Design Problems in Power Electronics

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Design Requirements for Reliable Power Electronics

With the increase in the use of power electronics in the Power Quality field (Power Factor and Harmonic mitigation), a number of significant design issues have arisen that have drastically increased costs, physical size, and cooling requirements. Whilst each of these can be solved through careful design, it is unfortunate that the vast majority of SVG and APF designers do not seem to consider these issues. Reliability of power electronics requires dependable operation of Capacitors, Semiconductors, Fans, and other components. This paper concentrates on the reliability issues of capacitors, as these are the most misunderstood and yet are glossed over by most SVG and APF sales people.

In order to address each issue individually, an understanding of how these products work is required and this is summarised here. Fundamentally, what these products do is generate a three phase supply that can be manipulated with software. By manipulation, we mean that to correct power factor, the phases can be shifted in time to be either leading or lagging with respect to the mains supply and then the shifted supply is simply superimposed onto the existing site supply. For the APF, the existing site supply is analysed and the data is used to manufacture the same harmonic content but exactly shifted by 180^o, and then this shifted supply is superimposed onto the existing site supply to cancel the offending harmonics. In order to generate these supplies, a very powerful DC bus is required. This is quite easily achieved by firstly rectifying the existing site AC supply, smoothing it and making this high voltage supply (typically >500V DC), available to generate the required new AC supply. Characteristics of this DC bus need to be as follows:

- Sufficiently high voltage to enable a 400-450V AC waveform to be generated

- Sufficiently high current capacity on the bus to supply energy fast enough for the factory or building load, and the harmonics of that load
- Sufficient reliability so as to provide mean time between failures (MTBF's) that are acceptable

Achieving the high DC voltage is not so hard and is proven technology with reasonable reliability. Providing the high current at the speeds needed requires a lot of energy on the DC bus to be available almost instantly. Trying to 'pull' the required energy from the existing supply quickly is just not possible and the way this problem is solved by all manufacturers is to design the DC bus with vast amounts of capacitance on it. Capacitors can supply energy extremely quickly and are used in many everyday things specifically for this purpose. Some examples include electric fences, regenerative braking on electric cars, boom box power supplies in vehicles, and so on. Therefore, all SVG and APF manufacturers use capacitors to smooth and supply fast energy to their DC buses.

What are the requirements for these DC bus capacitors?

- In order to supply sufficient energy, large values of capacitance are required. Typically to supply 500A at 400V for 1 cycle at 50Hz requires 125,000,000µF – a very high number of microfarads
- The second requirement is to be able to provide this energy quickly and this means at high current within a short timeframe
- Thirdly, the capacitors need to be able to do this without excessive heat being generated
- Lastly, the capacitors need to be small enough to fit into a reasonable space

Available technologies for these capacitors are Metalised Polypropylene as used in conventional Power Factor correction systems, and Electrolytic capacitors as used in electronics. There are pros and cons of each type as summarised in the table below:

Capacitor Type	Typical Uses	Range of Capacitance	Advantages	Disadvantages
Metalised Polypropylene (MPP)	Power factor, pulse discharge, high quality audio	0.1 - 500µF	Low cost, low loss, inert materials, very reliable, 25 year shelf life, inbuilt over temperature and over pressure cut-off device	Very bulky, relatively low voltage withstand
Electrolytic	Electronics	1 - thousands of µF	Small, low cost, very high density	Higher losses means higher heat generation, filled with chemicals to obtain the high µF, nowhere near as reliable as MPP capacitors, 12-18 month shelf life, no inbuilt safety mechanism

Apart from the large physical size, MPP capacitors are ideal for Power electronics. They are low cost, high current, low loss, very reliable and absolutely benign in that they have no chemicals inside. There are a very few

SVG and APF manufacturers that use these capacitors, but those that do have a physically larger (and therefore more costly) product, although this is offset by reliability with 5 and 10 year warranties. Almost all SVG and APF manufacturers use electrolytic capacitors, reflected in their shorter warranty periods. There are a number of techniques available for mitigating some of the disadvantages of these capacitors and a summary of the issues faced and the solutions offered is detailed in the following paragraphs.

Electrolytic Capacitors

It is well known that electrolytic capacitors are physically small for the energy they are capable of storing. Given that even electrolytics are wound from polypropylene similarly to MPP capacitors, what makes them different?

What gives Electrolytic Capacitors very significantly higher energy density?

Electrolytics use various acids and chemicals that change the dielectric constant that determines the capacitance value, the voltage rating and the losses. For example, if we take a 1500μF electrolytic capacitor and removed its acids and chemicals, it would be in the order of 20μF, and have a lower maximum operating voltage. It would also have lower losses and therefore run cooler.

What is the problem with these acids and chemicals that are used inside Electrolytic Capacitors?

- Most of the chemicals used are corrosive
- The losses inside the capacitor are higher and this means that the capacitor will run hotter (a huge issue as heat is the number one cause of capacitor failure)
- When the temperature of the acids and chemicals is raised, gases are emitted
- The shelf life of electrolytic capacitors is 12-18 months because the acids/chemicals tend to dry out
- Mean time to repair (MTTR) is greatly increased
- No inbuilt safety cut-offs

The gases released when the capacitor is heated are usually corrosive, and this is why there are vents in the base of electrolytics. If no vent is obvious, the base will be a semi-permeable membrane type rubber that allows the gases to escape. The vent is often shown as a circular white bung, as shown in the picture. These gases should be kept away from anything that will corrode, especially other electronic devices. Unfortunately, many low cost SVG's and APF's use fans to forcefully blow air containing these corrosive gases throughout the rest of the electronics – to their detriment. Ideally, SVG's and APF's should have two separate air flow channels; one for the bulk electronics and one for the capacitors. In order to keep these two air flows separate, the capacitors would need to be in a different sealed space. Almost without exception this is not done and this is why SVG warranties are limited to 1-2 years only. Contrast this with a conventional MPP capacitor based system that has been properly designed – warranties are 5, 7, or even 10 years with the proviso that cooling fan services are performed regularly.

When the acids/chemicals dry out (over 12-18 months on the shelf), there is insufficient electrolyte causing the capacitor to fail. This may happen the instant the power is applied, and it is always a spectacular failure (ie: BANG!!). Most manufacturers recommend applying power to spare parts every 6-12 months to prevent this drying out occurring, by re-vitalising the electrolyte. In fact, many companies publish papers on how to refurbish or "re-cycle" capacitors that have been stored for too long prior to using them. See the Appendix for papers by ABB, Schneider and WEG on reforming electrolytic capacitors. With this requirement for reforming capacitors at 12 month intervals, as recommended by ABB, Schneider, and WEG amongst others, comes the vexatious question of reliability and mean time to repair (MTTR). If spare parts can not be stored for periods greater than 12 months without the need to reform the bus capacitors, (and most companies neither have the tools nor confidence to do this), and if the vendor can not guarantee to supply spare parts that are less than ~3 months old, then this means that the end-user probably has to purchase additional hardware and keep it powered up so that in the event of a system failure, continuity of performance can be assured. This adds cost and takes installation space to accommodate the spare module(s).

To further this issue, unlike MPP capacitors, electrolytics do not have inbuilt safety cut-offs. This is a major safety disadvantage in terms of reliability and the damage caused when failure occurs. Electrolytic failures are usually impressively destructive. MPP cap failures usually have no effect whatsoever on surrounding components. Examples of some electrolytic capacitor failures are below:

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What about the heat generated?

Conventional MPP capacitor based systems are known for producing heat from harmonic blocking reactors and from harmonic currents that are present on the supply. These require forced air cooling and careful design of the air flows within cabinetry (see kVArCorrect's papers on Thermal Considerations). SVG's and APF's are essentially the same and in fact, produce more heat per kVAr or Ampere than conventional systems do. SVG's and APF's deal with heat by building fans into their products and having monitoring software such that if a temperature issue arises, the unit will shut down. This is no different to well designed conventional systems that will shut down when the temperature is too high, albeit usually conventional systems will have a higher temperature rating than Active systems, as they do not have to handle the corrosive gas emissions from the electrolytic capacitors. As mentioned, the losses inside the electrolytic capacitor are higher causing the capacitor to run hotter. The difference in temperature rating between the two technologies is generally approximately 10^{o}C and is the reason that switchroom air conditioning is often required for SVG's and APF's, whereas air conditioning is not usually required for conventional MPP capacitor systems. This all adds to the installation cost difference between the two technologies, as well as the less spoken about running/maintenance costs.

Final Comparisons

Power Electronics can use either MPP capacitors, or electrolytic capacitors. MPP capacitors are physically larger and therefore increase the system cost, yet they are by far the best suited to this application, allowing longer warranty periods. Electrolytic capacitors are small in size, and have very high density at low cost. To put the two technologies into perspective, a conventional 300kVAr capacitor based system will have a total of 5,400µF of MPP capacitors, whereas an SVG or APF of the same size will have 60,000-100,000µF of electrolytic capacitors. The use of electrolytic capacitors comes with many disadvantages, although some of these can be designed around. The biggest challenge is that power factor correction system designers often do not recognise these problems or adequately design around them, resulting in SVG's and APF's generally having lower warranty periods available in addition to lower reliability, higher risk of spectacular failure, and increased running and maintenance costs.

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 2019. Having been associated with the design, manufacture and supply of many thousands of power factor capacitors and almost 500 power factor systems, in addition to many years of testing and documenting the thermal behaviour of power capacitors, kVArCorrect are confident that their power quality solutions (with warranties up to 10 years) are leading the market.