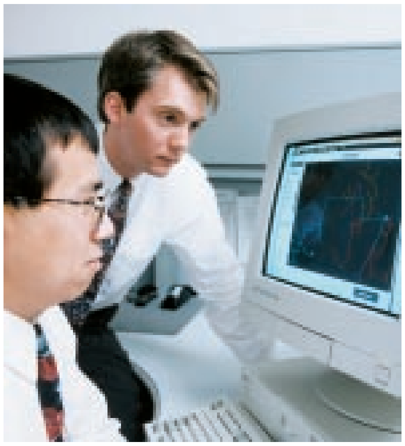
An S-DVR can be applied as either a 1:1 or step-down transformer. Tap changing is performed on the primary winding. The S-DVR compensates for the magnitude of a voltage sag but not the phase shift.





# Technical Services & Support

## Monitoring, Analysis, & Design



To truly optimize a power system with any of the system solutions described herein, the first step should be an engineering study.

ABB Power Systems can assist by assessing an existing system then providing monitoring and further analysis as needed. ABB experience ranges from small industrial to high voltage utility transmission systems. Actual study objectives can range from solving day-to-day operating problems to developing long-term expansion plans.

### Technical study capabilities include:

- Power quality site assessment
- Power quality monitoring
- Reactive power and voltage control
- Reliability analysis
- Cost/benefit analysis
- Economic justification
- Equipment Specification

After the completion of a study and equipment purchase, ABB can provide installation services for power quality systems and other substation equipment. A complete array of turnkey services is available including:

- Civil and electrical design
- Civil construction
- Electrical contracting
- Equipment start-up
- Equipment commissioning

The service and support organization maintains relationships with numerous outside entities which can provide assistance with scopes beyond their everyday capabilities. Additionally, the expertise of other ABB operations in the US, Sweden, or Switzerland is available, as a project necessitates.

Beyond the purchase and start-up phases, ABB Power Systems is committed to support projects after they are commissioned. This commitment includes technical, administrative, and coordination support to all Power Systems' projects throughout the useful equipment lifetime.

After sales service and support from ABB Power Systems provides comprehensive maintenance services including:

- **Engineering & maintenance support**
- **Spare parts**
- **Preventive maintenance**
- **Corrective maintenance**
- **Emergency repairs**

A unique advantage of the ABB service and support organization is that its engineers have been involved in the construction and commissioning phases of the projects they support. As a result, the engineers providing support have a detailed knowledge of system operation. In addition, this experience enables a fast response when technical and administrative assistance is needed.

ABB can also provide training programs, technical audits, and continuous on-site services to keep systems operating at optimum efficiency.

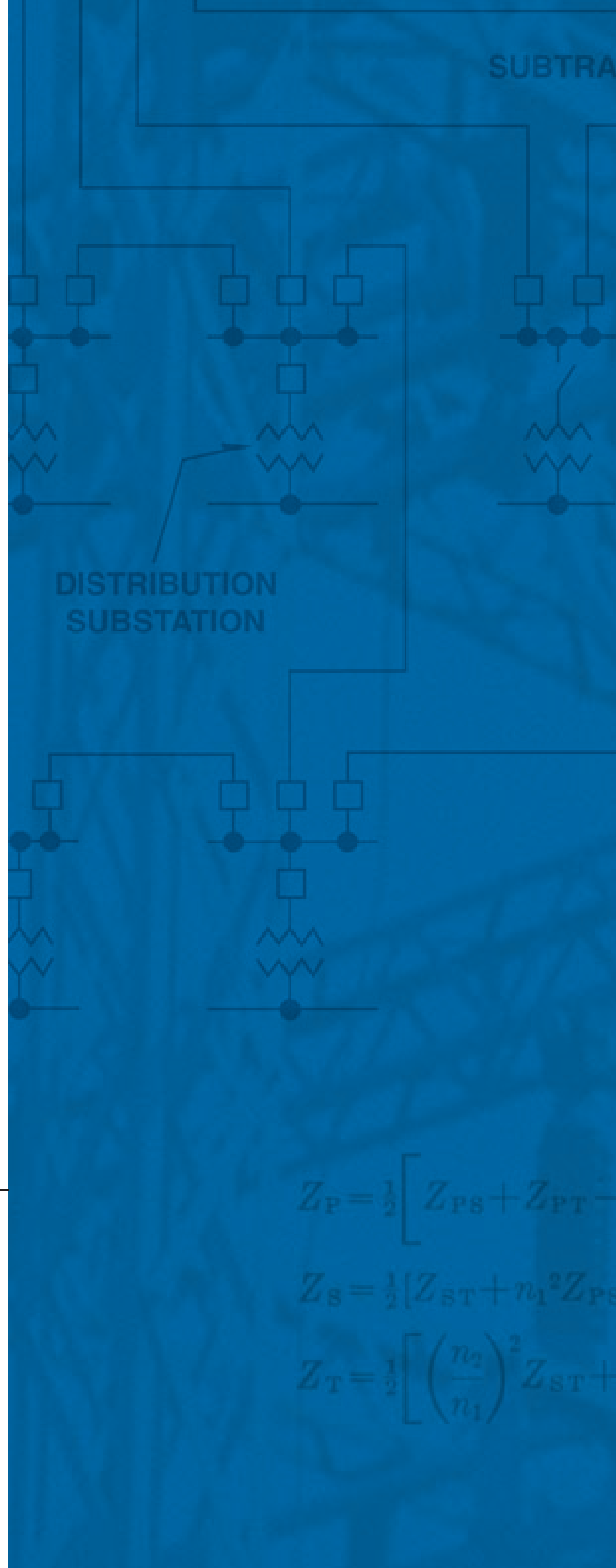
# Power Quality Experience

This experience list is intended to show the long term commitment and depth of expertise of ABB to power quality and high power electronics across a range of industries. It presents only a fraction of the hundreds of ABB projects in these areas worldwide.

| System | Date | Location | Industry | Application |
|---|---|---|---|---|
| SVC-Q | 1974 | New York State | Steel | EAR - Reduce flicker & increase production |
| SVC-Q | 1974 | South Africa | Steel | Rolling Mill - Flicker & Harmonics |
| Service | 1978 | Western USA | Utility | Uprate to HVDC converter stations |
| SVC-Q | 1980 | Pennsylvania | Steel | EAF |
| SVC-Q | 1985 | Wales, U.K. | Steel | Rolling Mill |
| MiniComp | 1988 | Kansas | Pipeline | Starting large pumps on weak system |
| MiniComp | 1988 | Pennsylvania | Welding | Flicker, Phase Imbalance |
| MiniComp | 1989 | British Columbia | Mining | Expand remote mining operation limited by weak utility system |
| Service | 1989 | Western USA | Utility | Second uprate to HVDC converter stations |
| MiniComp | 1990 | Georgia | Pulp&Paper | Wood chipper causing voltage flicker |
| SVC-Q | 1990 | Illinois | Steel | EAF |
| MiniComp | 1992 | California | Utility | Induction generators at wind farm cause voltage instability on 66 kV system |
| Service | 1994 | Pacific Northwest | Utility | SVC turnkey |
| MiniComp | 1995 | Panama | Shipping | Large motor starts on weak system |
| Harmonic Filter | 1996 | Arizona | Mining & Metals | SIKAP design, harmonics caused by electrowinning rectifiers |
| MiniComp | 1996 | New Jersey | Plastic Extrusion | System too weak for starting 5000 hp motor |
| Harmonic Filter | 1997 | Louisiana | Chemical | Open rack design, rectifiers |
| Service | 1997 | Connecticut | Traction (Rail) | Turnkey, filter substation |
| DVR | 1998 | South East Asia | Semiconductor | 230 kV faults cause voltage sags, disrupt production in fab. |
| DUPS | 1998 | South East Asia | Semiconductor | Frequent outages unacceptable for profitable plant operation |
| MiniComp | 1998 | Utah | Cement | Utility system too weak to support large motor starts |
| Service | 1998 | California | Municipal Utility | Turnkey 138kV substation |
| MiniComp | 1998 | Illinois | Utility Power Generation Plant | Allows auxiliary system motors to cold-start plant during transmission contingency |

## Application Guide

| | MiniComp | SVC-Q | Harmonic Filters | DUPS | DVR | S-DVR |
|---|---|---|---|---|---|---|
| Voltage Flicker Mitigation | ● | ● | | | | |
| Harmonic Reduction | ● | ● | ● | | | |
| Power Factor Correction | ● | ● | ● | | | |
| Outage Protection | | | | ● | | |
| Sag Mitigation | | | | ● | ● | ● |
| Swell Protection | | | | ● | ● | ● |

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