ABB, DM, Power Protection – Laurent Maillefer, May 2014

Reactive Power Conditioning
The full power factor solution

Reactive Power Conditioning
The Problem

Datacenter

- leading power factor
- current imbalance
- harmonics on generator

Motors and drives

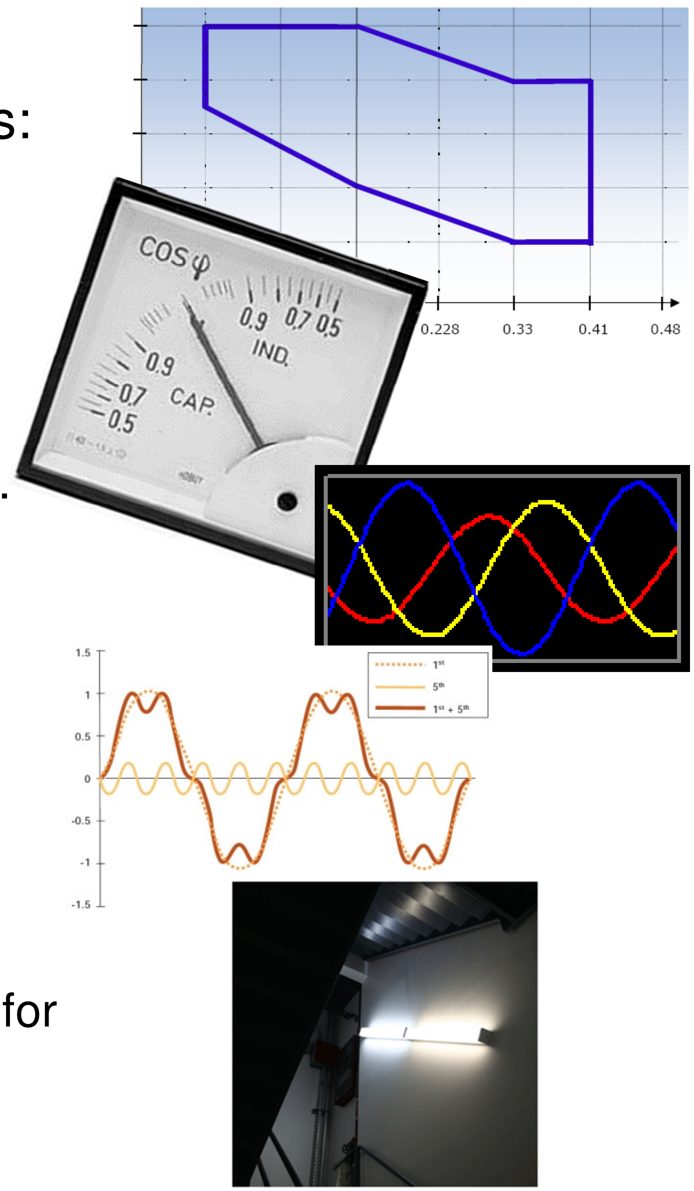
- lagging power factor
- low order harmonics
- DOL motor starting
- voltage imbalance

Light Industry

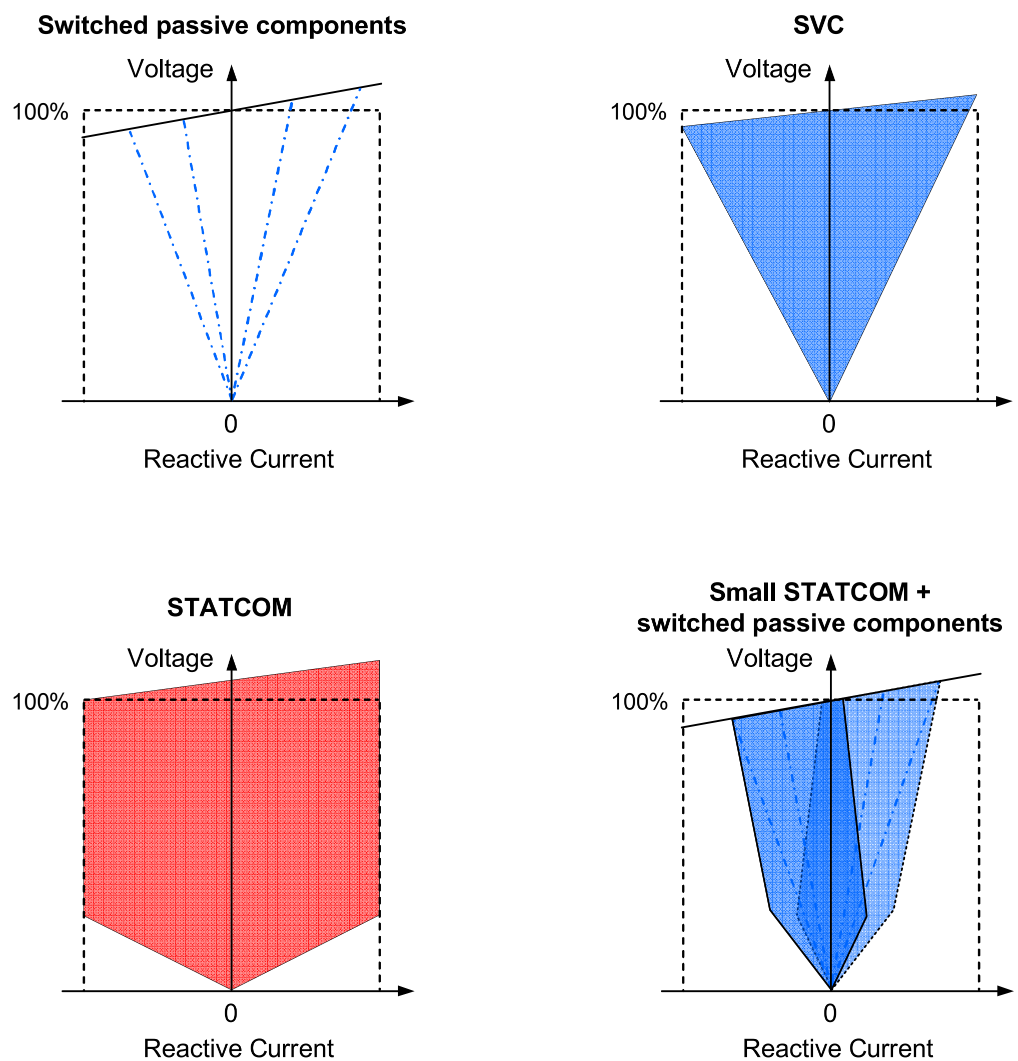
- small voltage sags
- light flicker
- power factor
- current imbalance

Reactive Power Conditioning
The Problem

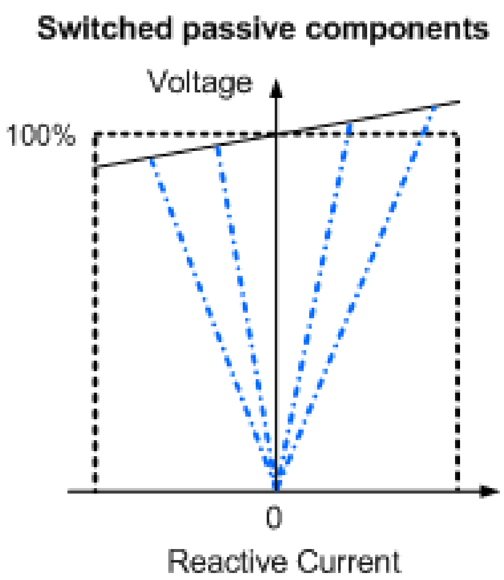
- **Typical applications problems that can be fixed or mitigated by reactive power:**
- Power factor correction with dynamic issues such as:
- Fluctuating reactive loads (Voltage problems)
  - Welders, Cranes, hoists
- Unbalanced loads (Negative Sequence problems)
  - 1 and 2 phase loads welders, saws, presses, pumps etc.
- Low order harmonics (Harmonics)
  - 6 pulse AC motor drives and UPSs drawing 5th and 7th harmonic current – power factor and generator compatibility issues
- Leading power factor (Power Factor problems)
  - Some IT server power supplies will draw significant leading power factor which can be significant problem for UPSs and generators in datacenters



Reactive power solutions
Overview



Reactive power solutions
1: Switched capacitor/inductor banks



The simplest solution is without any doubts a combination of switched passive elements, i.e. switched capacitors and inductors.

The figure to the left shows qualitatively the reactive current versus connected voltage of such a solution. The reactive current depends linearly on the grid voltage and as a consequence the reactive power changes with the square of the grid voltage. Depending on the amount of switched component branches, the reactive current can only be altered in more or less large steps. Due to the limited switching time of capacitors, the dynamic performance of this solution is reduced. Furthermore, switching transients have to be accepted with this solution as well as regular maintenance of the breakers.

Reactive power solutions
2: Static VAr Compensator (SVC)

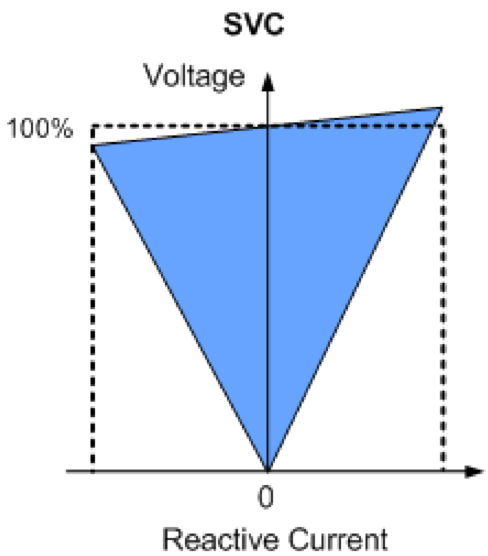


Figure to the left shows the reactive current versus connected voltage of a widely used reactive power compensator: the SVC (Static VAr Compensator). The SVC combines thyristor switched capacitors (TSC) with thyristor controlled reactors (TCR). Doing so, a smooth variation of reactive power over the complete installed power range is possible.

Reactive power solutions
3 & 4: Statcom

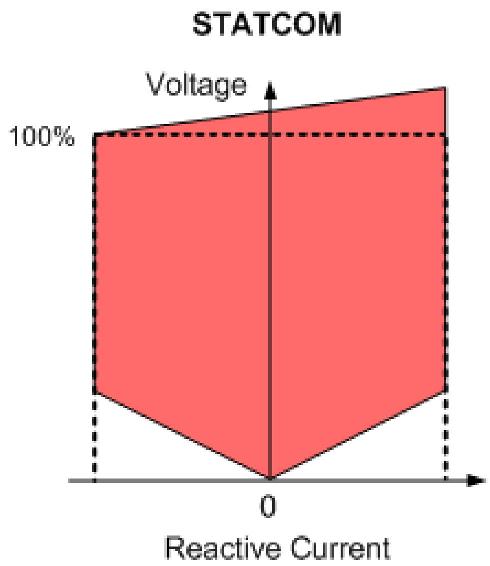


Figure to the left shows the reactive current versus connected voltage of a STATCOM. The performance is similar to a SVC, i.e. it performs smooth variation of reactive current across its operating range with high dynamics. It has some advantages when compared to the Static Var Compensator (SVC), e.g., current injection independent of the system voltage, faster control and less of a space requirement.

Another option is the combination of switched passive components with a small-sized STATCOM. This solution still includes disadvantages of switched passive components, e.g. switching transients and the need for regular maintenance of the breakers.

From an operator's point of view, a solution for reactive power compensation without mechanically switched components is therefore preferred.

Reactive power solutions
Comparison

	Advantages	**Disadvantages**
Switched Capacitor Bank	• Robust • Reliable	• Q can only be controlled stepwise • $Q = f(U^2)$, $I_Q = 0$ @ $U = 0$ • Risk for resonances in grid • Need to be switched → resonances can be hit → special breakers needed (re-strike) → discharge time (zero-crossing switching) → Pre-insertion resistors (or reactors)
SVC	• Continuous Q control • High dynamics • Established technology (for >30 years)	• $Q = f(U^2)$, $I_Q = 0$ @ $U = 0$ • Space requirements • Harmonics

Reactive power solutions
Comparison

	Advantages	**Disadvantages**
STATCOM	• $Q = f(U)$, $I_Q = I_N$ • Continuous Q control • High dynamics • Space requirements	• $I_Q = 0$ @ $U <$ approx. 15%
STATCOM + Switched Cap. (+ Reactor) Bank	• Continuous Q control	• $Q = f(U, U^2)$ • Space requirements • Switched capacitors (see above) • Resonances
Synchronous Condenser	• Continuous Q control • $I_Q > I_N$ down to $U = 0$ (short term) • Overloadability • Space requirements	• Auxiliary equipment (starter, excitation) • Losses • Foundation • Low dynamics • Maintenance and repair time (availability)

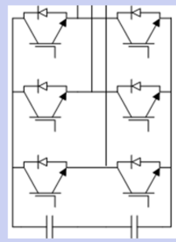
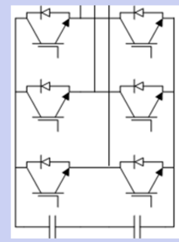
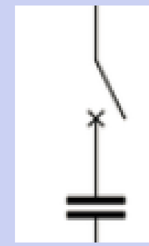
The Economic Benefit
2MVA transformer example

An example is shown below, where a 2MVA transformer (of 6% impedance) is feeding a 400 Vac bus with mixed reactive and harmonic industrial loads of 1.5MVA:

	No Compensation	VAr only (caps)	Harmonics only	Reactive Power Conditioning
Displacement PF	0.85	0.99	0.85	1.00
5th Harmonic current	30%	30%	0%	0%
7th Harmonic current	12%	12%	0%	0%
11th Harmonic current	5%	5%	0%	5%
13th Harmonic current	2%	2%	0%	2%
THDi	33%	33%	0%	5%
Distortion PF	0.950	0.950	1.000	0.999
Total PF	**0.808**	**0.941**	**0.850**	**0.999**
Load Voltage	389 V	397 V	389 V	400 V
Transformer Loading	93%	80%	88%	75%

What your meter is counting for your electricity bill is true RMS current!

Reactive Power Conditioning
Feature/performance comparison of diff. solutions

Technology	Reactive Power Conditioner	Active Harmonic Filter	Switched Passive Elements
Feature/Benefit			
Speed (VAr vs time)	Fast	Fast	Slow
Footprint	Small	Medium	Large
Loss	Low	Medium	Very Low
Harmonic bandwidth	Medium	High	Low
Overload	Often 200%	Typically none	None
Cost	Medium	High	Low

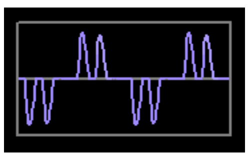
Technology Comparison
RPC versus broadband active harmonic filters

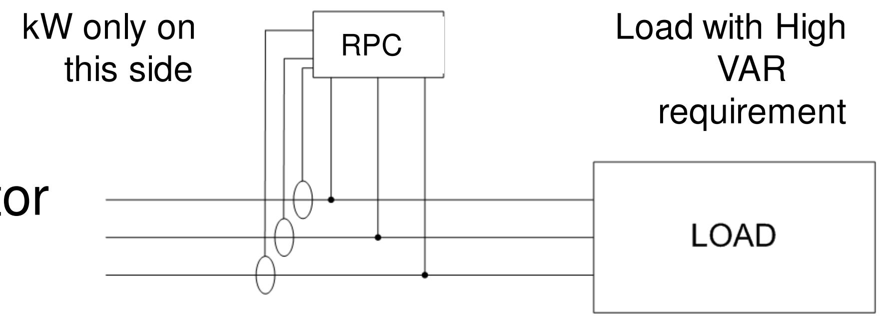
- Broadband active harmonic filters are designed mitigating harmonics typically up to the 50th harmonic. To do this they need to switch their semiconductors at high switching speeds which results in additional loss and component de-rating.
- The Reactive Power Conditioner is optimised to correct just 50/60 Hz issues and low order harmonics (5th and 7th) which means lower switching frequencies can be used and as a result the product can be smaller, cheaper and have lower losses.
- For some applications, such as meeting certain standards, high order harmonics must be corrected and a broadband active filter is a good choice. Even in these cases it may be more economic to use a combination of products RPC for nominal and low order harmonics and with a small active harmonic filter for the high order harmonics.
- Most general fast VAr and difficult VAr applications do not require correction of high order harmonics.

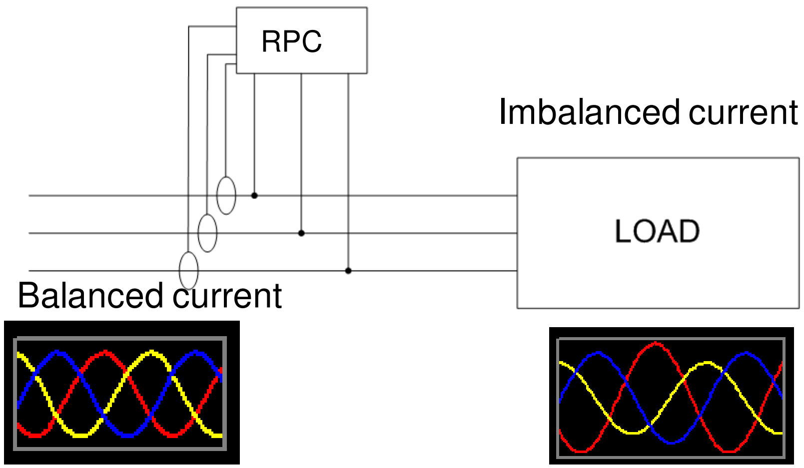
Reactive Power Conditioning – How it works

Reactive Power

- Reactive Power Conditioner = current source
- By injecting reactive current at fundamental frequency either leading or lagging power factor or small voltage problems can be corrected
- Injecting negative sequence current (different voltage vector rotation) in the load current allows imbalance to be corrected
- Injecting harmonic current equal but opposite to the load harmonic currents allows harmonics to be corrected

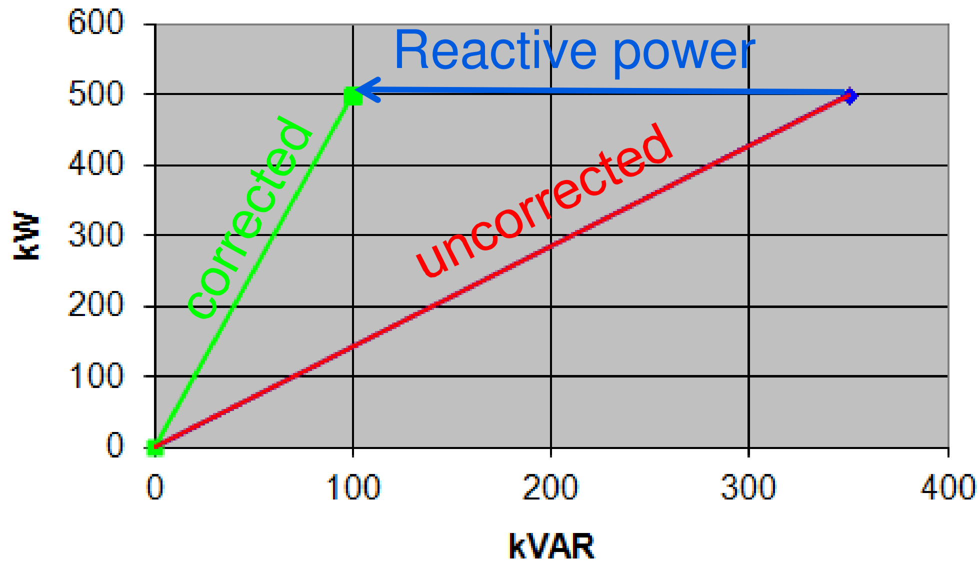






What Size Do I Need?
Power Factor

- How much Var's are needed to correct the power factor?
- Data needed are power (real or apparent), the current power factor and the target power factor.
- $S^2 = P^2 + Q^2$
- $\cos \varphi = P/S$



- The system can be sized to provide 100% of the kVAr requirement
- Alternatively the Power Electronics can be sized for dynamic VArs (making use of the overload capability) and switched capacitors used for steady state or slow requirements.

Reactive Power Conditioning – What Size Do I Need?
Dynamic VArs and Flicker

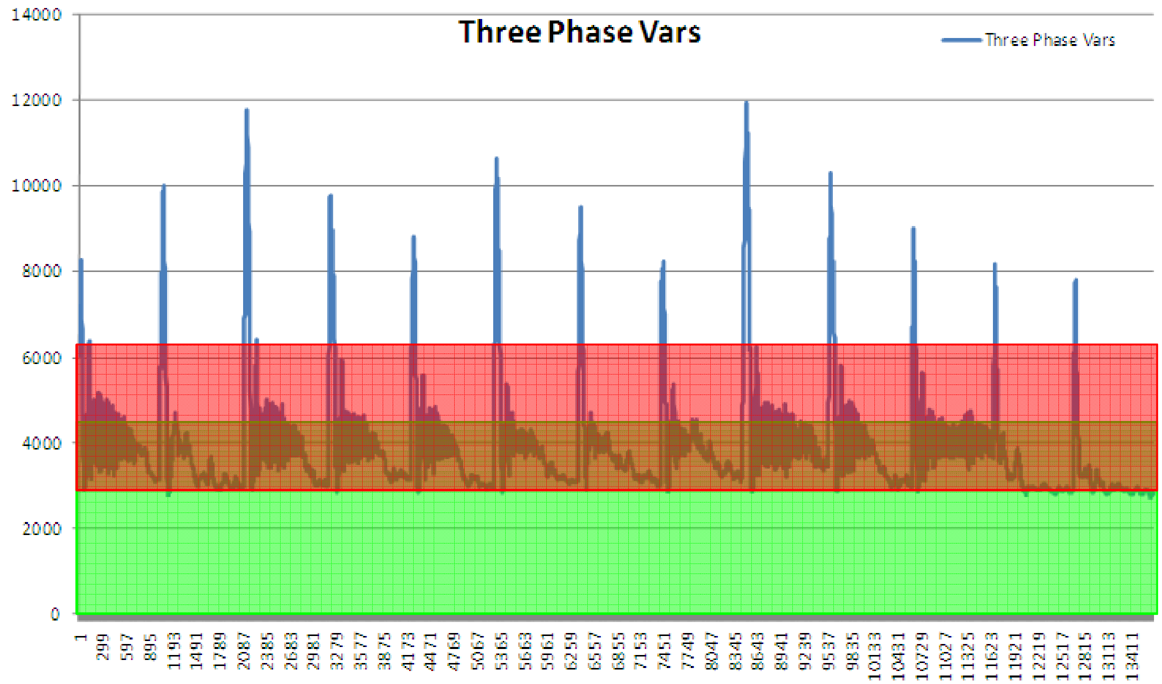
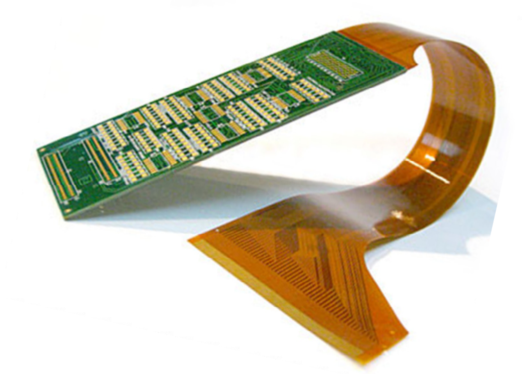


Figure 7: Variation in reactive power during shredding cycle

- The average reactive power was compensated by a 4MVAr capacitor bank
- Dynamic reactive power (flicker) was compensated by a 1.5 MVAr power electronics based RPC

Reactive Power Conditioning
Industry Case Study: Polymide Film for FPC*



Problem

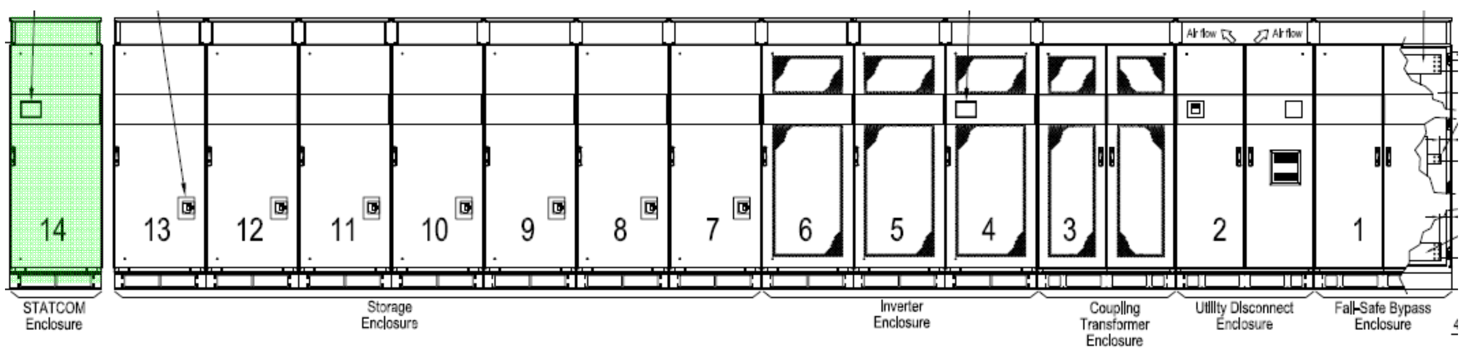
- Customer needed Uninterruptible Power Supply and PF>0.9

Solution

- A single conversion UPS 2100 kVA (30sec) and a 320 kVAr RPC on 415 Vac

Benefit

- Price competitiveness
- PF>0.9
- Reduced 5th and 7th harmonics
- Small footprint



*Flexible Printed Circuits

Reactive Power Conditioning
Industry Case Study: Datacenter Leading Power Factor

- Many modern AC datacenters run 1+1 reticulated power supply configurations feeding lightly loaded switch-mode computer power supplies in racks which run at leading power factor (0.85 to 0.9 lead typical)
- Leading power factor means UPS systems need de-rating. Should the UPS switch to bypass the generator will be exposed to leading power factor which may cause self-excitation exposing the datacenter to dangerous voltages

RPC solutions

1. Install RPC on computer loads
2. Install RPC on UPS input supply
3. Install RPC on generator only

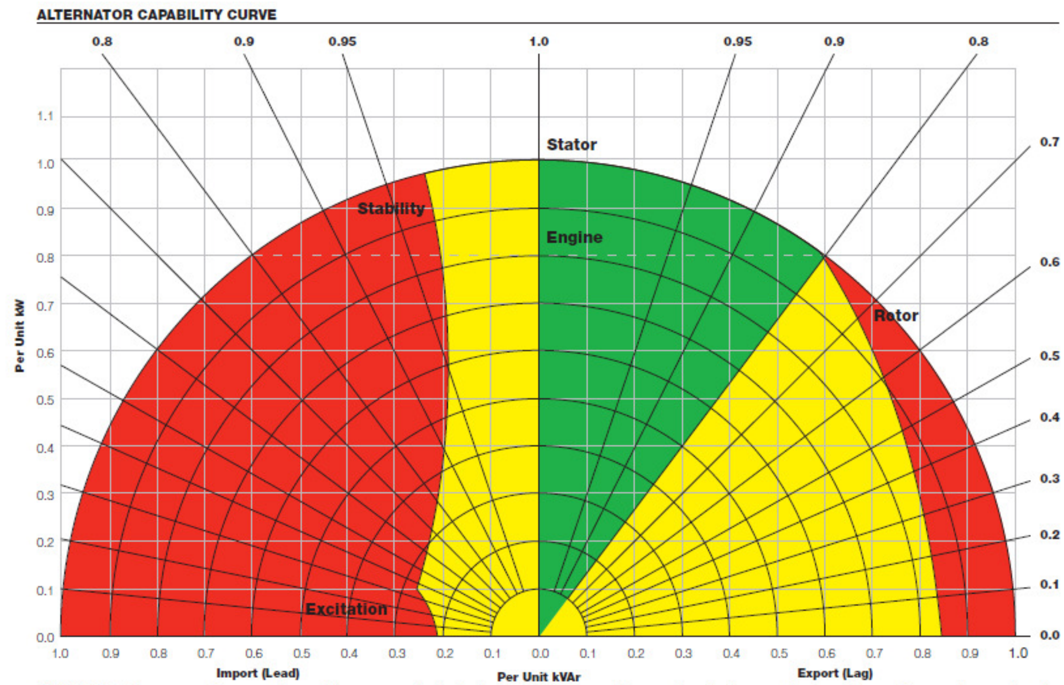
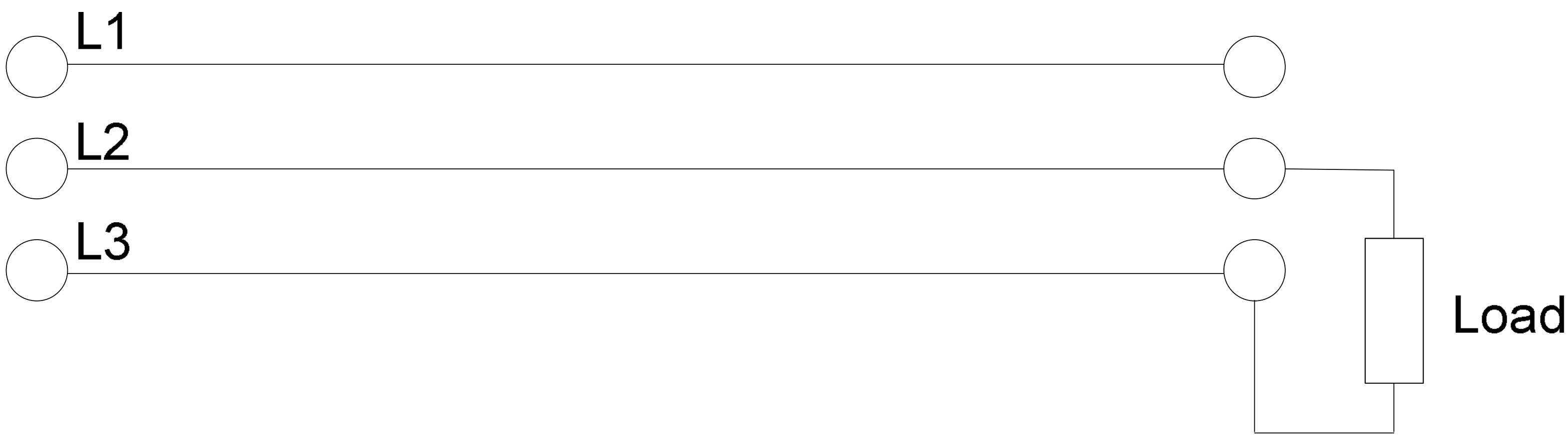
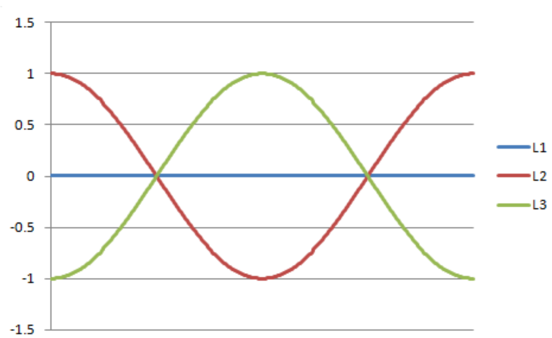


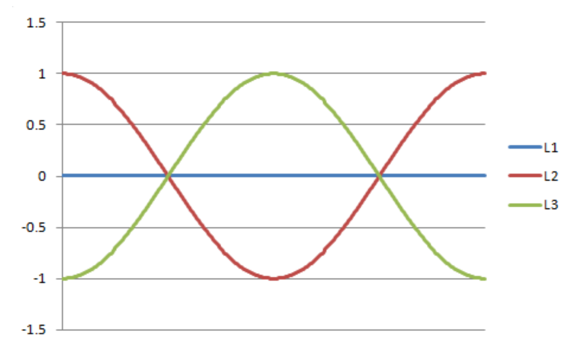
FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in red regional will cause damage or misoperation.

Reactive Power Conditioning
Unbalanced Current caused by load between 2 phases





Current waveforms

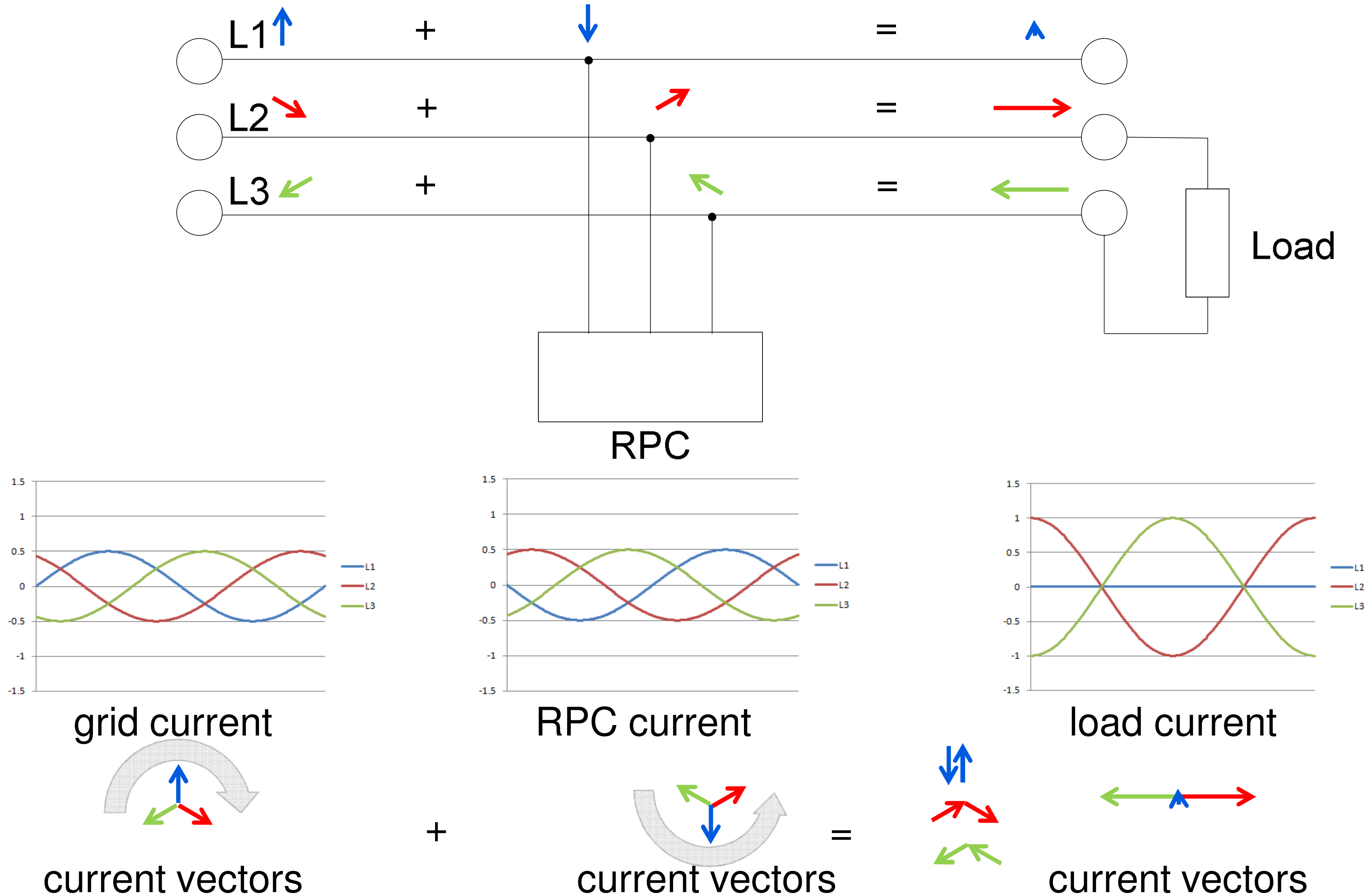


Current waveforms

Current vectors

Reactive Power Conditioning

Negative Sequence Current Injection by RPC



Reactive Power Conditioning
Conclusion

- True power factor covers displacement and distortion.
- Power electronics based RPC systems provide a seamless solution to cover the bulk problem (displacement & low order harmonics) with the followings benefits:
  - High Overload Capability
  - Low loss
  - Small footprint
- Hybrids can be build to create most economic solution
- Economic benefits can be easily calculated by true RMS current evaluation.