Quality and reliability of self-healing power capacitors for voltages up to 1000 V AC

It's all about saving your money!

Contents

The quality of power capacitors is supremely important for maintaining a secure and effective electrical power supply. This is because these components are continuously in use under their rated conditions and are also subjected to the additional stress imposed by the ever-increasing harmonics pollution due to nonlinear loads in the network. Power capacitors boost energy efficiency, reduce CO_2 emissions and cut energy costs.

1. International standards for power capacitors for power factor correction

The standard EN 60831 (IEC 60831) “Shunt power capacitors of the self-healing type for AC systems having a rated voltage up to and including 1000 V”, Part 1, August 2003 and Part 2, September 1997, is the basis for everything to do with power capacitors and sets out certain minimum requirements. Part 1 specifies the general performance, testing and rating requirements for the capacitors, sets out the special safety requirements and provides some guidance on the installation and operation of power factor correction systems. Part 2 describes the ageing, self-healing and destruction tests for these capacitors.

The standards specify the required routine testing in the manufacturing process for the capacitors and also the type tests, in which it must be verified that capacitor series comply with the required conditions. Apart from specifying the required routine tests, however, they do not stipulate how the quality of the manufacturing process itself is to be monitored. As a rule, reference is made to the necessity of appropriate agreements being made between the customer and manufacturer. Compliance with the above standards alone is therefore no assurance of the permanent quality of the capacitors produced by a manufacturer. How then can it be ascertained, on the basis of hard facts, whether the capacitors from a given manufacturer are of good quality and will remain so for a long period of time?

As already mentioned in the introduction, the level of harmonics in public and industrial distribution networks has been on the increase for many years. In public supply networks it is usual nowadays for television programmes with high viewing rates to correlate closely with the level of harmonics, which rises significantly during the evening hours and at weekends. All power capacitors that are switched in to the network at these times are therefore subject to this additional loading. It is essentially the current load borne by the capacitors that is the critical factor. If, for example, the 11th harmonic is present with 8 % of the rated network voltage, the r.m.s. value of the rated voltage is only increased by some 0.3 %, but the current in the capacitors will already exceed its rated value by 33 %.[1)]

The current carrying capacity of a capacitor is therefore a very good indicator as to whether it is of good quality or an inferior make. Depending on the type, FRAKO power capacitors offer a current carrying capacity of up to 2.2 times the rated current.

Power capacitors with low power losses have particularly low inrush current damping, which must be taken into account in the design of the capacitor and when selecting the associated switchgear. Depending on the type concerned, **FRAKO** power capacitors can withstand transient current peaks of up to 300 times the rated current.

A capacitor's ability to withstand transient peak currents is also a good indicator that it will be able to endure a large number of switching cycles.

Depending on the type, **FRAKO** power capacitors can withstand tens of thousands of switching cycles each year.

In order for a manufacturer to maintain its technical commitments in the long term, a type test as per EN 60831 carried out only once for each series is not adequate. If the commitment to quality is taken seriously, the manufacturing process must be permanently monitored, with adjustments being made whenever necessary. With **FRAKO** this process starts with the receiving inspection for capacitor film, corrosion testing, breakdown testing and measurement of surface resistance before the winding process. It continues with daily random sampling of capacitor

[1)] Note: Networks with high levels of harmonics pollution require special versions of power factor correction systems.

coils, in which the quality of the contact bridge – which can be considered the Achilles heel of a capacitor in terms of its service life – is tested with a pulsed current. In addition, capacitors are taken every week from the manufacturing process and also tested with pulsed current to verify the good quality of their internal connections. Another weekly test is on newly manufactured capacitors of each class to verify that the specified effective current carrying capacities are maintained.

Only by continual testing and evaluation of the test results, when necessary making adjustments to the manufacturing processes, is it possible to guarantee consistent quality. The routine tests at the end of the manufacturing process required by EN 60831 [4] only represent an absolute minimum for the necessary duty of care on the part of the manufacturer.

2. Expected service life of power capacitors

At the present time there is unfortunately no universally valid description of how to calculate the life expectancy of a power capacitor. Several manufacturers resort to using a method described in the standard EN 60252-1 in which the duration of the test is multiplied by an “acceleration factor” $(U_{test}/U_N)^7$ to determine the service life of power capacitors. This extrapolation is not acceptable for at least two reasons. Firstly, this calculation method was developed for paper capacitors with a loss factor ten times greater than that of present-day plastic film capacitors. These modern capacitors have low losses, and their parameters are not comparable to paper capacitors. Secondly, it was developed for capacitors on applications in which service life was of far less importance than with today’s power capacitors. It was actually accepted that 3 % of the units installed would fail in the course of the average expected service life. Such a failure rate would never be acceptable for modern power capacitors. Tests on present-day power capacitors at an increased voltage and temperature provide a good indication of their quality, but a reliable forecast for their service life in terms of the number of operating hours cannot be derived from this. The only acceptable prediction for the service life of power capacitors comes from quantifying the actual rate of failure in working installations. Reputable manufacturers base their forecast of capacitor service life solely on experience gained in the field. **FRAKO** has been recording these results now for more than 15 years. Its quality management team checks the quality of the capacitors on the basis of these long-term statistical records and the expertise on applications accumulated over the same period. In addition, every capacitor series at **FRAKO** continually undergoes random testing, in stringent, specifically designed service life tests based on EN 60831 [4, 5], to verify that the capacitors do actually comply with the parameters specified in their development phase. This quality control function is a significant cost factor in the manufacturing process and is only carried out rigorously by very few manufacturers.

Apart from the responsibility borne by the manufacturer, the user of power capacitors should take due account of the following basic rule when planning the installation: capacitors may only be operated within the technical limits of their specifications. [3]

This applies in particular to the ambient temperature of the capacitors. As present-day power capacitors have very low power losses, particular attention should be paid to the heat dissipated by associated components, such as LV HBC fuses, capacitor contactors and filter reactors. The amount of radiant heat reaching the capacitors from these components should be kept as low as possible. Power capacitors generally have a longer expected service life at lower ambient temperatures. This is because the rate of chemical change in the dielectric material and the associated corrosion rate of the metal coating on it are approximately halved when the ambient temperature is some 7 to 10 degrees lower. This scientific fact should be treated with the utmost importance when planning power factor correction systems.

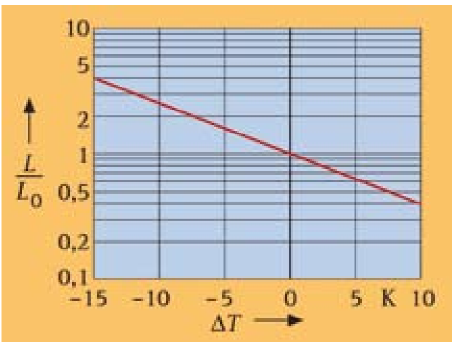


Fig. 1, Expected service life of a power capacitor as a function of temperature

3. Reliability of power capacitors

Power capacitors are components with an extremely high power density that are permanently operated at their rated power; an extraordinary challenge for the materials used in their construction, particularly the capacitor film, filler material and impregnating agent with the selected stabilizers. In a volume of one litre **FRAKO** can today accommodate some 16 kVAr of reactive power. This density is made possible by a very low dielectric loss factor of < 2 × 10-4. Present-day polypropylene films are extremely resilient with test field strengths of > 150 V/ µm and therefore highly efficient. A special treatment of the dielectric material is necessary to suppress partial discharges and hence maintain this high resilience at a constant and usable level for a long time.

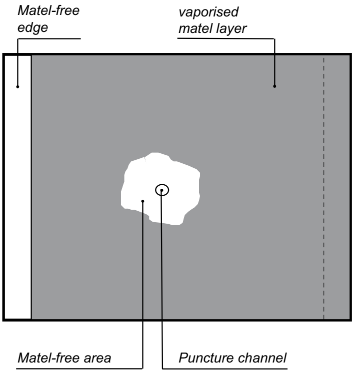
FRAKO achieves this objective by individual manufacturing processes and an innovative combination of a mineral filler material and a stabilizer. At the same time, great importance is attached to the environmental compatibility of these materials. The capacitors are rated as Water Hazard Class 1 (German Federal Environmental Agency) and can be disposed of without any difficulty under their waste code number.

The particularly high flash point of the filler (> 250°C) is an additional fire safety feature as it reduces the installation fire load. Building insurers acknowledge these properties with reduced insurance premiums.

a. Safety systems

Self-healing capacitor film

The film in **FRAKO** power capacitors is of the self-healing metallized type. This means that a layer of metal is deposited onto the substrate film in such a way that occasional overvoltage peaks in the supply voltage do not cause the capacitor to fail. Any puncturing of the dielectric caused by voltage peaks is automatically isolated by the self-healing process, so that the capacitor can continue to be operated without any interruption.



The loss of capacitance through this self-healing process is so small that it could not even be measured with precision instruments. In the practical application it is therefore not even noticed.

Fig. 2,
Self-healing action of the capacitor film

Segmented film

The self-healing process described above reaches its limits if the voltage peaks have so much energy that self-healing occurs through a number of layers of film and at many locations simultaneously. This would cause a high local temperature increase in the capacitor coil, which in turn would put an exceptional strain on the dielectric material, in an extreme case leading to the destruction of the capacitor. To avoid this effect, **FRAKO** has improved on a technique long known in other capacitor applications and used it in the manufacture of power capacitors. This technique is the segmented capacitor film.

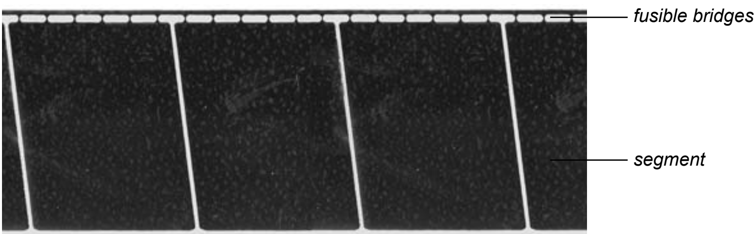


Fig. 3, Segmented capacitor film

This special film is constructed so that the overall metallized surface of the capacitor film is divided into numerous individual areas, each of these areas being joined to the electrical connection of the capacitor coil by special fusible bridges. These bridges have a function similar to a normal fuse in that they disconnect the individual areas from the supply if there is a local overload. This additional new safety feature of **FRAKO** power capacitors significantly increases their operational reliability.

Overpressure disconnector

Even with power capacitors of the best quality, there will be individual capacitors that fail unexpectedly. The objective of the **FRAKO** design is therefore to ensure – by timely disconnection of the capacitor – that in such cases the capacitor does not cause any damage to its surroundings. This can only be ensured, of course, if it is operated within the technical limits of its specifications (see also [3]).

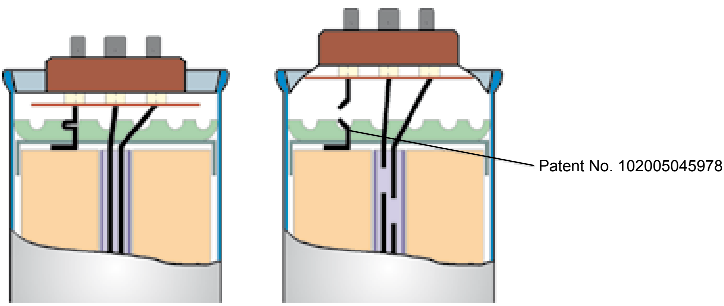


Fig. 4, Overpressure disconnector

The **FRAKO** overpressure disconnection system has been in use for about 25 years. It is based on a flanged diaphragm lid, a retaining system for the capacitor coil and patented leads with defined rupture points providing the internal electrical connections. The system has been continually improved and is now a mature design and a very reliable disconnection technique well proven in practical applications over the years.

For the disconnection system to function reliably, it is absolutely necessary that the gases generated when the dielectric material is destroyed can reach the diaphragm lid as quickly as possible without hindrance. This is one reason why **FRAKO** has rejected capacitor filler materials with a consistency like jelly or gelatine. Filling the capacitor with gas is also not advantageous for the disconnection system, since an overpressure sufficient to actuate the disconnection reliably cannot develop until the destruction of the capacitor coil is at an advanced stage. **FRAKO** verifies the correct functioning of the overpressure disconnection system by regular random tests on units from the production line. The tests are carried out on the basis of the destruction test set out in EN 60831-2 [5]. **FRAKO** power capacitors therefore offer the maximum that is technically possible with regard to operational reliability and safety.

b. Capacitor terminals

The methods for connecting power capacitors to the wiring deserve particular attention. The wiring itself must not present a mechanical obstacle to the travel of the diaphragm lid should the overpressure fail-safe mechanism be activated. The actual electrical contact must have a very low interface resistance and offer a robust electrical and mechanical contact that remains reliable in the long term. Economic considerations make it desirable to minimize the time needed to assemble the wiring and to dispense with the verification of tightening torques. All these conditions are fulfilled by the patented terminal base fitted by **FRAKO**. This is a perfected form of spring clamp, offering a secure connection over the entire service life of the capacitor without the need for threaded fasteners.

Another advantage of the terminal base is that all live components of the capacitor and its permanently attached discharge resistors are safely protected against inadvertent contact.

Fig. 5, Capacitor terminal base

4. FRAKO power capacitors in three series

Fig. 6, FRAKO type LKT power capacitors

FRAKO manufactures three series of power capacitors. Their technical data and recommended applications differ, but there is no difference in the quality of all these capacitors, which remains at the same high technical level.

FRAKO recommends its Basic power capacitors for standard automatic power factor correction systems without detuning. These capacitors are mainly exported for installation in countries where the power factor correction technology is not yet up to German standards. Fig. 7

For automatic detuned power factor correction systems **FRAKO** recommends its Standard capacitors. These are mainly used in **FRAKO**'s serially manufactured power factor correction systems. They are noted for their ruggedness and long service life. Fig. 8

Fig. 7

Fig. 8

Fig. 9

FRAKO recommends its Premium capacitors for tuned and detuned filter circuits and for dynamic power factor correction systems. These capacitors display an extraordinarily degree of ruggedness and have very long service lives. They are ideal for all special applications in power factor correction and in the field of network quality improvement. Fig. 9

Technical differences between the FRAKO capacitor series

Technical data	Basic	Standard	Premium
Max. overcurrent	1.5 × I_N (at U_N, 50 Hz)	1.8 × I_N (at U_N, 50 Hz)	2.2 × I_N (at U_N, 50 Hz)
Max. inrush current	200 × I_N (at U_N, 50 Hz)	250 × I_N (at U_N, 50 Hz)	300 × I_N (at U_N, 50 Hz)
Temperature class	-25 / + 50 °C	-40 / + 60 °C	-40 / + 65 °C
Max./min. temperature	+ 55 °C / - 25 °C	+ 60 °C / - 40 °C	+ 65 °C / - 40 °C
Average service life	100,000 h	130,000 h	170,000 h

5. Reliability, service life, energy efficiency and environmental compatibility all in one

The provisions of EN 60831 [4, 5] only set out the minimum requirements for a manufacturer of power capacitors. A manufacturer can only promise good products for a long period of time if quality criteria going beyond the stipulations of EN 60831 are monitored in the manufacturing process, and if regular random sampling is carried out to verify that the manufactured products consistently comply with the specifications in the data sheets. In addition, it is absolutely essential to record all feedback from the field as a verification of product quality. It is not just a question of making the best of promises in the selling process, but to be capable of keeping these promises and also providing solid evidence of this capability. At **FRAKO** some 30 % of the power capacitors manufactured are sold as components of the company's own systems. **FRAKO**'s quality assurance objectives for capacitors are therefore not restricted purely to the value of a component but are concerned with the value of a complete installation. From experience in the field with our own systems we know that our capacitors have a long service life, are very rugged and are highly reliable.

The longer a power capacitor can be operated, the more can energy costs and CO_2 emissions be saved, and the more favourable is the relationship between the cost of its materials and manufacture and the benefits achieved from it; all contributing to an excellent life cycle assessment. These properties, combined with the best possible operational reliability, result in a product that is highly recommendable with an excellent price/performance ratio

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References:

1. Sicherheit und Qualität von Leistungskondensatoren.
   etz Elektrotechnik + Automation 1999, 1-2
2. Sichere Starkstromkondensatoren – EN 60831 ein bewährter Standard. etz Elektrotechnik + Automation 1999, 9
3. General safety recommendations for power capacitors.
   ZVEI - German Electrical and Electronic Manufacturers' Association March 2008
4. EN 60831-1, Shunt power capacitors of the self-healing type for AC systems having a rated voltage up to and including 1000 V, Part 1, August 2003
5. EN 60831-2, Shunt power capacitors of the self-healing type for AC systems having a rated voltage up to and including 1000 V, Part 2, September 1997

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