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Power capacitors for wind generators

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Assuring a long life

Capacitors in wind generators are exposed to significantly harsher conditions than those in industrial power factor correction (PFC) systems due to the higher packing densities and strong load fluctuations prevailing in these plants. They also make use of detuned configurations. However, a few modifications during installation allow their operating life to be extended.

High packing densities of the capacitors in the switching cabinet—due to restricted space inside the wind generators—mean a higher specific power dissipation (W/cm^3). This leads to rising temperatures in the switching cabinets and consequently to higher operating temperatures for the power capacitors. They then heat up due to the resistive and dielectric losses incurred during operation. If the temperature rises are excessive, the hot-spot temperature climbs above defined limits, leading to failure or at least to a reduced operating life of the capacitor. Today, power capacitors are typically specified according to the highest temperature class (-25/D) on the basis of the IEC60831-1/2 or EN60831 standard. This temperature class is defined by the following temperatures:

- 55 °C maximum permissible peak temperature
- 45 °C maximum permissible mean daily temperature
- 35 °C maximum permissible mean annual temperature

These figures refer to the temperature of the air directly surrounding the capacitor.

Safety risks due to overheating

The polypropylene dielectric used in power capacitors has a high dielectric strength up to a specific hot-spot temperature. If this temperature is exceeded, the voltage strength drops greatly. The operating life of capacitors with a polypropylene dielectric consequently depends significantly on this hot-spot temperature. The Arrhenius equation, which describes temperature-dependent aging processes, suggests that a 7 °C temperature increase in metallized polypropylene capacitors will halve their operating life.

If the specified temperature is exceeded, the operating life is shortened as a result of increasing self-healing. From a certain limit temperature, the self-healing may fail, producing a non-self-healing breakdown. This means that in addition to the operating life considerations, safety risks may result when the values specified by the capacitor manufacturer or by the international IEC60831-1/2 capacitor standard are exceeded. So if the maximum operating temperature is significantly exceeded, the capacitor's own safety device (overpressure disconnector) cannot function. In the worst case, this can lead to rupture of the capacitor and to fire.

When planning, design and operating PFC-systems, care must therefore be taken to ensure sufficient ventilation of the switching cabinets: this will always be forced ventilation in view of the high packing densities frequently found here. Sufficient spacing must also be provided both between capacitors and hotter components such as inductors and power semiconductors (Fig. 1). The parameters specified by the capacitor manufacturer must always be observed.

FIGURE1: PFC SYSTEM WITH AN OPTIMIZED THERMAL DESIGN

PFC system without reactors with an optimum design

Switching operations for a longer operating life

Strong load fluctuations result in a large number of switching operations, some of them with insufficient inrush-current attenuation. Continuously changing output conditions occur in wind generators due to the unsteady wind speeds. So the phase shift and consequently the required capacitive reactive power are liable to high dynamics. The consequence is that capacitors must be frequently connected and disconnected. The number of capacitor switchings depends strongly not only on the design of the power plant but also on its location and the season.

In the ideal case, the software of the wind generator controls the capacitors so that all of them are switched at the same rate and have the same average operating time. As a rule, however, this measure alone is not sufficient.

The capacitors in conventional PFC systems and wind generators are connected to the power line via mechanical contactors (ideally capacitor contactors with inrush current attenuation). High capacitor inrush currents are produced during the switching of AC voltage capacitors, especially in the case of parallel connection to capacitors already connected to the power system and in the case of increased grid short circuit energy as in wind parks. Depending on the selection of the contactor and the actual connection time with respect to the momentary value of the sinusoidal half-wave (worst case at the peak voltage), inrush currents with very high amplitudes are produced in accordance with the equation $I = C\, dV/dt$. Due to high electrodynamic forces, excessive inrush currents produce higher stress on the capacitors, especially in the region of the electrode contacts. This affects not only aspects of the power quality (transients or voltage drops) and the operating life of the contactor, but also the operating life of the capacitor.

The operating life of metallized power capacitors is limited by the number of switching operations. According to the IEC60831-1/2 capacitor standard, their number should not exceed 5000 per year at a defined amplitude. Capacitors from EPCOS can certainly beat these values. In practice, more than 150,000 switching operations are currently achieved.

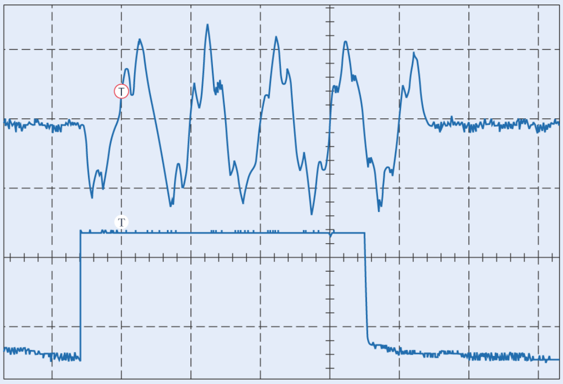
The number of switching operations shortens the operating life of the capacitors both directly and indirectly. Due to this high switching rate, capacitor connectors with operating-life expectations of between 100,000 and 200,000 specified switching operations already fail after one to two years of service. At the end of their operating life, they typically show impaired inrush current attenuation as well as damaged contacts in the primary circuit. This insufficient attenuation is the main factor in shortening the operating life of the capacitor. Scorched main contacts tend to produce oscillation effects and inefficient switching. This massive overloading of the capacitors also leads to premature failures and may represent a safety risk under certain conditions.

FIGURE 2: THYRISTOR MODULE

A thyristor module for gentle switching of power capacitors.

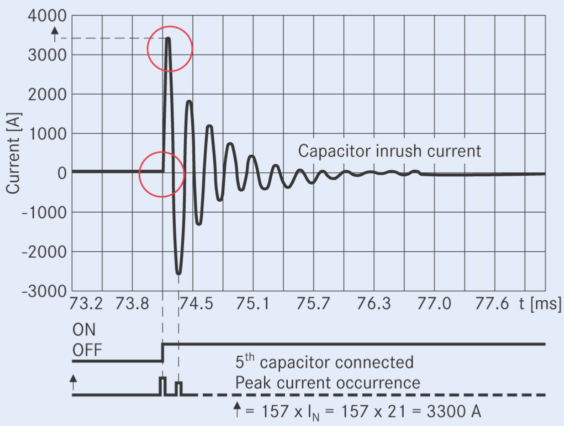
Such rapidly changing loads need technologies that react in real time. In dynamic PFC systems, electronic switches such as thyristor modules are replacing the slow electromechanical switches (Fig. 2). Apart from the response time, the operating life is also an important advantage, as thyristors show no mechanical wear. By dispensing with the mechanical contactors, the problem of high inrush currents is also resolved (Fig. 3). Thyristors switch the capacitors gently at the zero-current transition and thus avoid increased inrush currents that can attain up to 200 times the rated current (Fig. 4). The costs of thyristor modules are amortized within two to three years. If capacitor failures leading to fire are considered, the amortization time is shortened still further.

FIGURE 3: INRUSH CURRENT WITH THYRISTOR MODULE



The lower graph shows the control pulse, the upper graph represents the load current of the thyristor module or power capacitor. The usual turn-on pulse is eliminated. The fast reaction time and harmonic distortion can also be seen.

FIGURE 4: INRUSH CURRENT WITH PROTECTION



This measurement in a plant shows an inrush current surge whose amplitude is 157 times that of the rated current.

Harmonics: a danger to power capacitors

The increasing number of nonlinear loads in industrial, commercial and private applications has an increasingly negative impact on the quality of the power system: It becomes polluted by harmonics. System perturbations in the form of harmonics and possible capacitor resonances together with system inductances represent a possible stress potential for components. If the frequencies of existing harmonic currents agree with the intrinsic resonant frequency of an LC system, resonance occurs with generation of correspondingly strong excess currents. Harmonic excitation can then result from the generator (parallel resonance) or from harmonic distortions on the medium-voltage side—for instance, due to other installations in a wind park (series resonance). Even without resonance, an additional current is applied to the capacitors, which then heat up.

Currently, in the industrial sector, detuned PFC systems are used almost exclusively. In these systems, a filter circuit choke is connected in series with the capacitor. This LC combination is designed to ensure that the filter frequency is maintained below the lowest harmonic frequency. As a consequence, the PFC system represents an inductive load with increased resistance at all harmonic frequencies. Detuning eliminates capacitor resonances and defines the stress of the capacitors within narrow limits. By avoiding resonance increases, the grid power quality is also improved. The reduction of harmonics also has a positive effect on the operating life of other electronic and electrical equipment. Moreover, maintenance and repair costs are reduced.

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As both parallel resonances (harmonic loading on the low-voltage side) and series resonances (harmonic loading on the medium- or high-voltage side) must be expected in complex network structures, a detuned PFC system is always a good way of resolving resonance problems.

Safety takes precedence

Self-healing power capacitors are usually equipped with overpressure disconnectors in order to disconnect them from the power system at the end of their useful life after many self-healing processes and the associated increasing internal overpressure. These disconnectors merely deal with the gas produced by regeneration processes caused by excessive overloading or when the overload has initiated a non-self-healing breakdown. They are ineffective against other cases of damage such as short circuits or failure scenarios of the component that do not involve gas production. Additional protective devices are required for this purpose. The most important protective element is a directly pre-connected HRC fuse for short-circuit protection. In selecting this fuse, the following criteria must be noted in particular (see also IEC61818):

- Rated voltage: This should always be selected one voltage stage higher than the supply voltage in order to ensure safe electric-arc quenching in the event of a fault. Especially in this sector, however, fuses with a rated voltage of 690 V are frequently found in 690-V wind generators, which contradicts the recommendations of IEC61818.
- Recommended rated current: 1.6 to 1.8 times the rated current.
- I^2t characteristic: the energy required to trigger the fuse must be below the lower limit of the rupture energy of the power capacitor and/or post-connected components. In the event of a fault, the fuse must trigger before the energy consumption of the capacitor exceeds a critical range (rupture energy).

Relays are another means of protecting capacitors in medium-voltage PFC systems. They also offer additional protective functions against ground leakage, surge currents, unsymmetry, undercurrent and over-voltages. In addition to special PFC capacitors, EPCOS offers a series of PFC products for industrial installations and private households and and continues to be world market leader in this field for many years. The range of reactive power extends from 0.8 to 56 kvar per capacitor at voltages of 230 to 800 V. Also, the product range offers all key components for a successful PFC: power factor controllers, multi measuring interface, harmonic filter reactors, capacitor contactors and thyristor modules – all carefully harmonized to each other. Combined with the technical experience of technical staff and partners all over the world, EPCOS not only provides single components, but real power quality solutions!

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