Caps unlocked

ABB's new QCap cylindrical capacitor improves power factors

RAYMOND MA-SHULUN, CYRILLE LENDERS, FRANCOIS DELINCÉ, MARIE PILLIEZ – Reactive power is a major concern for both industries and utilities. It impacts energy costs and CO_2 emissions and causes equipment malfunction and failure as well as reducing equipment lifetime and adding to maintenance costs. There are many ways to mitigate reactive power – and virtually all involve capacitors. The capacitor may have been around for about 250 years, but with it playing such an important role there is always a case to be made for seeking additional improvements, especially in terms of further reducing losses and enhancing safety and reliability – and this is exactly what ABB has done with its new QCap. But what exactly is it that sets this new capacitor apart?

Design parameters range over several orders of magnitude within a capacitor element ranging from about 10 nm for the thickness of the metal layer to about 100 m for the electrode length.

As 45 percent of electricity generated is consumed by motors, and the inductive nature of motors makes them a consumer of reactive power, measures to keep this reactive power out of the grid have immediate benefits. One way to achieve this is to compensate the reactive power locally. There is nothing novel about using capacitors in such applications, but ABB's QCap capacitor breaks new ground in terms of reliability, quality and safety → 1.

ABB's QCap is designed to be the ultimate safe and reliable capacitor with unbeatable quality.

After more than 250 years of progress (the Leyden jar was invented in 1746) capacitors have developed into a commodity product. However, especially for metallized film power capacitors, their design and manufacture remains a highly challenging field – a poorly designed capacitor can fail in a catastrophic manner.

The power capacitor is the electrical component that deals with the highest electrical fields → 2. Design parameters range over several orders of magnitude within a capacitor element ranging from about 10 nm for the thickness of the metal layer to about 100 m for the electrode length: Key dimensions needing to be controlled during manufacturing span 10 orders of magnitude → 3. Furthermore, mechanical stress during winding plays a key role on the capacitor's performance. The production of a good capacitor element requires a deep understanding of all process parameters.

Building on its long history of manufacturing power factor capacitors, ABB adheres to the following seven imperatives:
- Know-how in R&D and production
- In-house design
- Material selection
- In-house manufacturing
- Stringent test criteria
- 100 percent testing of capacitor elements and units
- Continuous improvement of manufacturing process

Title picture
ABB's new QCap cylindrical capacitor features an advanced protection system and other innovative features.

When a pure AC voltage (containing only one frequency) is applied to a reactive load, the current will lag (if the load is inductive) or lead (if it is capacitive) with respect to the voltage by a phase angle φ. The cosine of this angle is defined as power factor (PF) of this reactive load → a.

The cos(φ) of a reactive load can also be defined as the ratio of its active power to its apparent power. Most reactive loads are inductive for the simple reason that most electrical power is consumed by inductive motors. According to IEA (International Energy Agency), around 45 percent of global electricity is consumed by electric motors of all kinds [1]. A motor's power factor varies from 0.7 to 0.9 at its nominal power. If the load decreases, so does the power factor. For instance, a motor with a power factor of 0.7 at its nominal load will have a power factor of 0.3 at a quarter of its nominal load [2]. As the load decreases to zero, the motor runs as a nearly pure inductive load (power factor approaching zero). Since few electric motors continuously run at their full load, low power factors are a major concern.

The delivery of reactive power causes losses in transmission and distribution networks (and CO_2 emissions). High levels of reactive power can even threaten grid stability. Therefore, most utilities around the world impose a minimal power factor for customers, and charge penalties if it is not met.

A common practice used to mitigate the inductive power factor is to install capacitor banks (switched or fixed) close to the loads. The reactive power required by the motor is then supplied locally by the capacitors rather than drawn from the grid. As shown in the phase diagram → b, adding a capacitor to an inductive load reduces the inductive (kvar) and apparent power (kVA) consumed, without the motor's active power being affected.

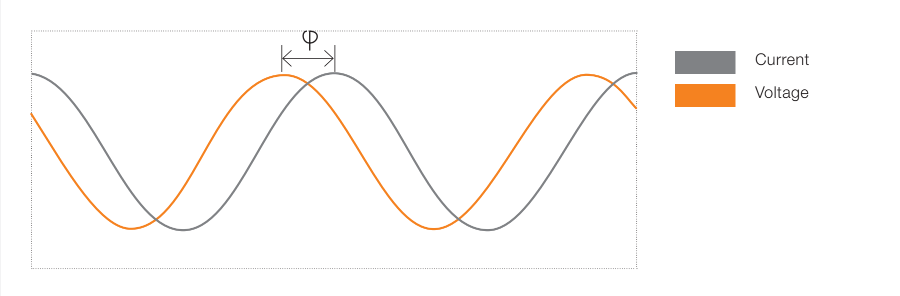
For many decades, capacitors have been a cost-effective solution to the reactive power challenge. However, the increasing use of variable-speed drives (VSDs) has opened an alternative method of operating electric motors while minimizing grid-side reactive power. But VSDs introduce a new challenge: grid-side harmonics. Harmonics are detrimental to other electrical equipment as they can cause overheating in cables, transformers and motors, or interfere with sensitive devices. The two main solutions used to mitigate harmonics are passive and active filters. Low-harmonic drives are also available but they are largely not cost competitive with passive and active filters. Thanks to their simple structure and low cost, passive filters are a common choice for suppressing harmonics. A passive filter is basically an LC filter, and thus requires a capacitor. With or without VSDs, capacitors continue to play an important role in connecting motors to the grid.

ABB has been a pioneer in developing and manufacturing power capacitors, catering for power factor correction (PFC) across the whole delivery chain of electricity, including high-, medium- and low-voltage applications.

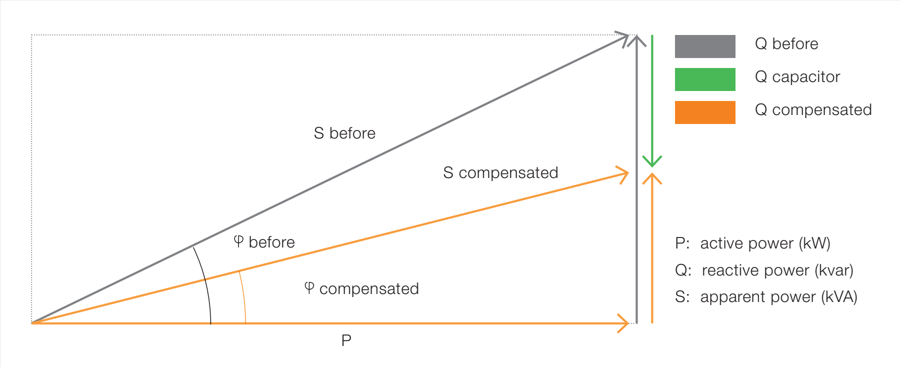
PFC solutions available on the market today can be divided into two categories: capacitor- and IGBT-based technologies → c.

In contrast to discrete step switching, IGBT-based technology can achieve stepless compensation. Active filters and stepless reactive compensators are two emerging products that improve the power factor by injecting compensating reactive current into the installation. Capacitor-based technology is the dominant solution in today's market.

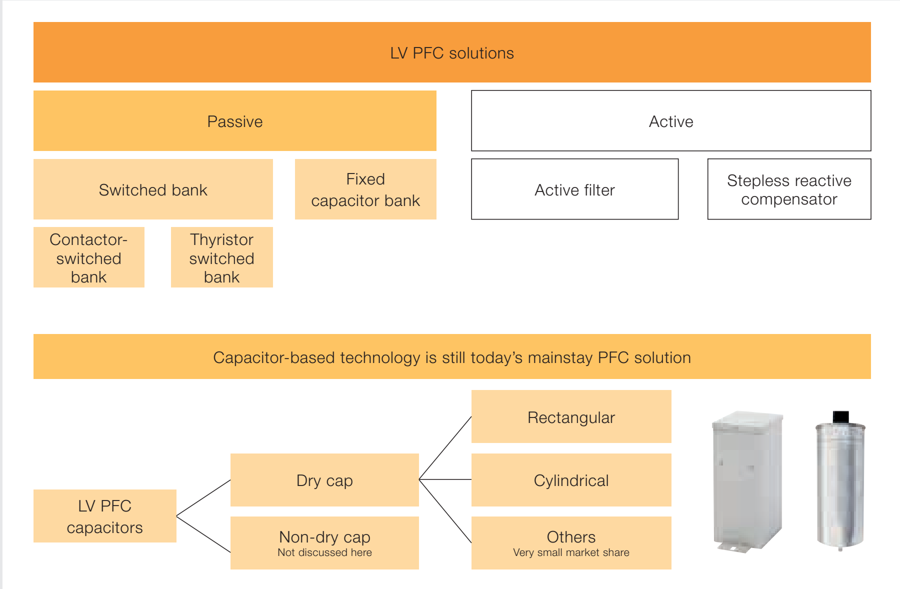
Capacitor banks today use mainly dry capacitors, with rectangular and cylindrical units being the most common. Some manufacturers also make other shapes but the market share of these is small.



a Reactive power is caused by the phase shift between current and voltage.



b Capacitors can be used to compensate the phase shift caused by electric motors.



c Power factor correction solutions

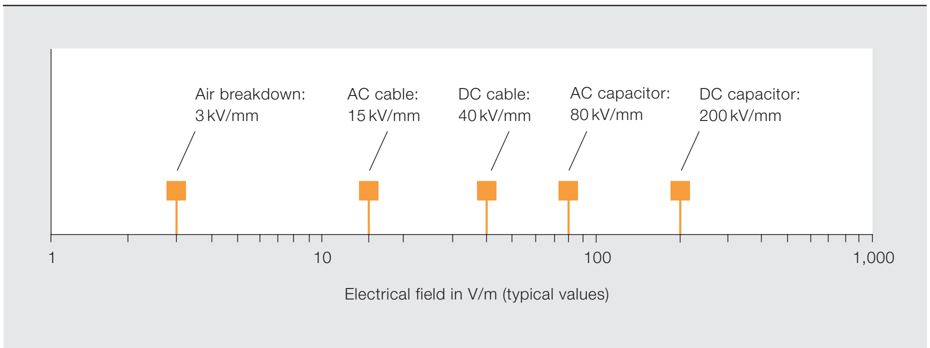
References

[1] Energy-Efficiency Policy Opportunities for Electric Motor-Driven System, P. Waide, C.U. Brunner, p. 35, OECD/IEA, Paris, 2011.

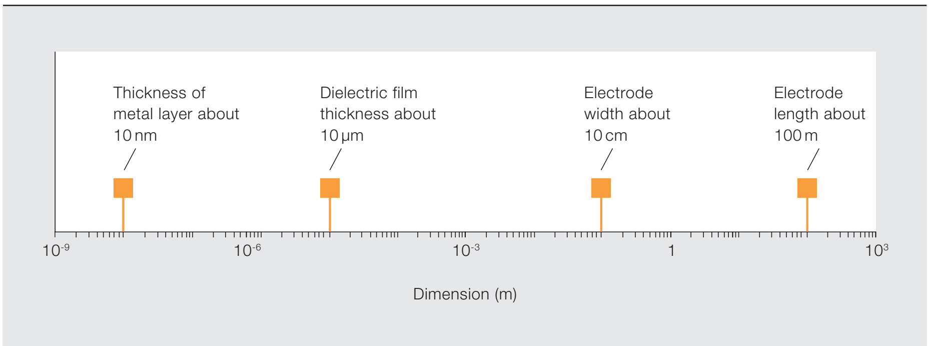
[2] Low voltage motors – Motor guide (ABB document 9AKK105285), p. 64, Feb. 2014.

Low power losses are a key requirement for a capacitor. High internal temperature is one of the primary causes of premature capacitor failures.

2 The power capacitor is the electrical component that deals with the highest electrical fields.



3 The major design parameters of a capacitor span 10 orders of magnitude.



A cool capacitor

As the newly developed low-voltage power capacitor for power factor correction, ABB's QCap complements the company's existing LV CLMD-type capacitor (rectangular type). It delivers value to customers by providing three enhanced technical merits:

- Low power losses
- Good heat dissipation
- Advanced safety features

Low power losses are a key requirement for a capacitor. Even if losses are relatively low compared with the reactive power available (typically 0.2 to 0.3 W/kvar), the heat generated is difficult to extract due to the plastic nature of the dielectric. The metallic electrodes are so thin that they barely contribute to heat transfer.

A metallized dry capacitor is able to isolate a small localized dielectric breakdown through a self-healing process.

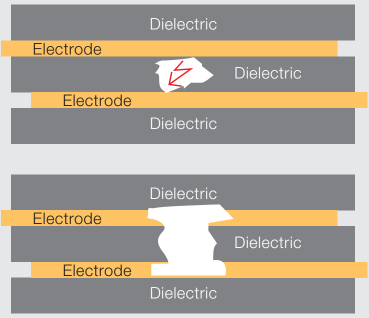
Losses are generated by dielectric polarization and by the Joule effect in the conductive parts, especially the electrodes. To optimize conduction losses, the thickness of the metal deposit can be varied according to its location. Using a thick metal layer throughout is not a good approach as it would in fact deteriorate dielectric performance. Temperature also has a fundamental impact on dielectric performance, leading to breakdown and aging. Consequently, high internal temperature is one of the primary causes of premature capacitor failures.

A holistic design perspective has been adopted to minimize losses. QCap uses optimized film width and device diameter to ensure a very low temperature rise. Film widths either too small or too large cause unnecessary temperature rises.

QCap's low losses are achieved through:

- Use of the highest-class dielectric film

4 Self-healing process of QCap



4a Electric arc isolates short circuit

4b Self-healed dielectric

– ABB's unique metallization profile, minimizing electrode losses without compromising dielectric performance
– Optimized geometry, ensuring better thermal behavior

A safe capacitor

QCap's extremely safe design not only ensures the customer's peace of mind during the capacitor's entire operating lifetime, but also guarantees that when the device finally reaches the end of its lifespan (be it through failure or age) that it will do so safely. The principle of QCap's safety mechanism consists of two features:
– Self-healing technology
– Overpressure disconnection

Self-healing technology

A metallized dry capacitor is able to isolate a small localized dielectric breakdown through a self-healing process. Self-healing is a unique feature of capacitors with metallized dielectric.

Moisture or dust trapped inside the device, or some other type of defect, can cause a local dielectric breakdown. The resulting short circuit between two electrodes will emit plasma, vaporizing the dielectric material and the surrounding metal and leave a hole. The breakdown area is thus isolated and the capacitor self healed → 4.

Besides preventing the breakdown from spreading, the self-healing process leads to the loss of a small part of the capacitance (typically 1 part per million). It also releases a small amount of gas.

Overpressure disconnection

The usual way to protect a circuit against device failure is to use a fuse. However, a capacitor (especially a metallized film one) can fail in both a low and high impedance mode. A low-impedance fault leads to a short circuit and can be protected by a fuse. However, a high impedance fault will not lead to a current increase, but to resistive behavior creating a local hotspot in the dielectric material and ultimately its meltdown. This kind of failure cannot be protected by a fuse[1], since the current through the capacitor is not necessarily larger than its nominal current (only the phase would shift from reactive to active).

> A high-impedance fault cannot be protected by a fuse.

The gas accumulation from self-healing actions slowly increases the pressure in a sealed can. This phenomenon can be used to protect the capacitor in the event of a failure.

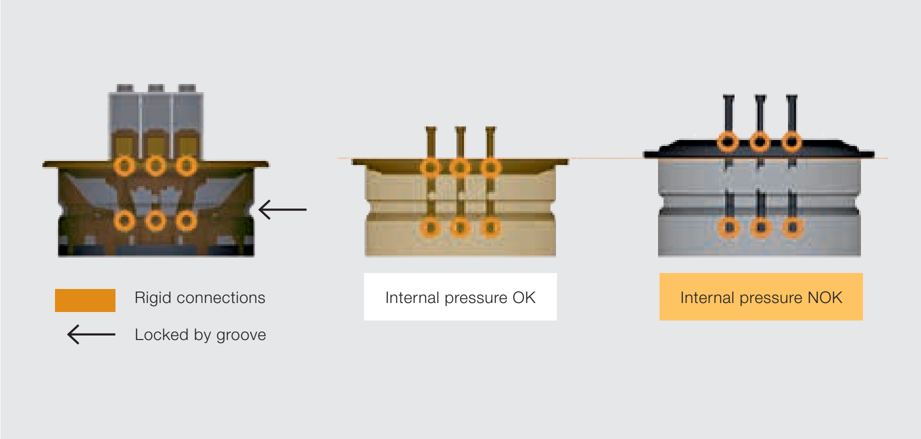
QCap features a protection system based on overpressure. The device terminals are internally connected using three notched wires that break when the

Footnote

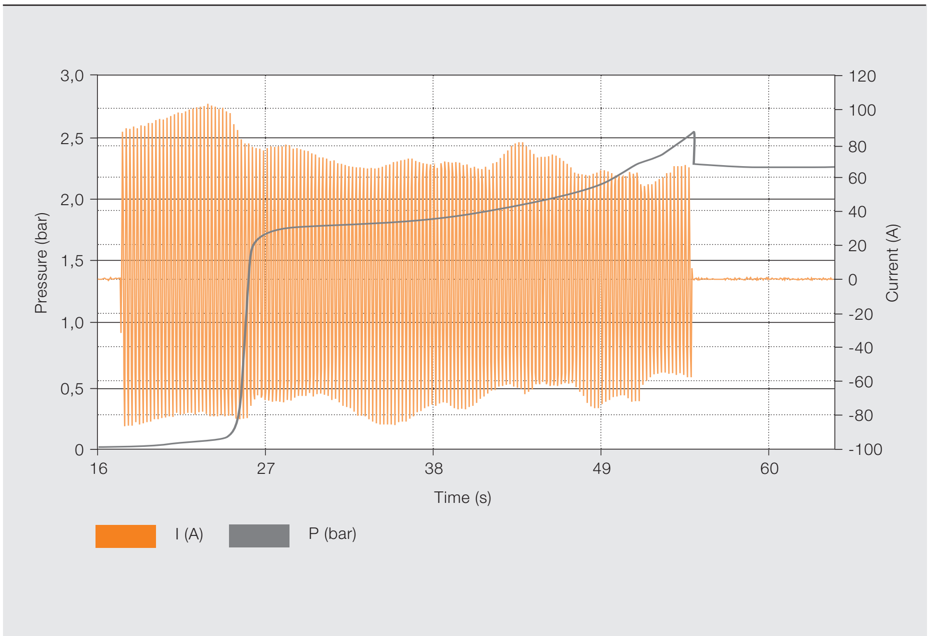
1 With the CLMD type, the strategy is to turn the high-impedance fault into a low-impedance fault by using a small parallel non self-healing capacitor, which upon failure will operate an internal fuse.

The gas accumulation from self-healing actions slowly increases the pressure in a sealed can. This phenomenon can be used to protect the capacitor in case of failure.

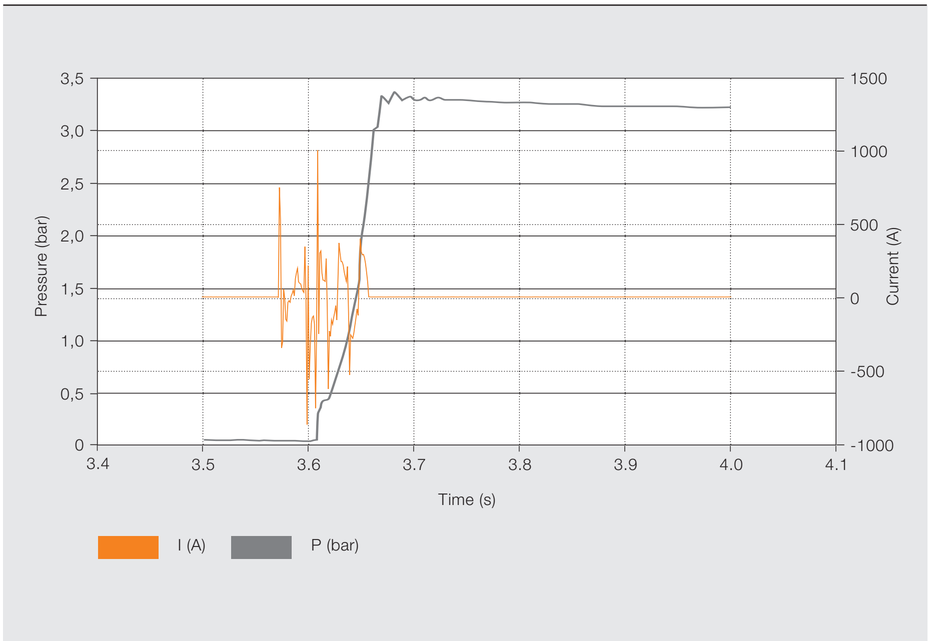
5 One of the safety features of the QCap capacitor is that it is disconnected by the buildup of pressure.



6 QCap self-disconnection in an overpressure scenario

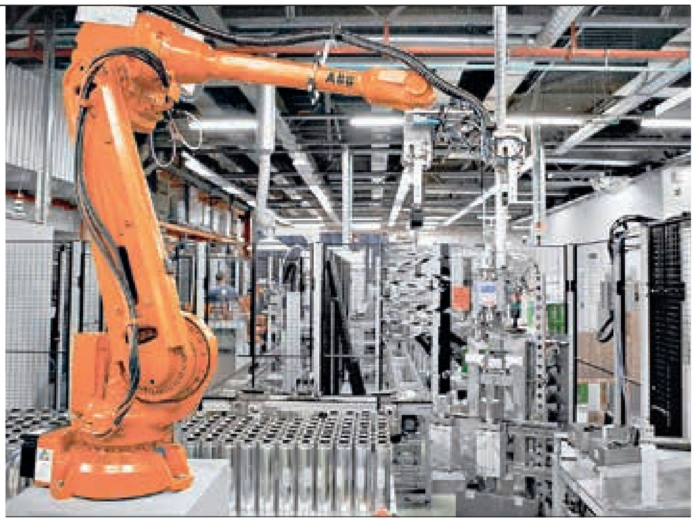


6a Pressure and current over time during detruction test – slow pressure rise



6b Pressure and current over time during destruction test – fast pressure rise

7a QCap capacitors



7b On the production line

ABB's QCap capacitor breaks new ground in terms of reliability, quality and safety.

lid rises due to gas pressure. To make sure the disconnection works reliably, the wires are indirectly anchored to the lid at one end and to the can at the other. The groove shown in ➔ 5 is designed to support this. The lid is manufactured to have two stable positions (normal and expanded). When pressure pushes up the lid, all three wires break and the capacitor is isolated from the grid.

The pressure threshold can be reached either by the long-term accumulation of gas released by self-healings (normal end of life) or by a high-impedance fault as described above.

Two recordings of the pressure rise and current during a destruction test are shown in ➔ 6. The elements were previously intentionally damaged by applying a DC voltage that was ramped up until a fault current limited to 300 mA was reached. Full AC power was subsequently applied.

The overpressure disconnection mechanism only works when the containing can is sealed, but this feature also has other advantages such as providing a barrier against electrode damage due to oxidation and moisture.

QCap: the ABB quality cylindrical capacitor

ABB's QCap is designed to be the ultimate safe and reliable capacitor with unbeatable quality. In summary, its six distinct features are:

- Reduced losses (minimizing premature failures)
- Best quality film (ensuring operating quality)
- Unique disconnection system in case of failure (ensuring safety)
- Optimized thermal dissipation (optimizing reliability)
- Manufactured on an automated production line (ensuring quality consistency) ➔ 7
- Elements and capacitor units 100 percent tested with stringent criteria

Raymond Ma-Shulun
Cyrille Lenders
Francois Delincé
Marie Pilliez
ABB Power Products
Jumet, Belgium
raymond.ma-shulun@be.abb.com
cyrille.lenders@be.abb.com
francois.delince@be.abb.com
marie.pilliez@be.abb.com