All Capacitors are Not Created Equal

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MPP Capacitors

With the advent of metalised polypropylene (MPP) capacitors in the 1980's, the opportunity to make more kVAr in physically smaller capacitors went ahead at a very fast pace. Where previously something like a 5kVAr, 3 phase, 415V capacitor took up between 3 and 4 litres of volume, using the new films meant this could be reduced to under 1 litre. However, the reduction in surface area to approximately one third of the previous surface area inadvertently caused significant thermal issues. History shows that these problems have been very poorly handled. MPP capacitors have mostly not achieved the reliability levels attained by the previous generation of power factor correction capacitors, and the biggest cause of this is the reduced ability to handle the heat generated by the losses in the cells. Although there have been advances in both film technology as well as the reduction of internal losses, the fact remains that thermal issues are the major cause of premature capacitor failure.

This document is a technical overview of the design parameters of Low Voltage Power Factor Correction Capacitors.

Problems

There are a number of causes of heat in power factor capacitors:

- Losses in the actual polypropylene film
- Poor internal manufacturing causing higher resistance joints that generate heat
- The geometry of the cells inside the capacitor
- High levels of system disturbances on the supply (such as harmonic distortion)

Furthermore, there are a number of reasons that then prohibit the heat from dissipating effectively:

- Little or no air flow
- Air that is too warm to effectively remove the heat generated

- Poor thermal conduction inside the capacitor
- Less than best cell geometry

Polypropylene Film

The losses in the raw film are determined at point of film manufacture along with decisions made by the cell designer. These losses are proportional to the equivalent series resistance (ESR) of the cell, and the higher the ESR, the higher the losses. Generally, raw films from different manufacturers have very similar ESR values. Having said this, many capacitor manufacturers specify different features for their films, such as *ramped metalisation*, *segmented film*, or *single sided metalisation*. Whilst all of these have certain benefits in particular areas, they usually increase the ESR and therefore increase the amount of heat generated. The design choices made will almost certainly make compromises in one area to gain benefits in another area – and these sacrifices have the potential to be problematic. More detailed data about ESR and various types of films is available from the author.

Capacitor Manufacture

Poor internal manufacturing usually comes down to poor terminations, undersized connection wires, incorrect solder used on joints, or poor metal spray on the cells. These issues are controllable in well run factories. Cells can be wound from a variety of widths of polypropylene. To get the capacitance required, the focus is on the surface area of the capacitor plates and the inverse of the distance between the two plates.

Capacitance is defined by $C = (E_0 E_1) \times (A / d)$ where:

E_0 & E_1 are constants A is plate area d is the distance between plates

The distance between the plates is fixed by the thickness of the film used, and this thickness is determined by the voltage that the capacitor must withstand. This means the easiest parameter to adjust in order to change the amount of capacitance is the plate area – in other words, changing the width and/or the length of the film used to roll up into the cell. Greater film length makes larger diameter cells; wider film makes taller cells. This means that the decision of the film width to be used determines the diameter of the wound cell. A tall, thin cell will produce more heat than a short, fat cell. This is because it has a higher ESR (reasons for this are available from the author upon request). As well as having higher heat generation, a tall, skinny cell cannot remove the heat out of the cell as quickly as a short, fat cell. This is purely because the heat has further to travel to the ends of the cell, which function as heat exit points. Heat gravitates towards the ends by travelling along the metallisation within the cell – rather than attempting to conduct through the many layers of polypropylene, which is an insulator, to the sides of the cell. Therefore, the taller the cell, the further the heat needs to travel to reach a point it can dissipate, and the hotter the cell will operate. The greater the surface area of the end of the cell, the faster the heat can exit from the cell. Without doubt, the shorter the capacitor, the better able it will be at "handing off" its thermal load to its surroundings.

System Disturbances

High levels of system disturbances such as harmonics can be dealt with by the fitting of series harmonic blocking reactors, and the availability of several smaller capacitors instead of one large capacitor per step. For example, with a 50kVAr step, a single 50kVAr capacitor would be very difficult to cool, even with harmonic blocking reactors fitted. Two 25kVAr capacitors would be easier to cool, and three 17kVAr capacitors would be easier still. A downside of fitting harmonic blocking reactors is that they themselves produce very significant heat loads that have to be dealt with. Often the reactors are housed in the same cabinet as the capacitors, and even worse, mounted beneath the capacitors such that their heat rises onto the capacitors. It is worth remembering that a reactor can happily operate at 125^{o}C, whereas capacitors suffer significantly reduced life expectancy at temperatures over 40^{o}C. Most capacitors are rated to 55-65^{o}C, but when their life expectancy curves at these higher temperatures are examined, the inescapable fact is that their longest life expectancy figures are at the lowest temperatures. This is to do with the physics of polypropylene polymers.

Cooling

Most capacitors have two temperature ratings; an ambient temperature of the surrounding air, and the maximum can temperature. These two temperatures are related, and both are affected by air flow, air temperature, and the nature of the thermal load itself. Thermal load generated inside the cell is cumulative, so while a heavy load that is present for a short time will generate heat that may take some time to get to the surface of the cell, a consistently high load will cause heat to be generated and accumulate within the cell, requiring a greater air flow of cooler air. The placement of capacitors within the system and the supporting thermal structure is critical to the amount and temperature of the air flow – please see "*Thermal Issues in Power Factor Systems*" by Allan Ramson.

Internal Conductivity

The capacitor designer controls the medium used to fill the capacitor with. Common choices are mineral oil; vegetable oil; polyurethane resin; epoxy; gas; natural air. Each fill material has a number of pluses and minuses, with oils being substantially better at transporting heat within the capacitor. However, advances in the last few years have seen urethane and silicone resins with dramatically improved thermal performance, making them the preferred fill material by most manufacturers.

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The Ideal Capacitor

Although many other factors contribute, features of the ideal capacitor would include:

- Lowest loss film available being used
- Plain film (not segmented, ramped or single-sided metallisation)
- Short cells with large diameter
- Oil filled
- Multiple small capacitors rather than a single large capacitor

For example, a number of manufacturers make a 17.5kVAr capacitor that is 280mm high with a diameter of 85mm (Frako, AmpControl, Schneider, Lifasa, Ducati, Epcos, Vishay). These capacitors are made up of 96µF cells wound from 75mm wide film. The different manufacturers use various fill materials as well as differing films, from plain, segmented, ramped metallisation, etc. All of these capacitors will generate more internal heat than a 17.5kVAr capacitor manufactured by German company KBR. This is because KBR uses 50mm wide film, resulting in an overall capacitor size of 210mm high, and either 116mm or 136mm in diameter (short and fat). In addition, KBR capacitors feature the patented 'Cool-Cap' technology, which produces the lowest internal losses of all. The afore-mentioned capacitors advertise life expectancies from 120,000 hours to 160,000 hours, whereas the KBR capacitors are specified at >250,000 hours.

<KBR capacitors are available in Australasia exclusively from kVArCorrect>

Summary

While the developments in metallised polypropylene has allowed capacitors to reduce in size, both the heat generated as well as the ability of the capacitor to dissipate that heat have often been overlooked in design and manufacture. When choosing a capacitor, always choose short and fat over tall and thin. It is recommended that can height is no more than 210mm, as this means the film used is no more than 50mm. If possible, ensure plain film is being used rather than segmented or other variants. Opt for the highest claimed life expectancy available – 150,000 hours should be viewed as the minimum acceptable quality. Select a voltage rating of at least 480V. For Australasian supplies, 440V is not high enough to cope with the spikes, surges, and harmonic induced high voltages.

About the Author

The opinions expressed here are the researched views of Allan Ramson, General Manager, kVArCorrect Ltd. All claims have been substantiated by testing and observations from the Australasian market between 2007 and 2017. Having been associated with the design, manufacture and supply of many thousands of power factor capacitors and almost 500 power factor systems, kVArCorrect are confident that the KBR capacitors are the best capacitors tested and used.

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