

WHY DO CAPACITORS FAIL?

1. Introduction

Capacitors play a crucial role in a UPS system by helping to smooth, filter, and store energy.

A typical UPS contains dozens of different types of capacitors in both the main power section and at the printed circuit board (PCB) level. For the purposes of this whitepaper, our focus is on the former – the capacitors in the main power section. These components range in size from a miniature drink can through to a tube of Pringles.



Capacitors are enclosed in aluminium or chromium-plated cylinders and contain a pair of conducting surfaces, typically electrodes or metallic plates. A third element, known as the dielectric medium, separates and insulates these elements.

The volume of charge that a capacitor can store is measured in farads – named after physicist Michael Faraday – and determined by the thickness of the dielectric layer and the surface area of the aluminium plated.

The main capacitors in the power section of the UPS can be categorized as follows:

- **AC input capacitors**, which form part of the UPS input filter and/or power factor correction stage. They are subjected to the incoming mains supply, with the crucial role of smoothing out

input transients, reducing output reflected switching noise and harmonic distortion.

- **AC output capacitors**, which form part of the UPS output filters. Their role is to connect to the critical load output, helping to control the waveform of the UPS output voltage and provide reactive power.
- **DC capacitors**, which form part of the rectification system and energy storage. Their role is to help smooth out any fluctuations in voltage, also known as supply voltage filtering, and provide short-term energy storage for mains to battery transitions to ensure a no break supply to the critical load.

All capacitors in the power section of the UPS are subjected to potential high frequency switching and UPS loads, as well as stresses caused by the physical and electrical operational environment.

2. How long do capacitors last for?

Along with batteries, capacitors are the UPS components most prone to failure. Capacitors age over time, losing the ability to perform their job.

The electrolyte, paper, and aluminium foil inside the capacitor degrades physically and chemically. Several factors, such as excessive heat or current, can speed up the deterioration rate.

Depending on the manufacturer rating, a capacitor could deliver up to 10 years of service life with favourable operating conditions. However, accepted industry best practice recommends replacing capacitors between years 4 to 8 to minimize the risk of a serious failure.

In specific roles or locations, some capacitors may need to be swapped as early as year 4 to prevent failure.

3. What factors affect capacitor lifespan?

Capacitor lifespan is shortened by any detrimental environmental extremes (i.e. hot or cold temperatures) and its workload.

- **Excessive current:** regularly exposing the capacitors to steady currents that exceed the manufacturer's rating will quickly cause damage. Short periods of high ripple current tend to be harmless, as long as the capacitor isn't forced to overheat to compensate.
- **Overuse:** the harder a capacitor has to work, the quicker it will need replacing. The more it has to filter unusual levels of voltage noise or transients, the faster the rate of deterioration.
- **Excess heat:** this will eventually start to evaporate the solution inside the capacitor, building up unsafe pressure. Heat can come from inside the capacitor, possibly as the result of a blocked air filter that limits airflow, or from generally high ambient temperatures where the UPS is installed.



Who is Michael Faraday?

The man who gives his name to the volume of charge a capacitor can store (farad) is one of the most influential scientists in history.

Michael Faraday was born in London in September 1791. Even though he enjoyed little formal education, his work lives on today thanks to his contribution to the study of electromagnetism and electrochemistry.

In 1831 he discovered electromagnetic induction – the principle behind the electronic transformer and generator. He also coined several familiar phrases including 'electrode', 'cathode' and 'ion'.

Albert Einstein is said to have kept a picture of Faraday on the wall in his study. While several institutions, including the Royal Society and the Institution of Engineering and Technology (IET), have created awards in his name.

4. Can you tell if a capacitor is about to fail?

There are several tell-tale signs a service engineer might spot when carrying out routine preventive UPS maintenance, including:

- **Oil leakage:** this increases temperature and impedance in the capacitor.
- **Deformation:** usually caused by excess heat or internal fluid leaks.
- **Scorched wires connected to the capacitor:** this tends to be caused by over-current and can be identified during thermal imaging.
- **Burnt valve cap protrusion:** a clear sign of stress that will probably result in a failure when the protrusion breaks. Likely caused by a short circuit in the capacitor which generates gas and leads to a build-up of pressure.
- **Increase in temperature:** a thermometer or ideally a thermal imager is able to detect even small variations in the operating temperature of a capacitor. When the internal temperature starts to increase, it's a tell-tale sign the capacitor is starting to fail.
- **Capacitance:** as the capacitor ages, it will slowly fall out of tolerance as the internal structure degrades, similar to the process with a battery. These changes in tolerance can be measured using a capacitance meter, which are typically found as part of most quality digital multimeters.

5. What happens when a capacitor fails?

There are two main types of capacitor failure. Firstly, they can fail in an "open" condition where they basically stop working. This type of breakdown can often pass undetected, as there's little visible evidence that something has gone wrong.

The second option is a "short" condition failure, where there's an obvious leak of the dielectric medium. Sometimes there's even a loud popping sound like a firework.

The electrolyte is conductive, so leakages can create unintended connections that could disrupt UPS performance. It is also corrosive, so is likely to damage any surrounding components.

Because of this, many electrolytic capacitors have a scored mark at one end. This is designed to let the corrosive electrolyte leak slowly in a more controlled fashion, as opposed to a more damaging eruption that would quickly spread the material across a wider area.



Alternatively, there is a third condition, where the capacitor will fail gradually and fall out of tolerance. It's also worth considering that in many cases, a capacitor is made up of multiple capacitors inside.

So in the case of a capacitor being split into two internal sections, there are contrasting scenarios. During a failure, half of the capacitor could fail open, which would result in overall capacitance being lost. Or half of the capacitor could fail short, which would result in the overall capacitance being halved.

Most modern power capacitors are fitted with pressure release valves or complete pressure release caps, which enables the capacitor to alleviate the internal pressure should a failure occur.

This does result in a rise in temperature, though, which in turn causes the internal pressure to increase. In certain instances, a sudden change in pressure leads to the capacitor releasing pressure at an extremely high rate, discharging electrolyte across the surrounding area.

The worst-case scenario is when capacitors do not receive any maintenance activities because they can completely dry out and become a serious fire risk.

When an individual capacitor fails the remainder must pick up the workload, which in turn will shorten their lifespan. If a single capacitor fails, even if there is no obvious visible indication that it has, it can be a sign that the other capacitors aren't doing their jobs properly too.

6. How does capacitor failure affect a UPS?

This is dependent upon where the capacitor is located, the overall health of the capacitors, and whether they're working in a series or parallel.

Take, for example, a situation where the capacitors are operating well below their recommended voltage rating and/or capacitance requirements. A single failure is unlikely to impact the UPS too much as the remaining capacitors will be able to pick up the slack.

Ultimately, however, capacitor failure will negatively impact the performance of a UPS. Its filtering ability will suffer; there will be more issues with harmonics and electrical noise; the energy storage volume will reduce, and battery strings can be damaged.

In the worst-case scenario, a serious capacitor failure will trigger the UPS to switch to bypass mode, which leaves the critical load unprotected.

Deterioration and failure of AC capacitors can lead to:

- Increased inverter distortion
- Instability of the entire system (for parallel configurations)
- Sudden breakdown with fumes and noise disturbance, which could also damage other parts of the UPS
- Unscheduled machinery downtime
- Increased maintenance and repair costs compared to proactively replacing capacitors
- Unwanted damage caused by the capacitor exploding or the worst-case scenario of catching fire

Deterioration and failure of DC capacitors can lead to:

- Breakdown in the inverter/rectifier section
- Damage to other components within the UPS
- Unscheduled machinery downtime
- Increased maintenance and repair costs compared to proactively replacing capacitors
- Unwanted damage caused by the capacitor exploding or the worst-case scenario of catching fire

7. Minimizing the risk of capacitor failure

There is no standard age at which a capacitor will fail. To ensure the ongoing performance and reliability of your UPS system, it is advisable to treat them as consumables and proactively plan their replacement before they reach the end of their rated service life.

The recommended time frame for this is between years 4 to 8, depending on location and role.

The areas most under your control are general good housekeeping and robust UPS maintenance. Try to stick to the recommended ambient temperature and humidity levels, as well as keeping air filters clean so air can flow freely and keep the UPS cool.

During regular Preventive Maintenance Visits (PMVs), field service engineers should visually inspect the capacitors and scan with thermal imaging devices to highlight any potential problems. Analysis of maintenance field readings will also help to identify the capacitors most likely to fail.



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