DryQ – Dry and silent

Modern HVAC capacitor meets new demands for reactive power compensation

Birger Drugge, Henning Fuhrmann, Sari Laihonen, Johan Mood

Reactive power compensation and filtering would hardly be possible without capacitors. Traditional high voltage AC capacitors use oil and can hence be crippled by leaks as well as presenting both fire und environmental risks. ABB set about developing a new capacitor generation to overcome these problems – by eliminating the use of oil.

The new DryQ capacitors are made entirely of dry components, improving safety and environmental considerations. Their ingenious construction makes them easy to customize for different voltage classes. Their slender design and compact footprint make them ideal for use in restricted space. And their design makes them easy to combine into capacitor banks, greatly reducing the need for cross-wiring. Moreover, they are much quieter than conventional capacitors!

Throughout the world, the use of electrical energy is on the rise. As electricity reaches a larger part of the world's population, new investments in the power grid are necessary. Even in industrialized countries, consumption of electricity is still increasing, bringing existing transmission networks to their limits. More effective reactive power compensation can improve the power factor of networks and lead to better utilization of existing lines.

To reduce the impact of new installations, a minimization of land use is being sought. Additionally, environmental and safety aspects are being given greater consideration: Will noise from the installation disturb neighbouring houses? Is there a risk of oil leakage and what are the consequences?

As the leakage risk for oil-filled capacitors can never be totally eliminated, it was decided at an early stage of DryQ's development that the new capacitor should be dry and environmentally sustainable.

From wet to dry

The basic design of the DryQ capacitor is similar to that of its "sister-capacitor", the dry HVDC capacitor launched in 2000. Cylindrical capacitor elements of metallized polypropylene film replace the conventional liquid impregnated HV-capacitor elements, which consist of metal foil-electrodes separated by insulating film. The electrodes of the new design are evaporated directly onto the insulation film. This simplifies manufacturing and also eliminates insulation oil from between the foil and the film.

DryQ capacitors have a tubular polymeric casing, the length of which is proportional to the rated voltage of the capacitor. The casing is covered with silicone sheds, thus fulfilling the climatic requirements and insulation needed for the application.

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The electrical connections of the DryQ capacitor are located at the top and bottom of the tube. Bushings are integrated in the lids and no separate bushing insulators are needed. The consequent reduction in cross-wiring makes installation very convenient 1.

HVAC power capacitors – important invisibles in the network

Power capacitors are important passive components for electrical networks. They produce reactive power (as opposed to other components such as static converters, motors and power lines, which consume reactive power). Instead of transporting reactive power over long distances and so reducing the transmission capacity of the networks, HVAC capacitors are placed close to reactive power consumers, the result of which improves the stability of the network. Shunt banks are commonly used, ie, capacitors connected in parallel to the grid. The first application for DryQ capacitors is shunt banks rated for 40–170 kV and 10-100 MVAr.

In addition to reactive power production, power capacitors can be used in combination with suitable reactors to filter out undesired frequencies from the network. Such harmonics can be caused by thyristor-controlled equipment such as converters for high-frequency furnaces, arc furnaces and welding installations, and drive systems with speed regulation etc. Without filters, these harmonics are transmitted to the supplying network, causing problems for net owners and electricity consumers. To be more specific, the resulting overloads can lead to failures, damage of electrical equipment and even telephone interference.

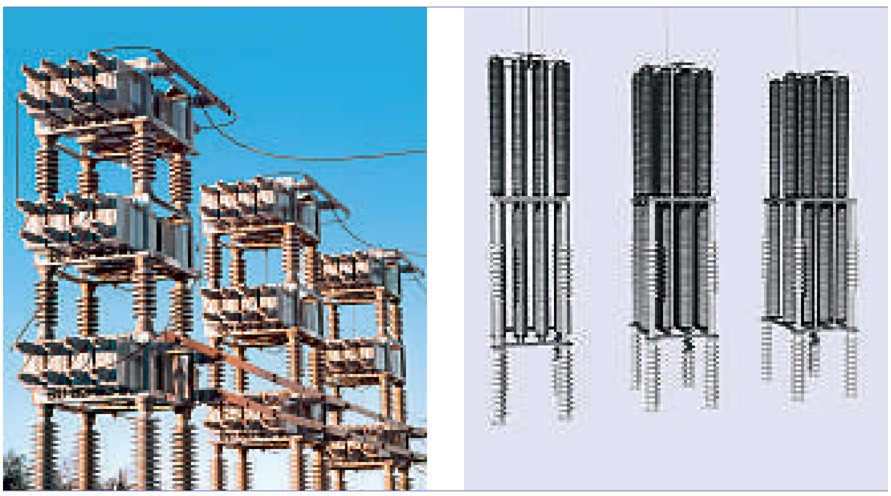
Series capacitors are another application for HVAC capacitors. Their purpose is to improve power transfer capacity of the transmission line by reducing the reactance, so reducing transfer losses.

DryQ – similar to its sister but not a twin

The DryQ is in many ways similar to its sister, the Dry HVDC capacitor: both use metalized film and have similar geometries and encapsulations. However, there are also significant differences.

A major difference lies in the electric losses. HVDC capacitors are used in systems where power semiconductor

1 Comparison between typical conventional (a) and DryQ (b) bank designs.



2 DryQ's proprietary high-voltage shed design with optimised cooling properties. The high voltage terminal in the top lid is also shown.

switching causes substantial currents at high frequencies. In this case, the resistive contribution to electrical losses will dominate.

In DryQ capacitors, all but a negligible fraction of the current is at the fundamental frequency (50 or 60 Hz). This is why it was possible to design the DryQ capacitor so that resistive losses are reduced to an absolute minimum. Consequently, most of the losses in a DryQ capacitor are dielectric and this is the dominating parameter when it comes to thermal design.

This perspective presented an additional challenge to ABB's engineers and researchers. Although polypropylene has exceptionally low dielectric losses, these had yet to be determined accurately for various film qualities. Given typical loss levels of 2×10^{-4} and lower, this is not a simple task, especially at high voltages and currents.

To determine these losses, a thermal method and a new, high-precision electrical technique were developed. In the thermal method, the capacitor losses were calculated based on the heat produced in the winding under nominal operation conditions. The electrical method employed a new, extremely precise measurement converter to measure phase shifts between current and voltage directly. The two methods were shown to be consistent with one another.

While these measurement methods gave full control over heat generation, a suitable cooling concept had yet to be developed. For this purpose ABB invented a proprietary silicone shed design optimizing cooling while having suitable electrical properties 2. The novel sheds expand the range of possible DryQ installation sites to some of the more demanding climatic conditions.

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Finally, the effect of solar radiation on the banks at different possible installation sites all over the world was simulated 3. These calculations were also verified in tests performed on full sized models in a climate chamber 4. The results show that even under conditions that are tougher than reality, DryQ capacitors operate safely and within the design limits.

Outdoor insulation for outdoor installations!

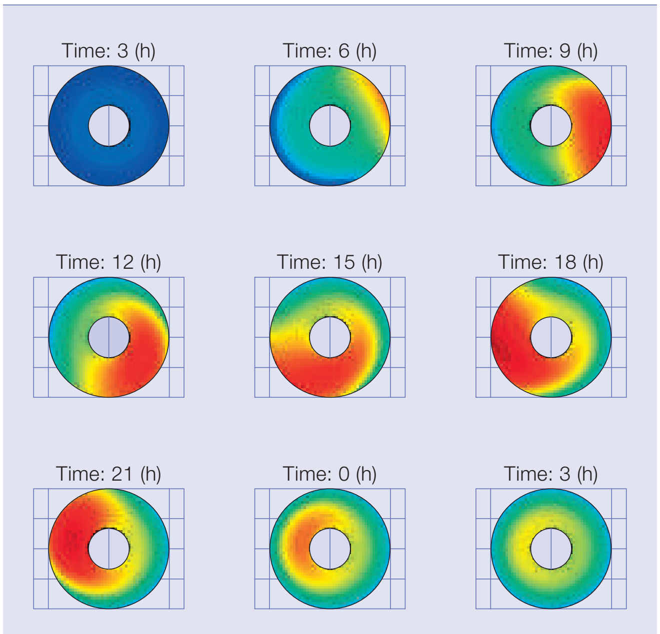
The casing for the DryQ capacitor is made of polymer material with the right combination of insulation and mechanical properties. As the bushings are integrated into the top and bottom lids, the encapsulation provides the required creepage distance between the electrical terminals of the capacitor. Additionally, sheds help interrupt water paths along the casing in heavy rain.

Silicone rubber is well established in numerous composite insulator applications and was the natural choice for the outdoor insulation material for DryQ. A strong but lightweight encapsulation design was achieved: metal walls and porcelain insulators could be avoided. With its continuously self-recovering hydrophobic surfaces, silicone rubber provides excellent outdoor protection for the capacitor throughout its lifetime. These self-recovering properties additionally allow the recommended cleaning interval to be increased.

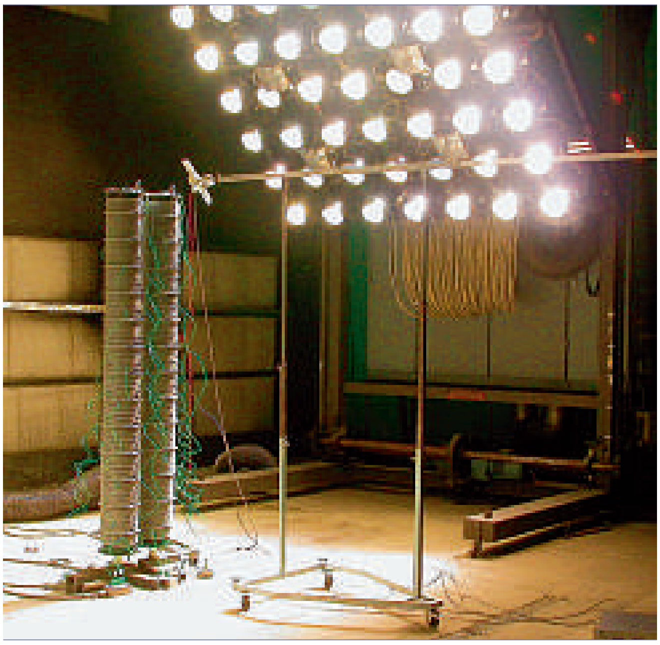
A slow and smooth capacitance decline – due to self-healing dielectric

Naturally all insulation materials undergo ageing during their useful lifetime – capacitor dielectrics are no exception. Ageing can lead to a breakdown in the dielectric. There are several ways to handle this possible breakdown and the resulting short-circuit between the electrodes. One possibility is to keep the electrical stress so low that breakdown will never happen. (ie, a very low energy density) – this approach is applied to cables, transformers and many other HV components.

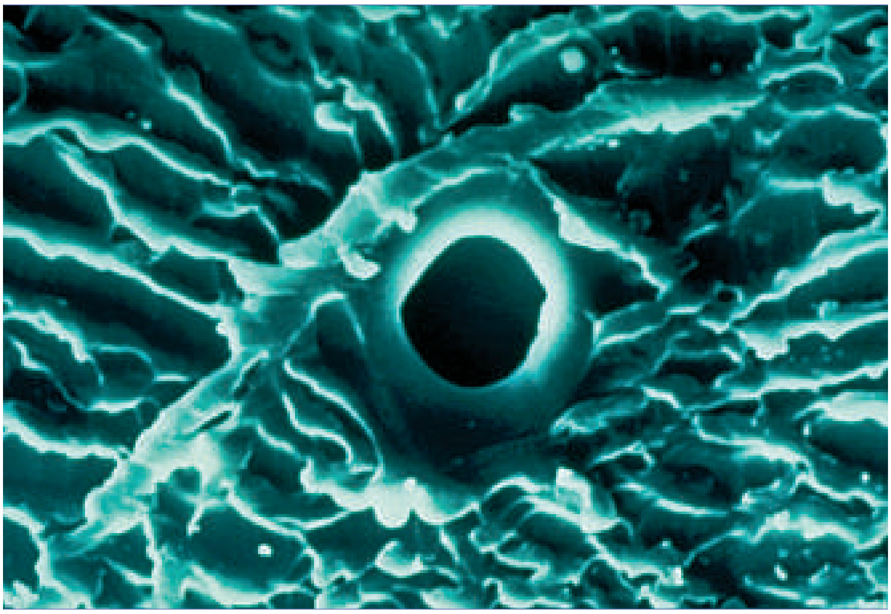
3 Thermal simulation, covering a day of operation of a DryQ capacitor at 62° latitude.



4 Two DryQ capacitors undergoing thermal testing in a climate chamber.



5 Clearing on a metallized film electrode of a dry capacitor, as seen in a scanning electron microscope. The hole in the center has been caused by a small discharge, which has also evaporated ("cleared") the metal around.



For capacitors, another strategy is applied. Conventional capacitors are usually equipped with internal fuses that will disconnect the part of the capacitor that has failed. From the operator's perspective, this leads to the loss of some percent of the capacitance.

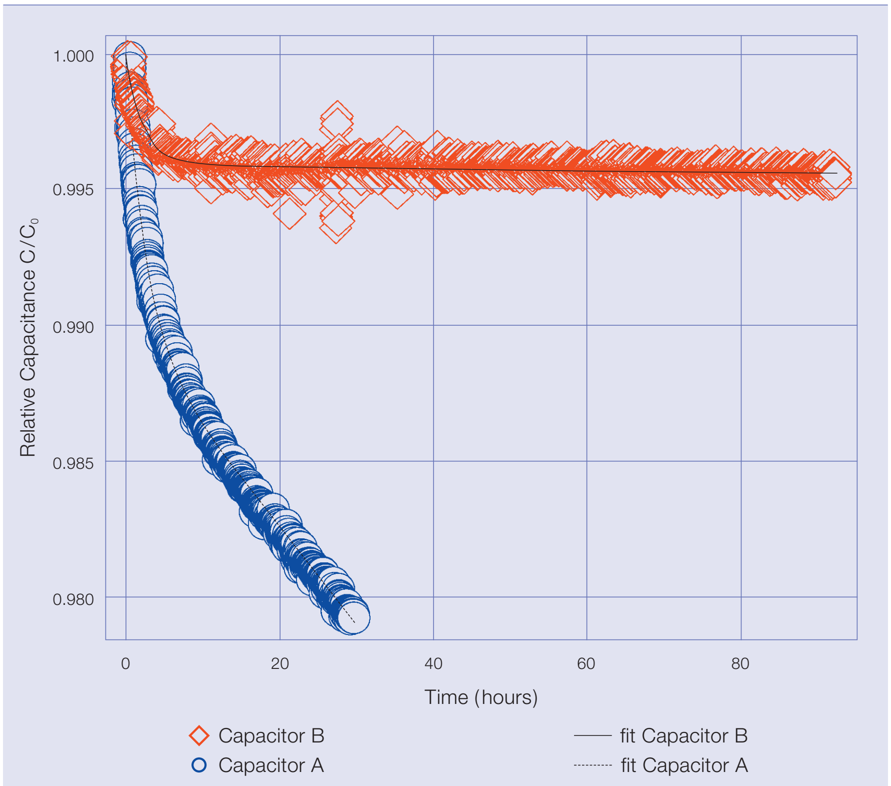
In contrast to this, a metallized film capacitor such as DryQ can handle dielectric breakdown without internal fuses: the metallization around the site of the dielectric breakdown evaporates and effectively isolates the small hole in the dielectric from the rest of the capacitor 5. This is the so-called clearing mechanism, a well-established principle in capacitor design. With its low voltage AC power capacitors in metallized film technology, ABB can look back on more than 30 years of success with metallized film AC capacitors.

The loss of capacitance caused by a single clearing is too small to be measured. However, over years of operation, a larger number of clearings will occur, leading to a slow but measurable loss of capacitance.

Typical HVAC capacitor applications place tough requirements on the long-term stability of the bank's capacitance. A change in reactive power may decrease the efficiency of the power line. With a typical specified lifetime of 30 years, accurate accelerated ageing methods were needed to design and test the new product.

For this purpose, ABB has developed a method to monitor the capacitance of a device undergoing accelerated ageing to an accuracy of about 0.1%. This setup automatically measures the device, for example in one-minute intervals, while voltage in excess of the nominal value is applied. The results allow a precise and quick prediction of the capacitor's performance in terms of capacitance loss over time 6.

6 Example of relative capacitance vs. time for two metallized polypropylene film capacitors during accelerated aging, measured at ABB's research labs. While the initial drop in capacitance is just a reversible effect caused by the heat up, capacitor A clearly looses capacitance much more quickly than capacitor B.



Small, light and silent!

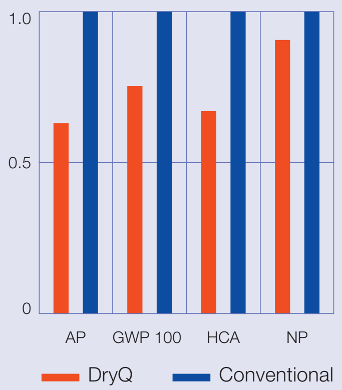
On account of its cylindrical shape, with electrical connections at the ends, DryQ is completely different to a conventional capacitor. The tube length scales with the voltage, and even higher voltages can be achieved through series connection of units. The customer has several configuration options for a specific capacitor bank depending on parameters such as ground space and noise aspects. In limited space, a DryQ bank can be built with an extremely low footprint: as little as to 50% of that needed for conventional capacitors. If the visible impact is more important, the DryQ bank can be assembled with a low profile that requires slightly more ground space. In either configuration, the DryQ capacitor bank weighs only about three quarters of a conventional capacitor bank and is delivered in pre-assembled racks for easy installation.

Reduced sound emissions

Sound emission from electrical equipment is an environmental issue that is growing in importance. Electrical harmonics in the network together with the eigenfrequency of the capacitor generate audible noise. ABB has developed a sound damper that can optionally be integrated with a conventional capacitor, achieving up to 18 dB noise reduction.

Sound aspects were carefully considered from the earliest stage of DryQ development. Its geometrical design with cylindrical polymer housing covered with silicone accounts for sound levels comparable to a sound-damped conventional capacitor. This makes DryQ the natural choice for shunt capacitors located in noise sensitive areas.

7 Results of a Life Cycle Assessment (LCA) comparing DryQ with the conventional capacitor design.



Acidification potential, AP
The risk for acidification of water and soil that can seriously affect farm crops, forests, water life and deteriorate building structures.

Global warming potential 100, GWP 100
The estimated greenhouse effect viewed in a 100-year perspective.

Human toxicity air, HCA
The toxicity for humans through breathing relating to toxicological parameters. The acceptable or tolerable concentration in air is given by air quality guidelines.

Nutrification potential, NP
The risk for nutrification of water mainly caused by nitrogen and phosphorus. NP is a measure of the capacity to form biomass relative to phosphate.

Sustainable

LCA, Life Cycle Assessment, is a tool for identifying environmental impacts of products or systems throughout their lifetime. LCA considers all the materials, production processes, energy usage and product performance during this period, as well as all transport and final disposal. 7 shows the result of the LCA for DryQ compared to conventional impregnated capacitors. The graph shows the conventional capacitor as 100% and the DryQ as a proportion. In this case, the four most relevant impact categories have been chosen for comparison.

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It is clear that DryQ is significantly better than conventional impregnated capacitors in all four categories. The use of shunt capacitors in the transmission and distribution networks is beneficial for the environment – also due to the reduction of total transmission losses. However, this benefit is not considered in the LCA, because this considers the capacitor only as a product and does not include its application.

Capacitor protection

A capacitor bank needs to be protected from failures, both originating from inside the capacitor bank and from external causes. The most common way to protect a capacitor bank is to connect it in a Y, YY or a H-arrangement. This means that the capacitor bank is electrically divided into sections that are balanced with respect to initial capacitance. In operation, if a capacitance change occurs somewhere in the bank, this leads to a measurable voltage or current imbalance.

All common protection schemes detect a change in the capacitance of a bank component. For a conventional capacitor bank the units are either internally or externally fused resulting in a stepwise change of capacitance when a failure is detected by the unbalance protection. The unbalance protection trips a breaker to disconnect the bank after a certain capacitance change. Similarly, the self-healing mechanism of a DryQ capacitor results in a gradual change of capacitance. Therefore DryQ can utilize the same protection scheme used for conventional capacitors.

Birger Drugge
Johan Mood
ABB Power Technologies
Sweden
birger.drugge@se.abb.com
johan.mood@se.abb.com

Henning Fuhrmann
ABB Switzerland Ltd, Corporate Research
Baden, Switzerland
henning.fuhrmann@ch.abb.com

Sari Laihonen
ABB AB, Corporate Research
Västerås, Sweden
sari.laihonen@se.abb.com