/ Perfect Welding / Solar Energy / Perfect Charging

ACTIVE VS PASSIVE COOLING OF POWER ELECTRONICS

Why active cooling is the better technology for power electronics.

Version 1.2, 09/2023 , Jürgen Wolfahrt, Franz Breitwieser, Volker Haider, Jasmin Gross
Solar Energy

TABLE OF CONTENTS

1 INTRODUCTION

High ambient temperatures not only affect the yield of an entire PV system, they also have a considerable effect on the service life of the inverters. It is not just the inverters themselves that are negatively affected by high outside temperatures, but also the performance and the service life of the electronic components inside the device.
So the question is, how to stop electronic components overheating, without investing vast sums of money in an air-conditioned inverter environment, for example.

This white paper examines and compares in some detail two standard inverter cooling technologies found on the market. The comparative tests are designed to highlight the differences and beneficial features of passive and active cooling technology.

1.1 Definition of passive cooling

Passive cooling technology relies on natural convection. Large heat sinks are used to keep the internal temperature low, which tends to make the device heavy.

1.2 Definition of active cooling

The aim of active cooling technology is to proactively avoid heat fields by using interior fans and to remove warm air in a controlled manner.

At Fronius, *Active Cooling* is a technology standard in all devices. In addition to a small heat sink, there is a fan to ensure that the air inside the inverters is circulating and so-called hot spots are avoided. A further fan is responsible for keeping the cooling fins of the power electronics at a low temperature. The fan speed varies, subject to the temperature inside the device.

2 PLANNING & SYSTEM DESIGN

Intelligent system design is a particularly important issue when it comes to family homes, as firstly, the roofs of the houses are often irregularly shaped and oriented towards different points of the compass and secondly, the roof area is limited.
In practice, there is also only a limited amount of free choice about where to install the inverter; you have to adapt to the given conditions. However, some inverters have strict regulations regarding the type, position and site of installation. These restrictions are usually caused by the cooling system used in the inverter.

2.1 Active cooling means greater flexibility

2.1.1 Flexibility in system design

If you look more closely at the maximum input current (I_{DCmax}) of an MPP tracker for passively cooled devices, you will discover that the flexibility of these is restricted. Due to the often limited amperage of MPP trackers for passively cooled devices, only one module string can usually be connected to a tracker. This is because higher amperages also cause higher component temperatures ($P = I^2 \times R$).
Passively cooled devices tend to use evenly distributed MPPT inputs. Due to the limited heat dissipation, the amperages of the MPPT inputs are limited. This results in limited design flexibility, as comparatively fewer DC module strings can be connected per MPPT input. This is also the reason why asymmetric distribution is only possible to a limited extent.

Actively cooled devices, on the other hand, can dissipate more heat, allowing higher amperages. In turn, the higher amperages per MPP tracker mean greater flexibility in system design, as more parallel strings can be connected.
Actively cooled devices from Fronius allow especially high currents (e.g. 25 A for a 5 kW Symo GEN24 [Plus]) with at least one MPPT input. It is then possible to connect two or more DC strings at this MPPT input. In addition to this, actively cooled Fronius inverters have at least one more MPPT input. This makes it possible to have a broad asymmetric distribution to the two MPPT inputs. This, together with the possible overdimensioning of the DC output by up to 150%, allows greater flexibility in system design, which is why it is also called SuperFlex Design.
This can be illustrated by a simple example.

Comparative example:

System data		
AC output	**Overdimensioning**	**Module output**
5 kW	130% (6.5 kWp)	285 watt (8.97 A)

With an actively cooled Fronius inverter, there is no problem connecting both the DC strings in our example system to one MPPT input. It would also be possible to connect additional solar modules from a roof with a different orientation to the second MPPT input.

By combining the SuperFlex Design with an active cooling system, Fronius inverters make it possible to produce the perfect design for roofs of different complexity. With passively cooled devices on the other hand, a relatively symmetrical PV generator distribution is often allocated, as can be seen on the following graphic.

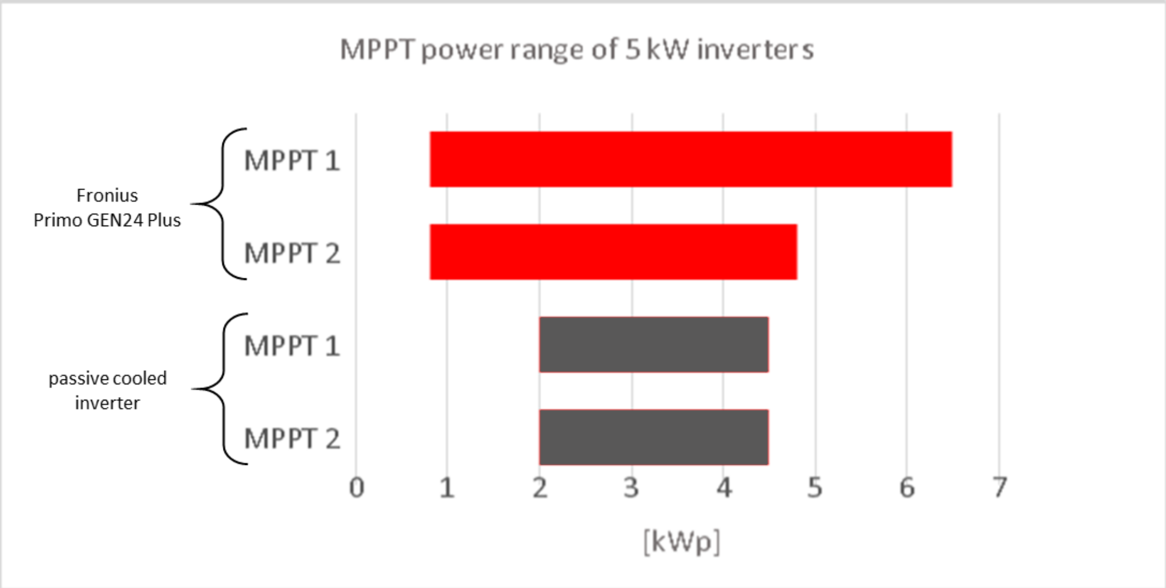

Figure 1: Comparison of MPP tracker power distribution for passively and actively cooled 5 kW inverters

It is apparent that the power distribution of the MPP trackers for actively cooled devices is more generously proportioned than for passively cooled devices. The reason for this is that inverters with passive cooling of the 5 kW power category, for example, usually only allow maximum currents of 10 A to 15 A.

In relation to our example system, this means that with passively cooled devices, the maximum asymmetric distribution is limited to 4.5 kW (MPPT1) and 2 kW (MPPT2), whereas with an actively cooled Fronius inverter, asymmetric distribution can be implemented with 5.7 kW (MPPT1) and 0.8 kW (MPPT2).

In a system with a standard 285 watt solar module (Trina TSM-285), which has a current of 8.97 A, Fronius inverters allow string lengths of 3 to 22 solar modules to be connected at tracker 1 and 3 to 20 solar modules at tracker 2. With a passively cooled device, on the other hand, only 7 to 15 solar modules can be connected at both trackers.

2.1.2 Flexibility of installation

With passively cooled inverters, the air must be allowed to flow in and out as freely as possible, which requires specific positioning of the inverter.
Inverters with a passive cooling system can only be mounted vertically (90°). There are also restrictions on side-by-side or one on top of the other installation, as otherwise the air heats up from device to device, greatly reducing the cooling effect. It is also inadvisable to position the inverter in direct sunlight, as the device with the passive cooling system is warmed by the radiant heat in addition to the ambient temperature.

There are no installation restrictions for devices with an active cooling system. The inverters can be mounted vertically or horizontally (0° - 90°) and even flat (on a roof).

Figure 2: Flexible mounting options for actively cooled Fronius inverters [source: Fronius]

With an intelligent, active air guide, it is possible to mount inverters side-by-side. The cool air is drawn in from the side, for example, and the heated air is dissipated upwards, as shown in the diagram below:

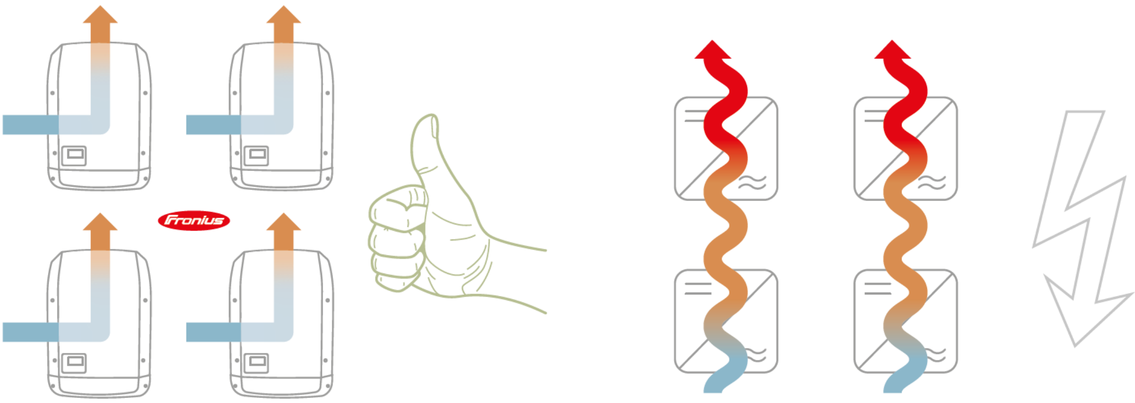

Figure 3: Flexible installation - an intelligent, active air guide allows installation side-by-side or one on top of the other [source: Fronius]

Controlled convection allows heat dissipation to increase approximately five-fold compared to passive convection, which means that the inverters can also be placed in locations with high levels of insolation.

3 MAINTENANCE

Maintenance is a component of every service decreed by technical regulations or the manufacturer's instructions to ensure that a device stays functional. Maintenance is generally carried out at regular intervals, the so-called maintenance interval. This must usually be carried out by qualified technicians.
Maintenance-free means that there are no stipulated maintenance intervals.

With a passive cooling system, accumulated dust and dirt must be removed at prescribed maintenance intervals. If this stipulated maintenance is not completed, it will have a negative effect on the warranty. The following competitor maintenance list shows what form such requirements might take (see Figure 4 below).

According to this manufacturer's maintenance list, miscellaneous inverter factors such as heat sink cleanliness, system operating status, cable connections and the grounding terminal must be checked up to twice a year, because the passive cooling system requires a considerable amount of maintenance. This results in high ongoing maintenance costs, especially in extremely dusty environments.

Check Item	Check Method	Maintenance Interval
System cleaning	Check periodically that the heat sink is free from dust and blockage. Turn off the DC switch and then turn it on at night to clean the oxide off the switch.	6 months to annually.
System running status	Check that the SUN2000 is not damaged or deformed. Check for normal sound emitted during operation of the SUN2000. Check that all SUN2000 parameter settings are correctly set during operation.	6 months
Electrical Connections	Check that cables are securely connected. Check that cables are intact and the parts in contact with a metallic surface are not scratched. Check that the idle RS485 and USB ports are covered by waterproof caps.	6 months
Grounding reliability	Check that PGND cables are securely connected.	6 months

Figure 4: Maintenance interval [source: HUAWEI Operating Instructions issue 07, 2018-05-04]

If, which is usually the case, a qualified technician is also required to clean the cooling fins of the passive cooling system, this again increases these ongoing costs (see picture below). If this maintenance is not carried out by a specialist as prescribed, this will have a negative effect on the warranty.

8003

⚠ QUALIFIED PERSON

Active power limited derating

The inverter has reduced its power output for more than ten minutes due to excessive temperature.

Corrective measures:

- Clean the cooling fins on the rear of the enclosure and the air ducts on the top using a soft brush.
- Ensure that the inverter has sufficient ventilation.
- Ensure that the ambient temperature +40 °C has not been exceeded.
- Ensure that the inverter is not exposed to direct solar irradiation.

Figure 5: Required specialist maintenance [source: SMA Operating Instructions, SB30-50-1AV-40-BE-de-10]

3.1 Active cooling reduces costs

An inverter with an active cooling system is usually maintenance-free, so ongoing costs are noticeably reduced.

But regular checks on the airways are still advisable for inverters with an active cooling system. Annual inspections after this period are recommended, especially in extremely dusty or dirty environments. However, this is not prescribed maintenance, so a qualified technician is not needed, which again saves costs.

4 SERVICE LIFE

The reliability of inverters is often expressed by MTBF values (Mean Time Between Failures) - an expectation of the duration of operation between two successive failures. This is a mathematical calculation based on the defect rate of a component, as determined in laboratory tests or during short periods of operation. The requirement here, for example, is for the inverter to be used under specified operating conditions (such as 4,000 hours of operation a year over 10 years). However, these calculated values usually differ greatly from the real failure rates.

The so-called FIT (Failure in Time) rate is more informative, but this can only be determined over a longer operating period (e.g. > 10 years). Fronius has worked in the inverter industry for more than 25 years and can therefore draw on FIT rates (see section 4.1.1).

However, the service life of electronic components is heavily temperature-dependent. The hotter these components get, the shorter the expected service life and the higher the probability of failure.

A frequently quoted rule of thumb for the reliability of capacitors in electronics is that **each temperature increase of 10 °C roughly halves the service life** (see Texas Instruments [1]).
Figure 5 below uses an electronic semiconductor as an example to show the failure rate, depending on the period of operation and subject to temperature.

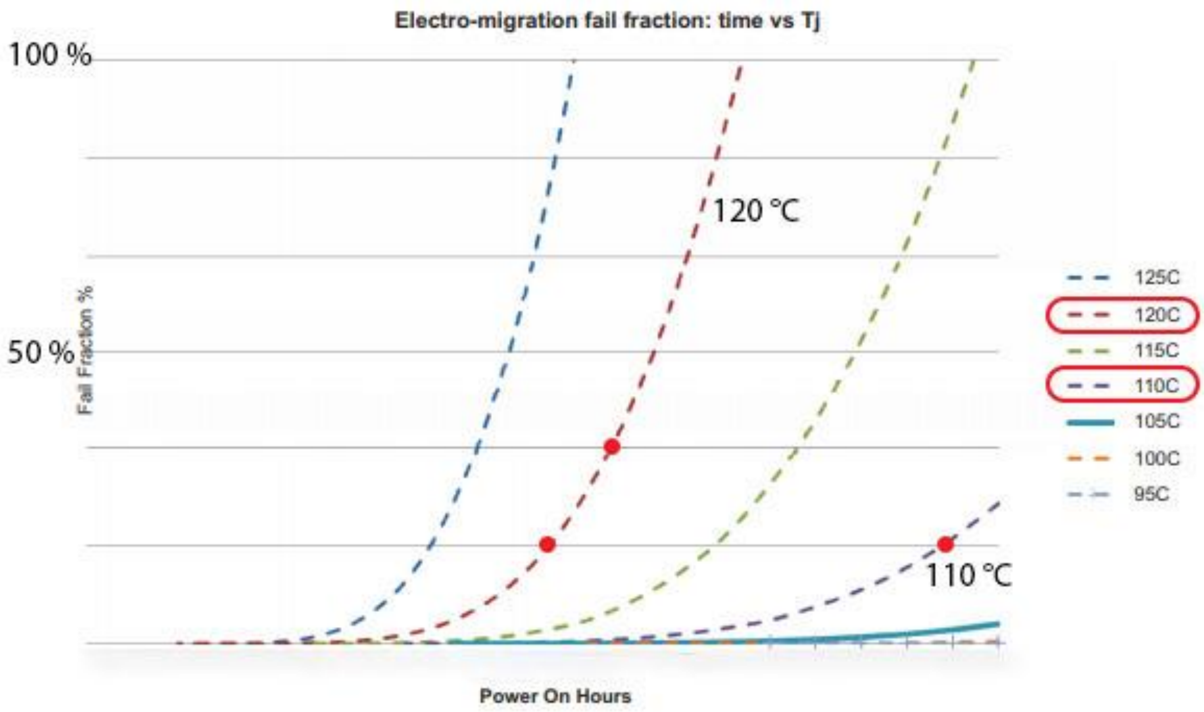

Figure 6: Failure rate subject to temperature and period of operation [source: Texas Instruments [1]]

This clearly shows that at extreme temperatures over a longer period of time, the failure rate increases dramatically and the service life is drastically reduced. If you look at the rise in temperature from 110 °C to 120 °C, for example, it is evident that the service life is halved.

4.1 A longer service life thanks to active cooling

With active cooling, the electronic components are exposed to a lower temperature and are therefore under less stress, which in turn leads to a longer service life.
Experience shows that higher temperatures can lead to local hot spots in inverters with passive cooling, so the service life will be reduced.

To stop electronic components overheating, the inverter implements a controlled reduction of output, known as "derating". With passively cooled devices, this power derating starts earlier than with actively cooled devices, which undoubtedly leads to losses in yield (see section 5).

4.1.1 Service life of a fans

The cooling effect is greater with actively cooled inverters. This is because fans are used.

With passively cooled inverters, flow rates of up to about 1 m/s are achieved, subject to the temperature difference between the element and the surrounding area and the length of the heat sink. Compare this with actively cooled inverters, where, due to the increased convection caused by the fan, around 5 m/s is achieved, which is up to 5 times the heat dissipation. This means that components can be cooled more quickly, which in turn increases the service life of the electronic components.

The fans used at Fronius for active cooling are designed for a service life of at least 20 years, a claim supported by the following data sources:

/ Supplier data: The service life specification of > 80,000 h is valid for operation at nominal voltage. However, the fans usually operate at a reduced voltage (lower speed), which improves the service life.

/ Component and system service life tests: At Fronius, devices were tested under continuous load for over
15,000 hours in the laboratory, which in practice means more than 20 years of customer operation. (Tests in the electronics industry, however, usually only run up to 1,000 h.)

/ Fronius warranty data: The Fronius IG [Plus] inverter (with up to 6 fans installed) has been in the field for more than 10 years. The total number of fan failures is < 0.1% of all devices sold. This converts to a component reliability of < 10 FIT (failure in time), corresponding to approx. < 1% of the total FIT of all the components, an excellent figure.

Figure 7 below shows the real operating data from two devices exposed to extremely high temperatures over a one-year period. The hours of fan operation are categorised according to 5 ambient temperature categories in steps of 10 °C (20-30 °C, 30-40 °C, 40-50 °C, 50-60 °C and 60-70 °C).

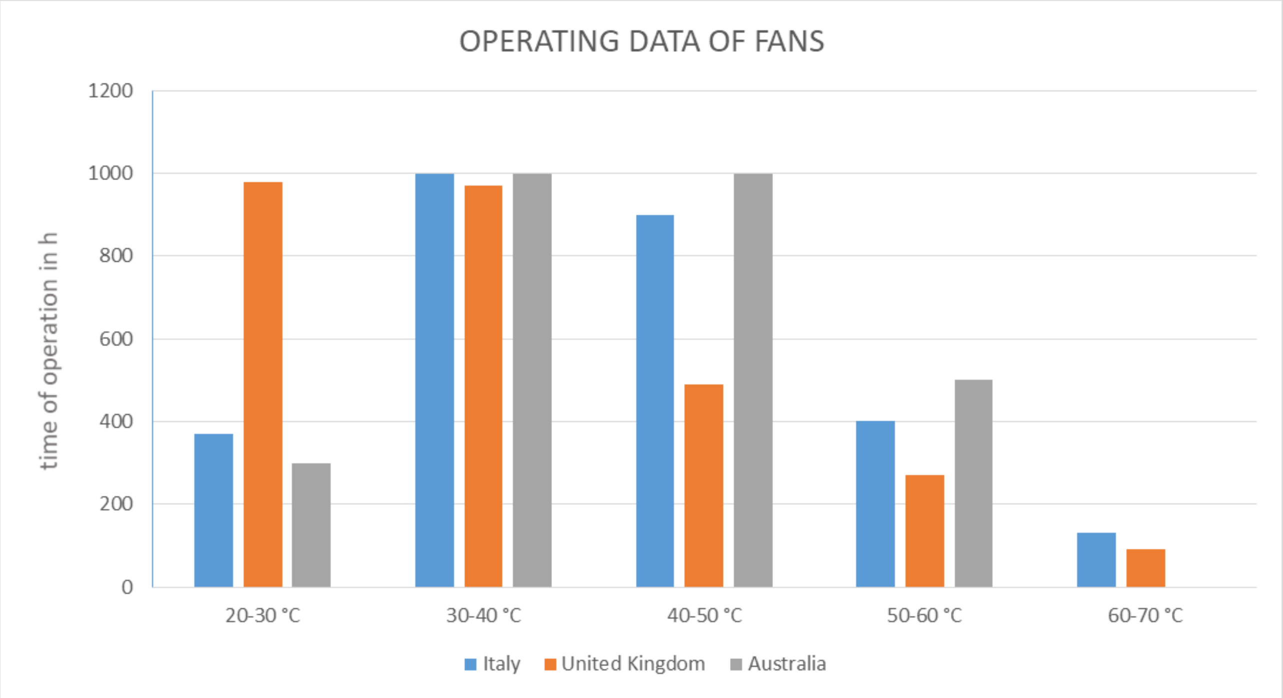

Figure 7: Annual operating data for the fans of actively cooled devices in Australia, Italy and the UK [source: Fronius]

The design of the speed-controlled fans in Fronius active cooling system devices is such that they **only run at full speed if the ambient temperature reaches 60 °C**. But in practice, this operating point – as shown in the graphic – only occurs for a few hours a year. The fans run at a lower speed for the remaining operating time in the year.

It is also noticeable that in Australia, the fans never run at full speed during the year. An inspection of well over 350 systems showed that in especially hot regions, such as Australia, hot solar modules have such reduced PV power that the inverter and therefore the fan never run at their full output power. The fans of inverters located in regions further north generally exhibit a higher speed over the year.

So in practice, it is easy to achieve far more operating hours than the 80,000 h specified by the manufacturer, for example, which were calculated at constant full speed.

5 YIELD

If an inverter is exposed to high temperatures, the output power is reduced (= derating), to stop the electronic components overheating. However – as already mentioned at the start – this has a negative effect on yield. The derating behaviour of inverters with active cooling is more beneficial in the higher temperature ranges. They only start to reduce their output power at higher ambient temperatures, as the cooling effect is significantly more effective than with passively cooled inverters.

Inverters with passive cooling are already working in derating mode at lower ambient temperatures and are therefore less suitable for a warm climate, as the expectation is that yields will sometimes be significantly reduced (see section 5.1.1).

5.1 Active cooling means higher yields

Those inverters that have an active cooling system can be operated for longer at unrestricted power and therefore achieve higher yields. This is clearly evident in the illustration below. It compares a Fronius inverter with an active cooling system to an inverter with a passive cooling system at different voltages.

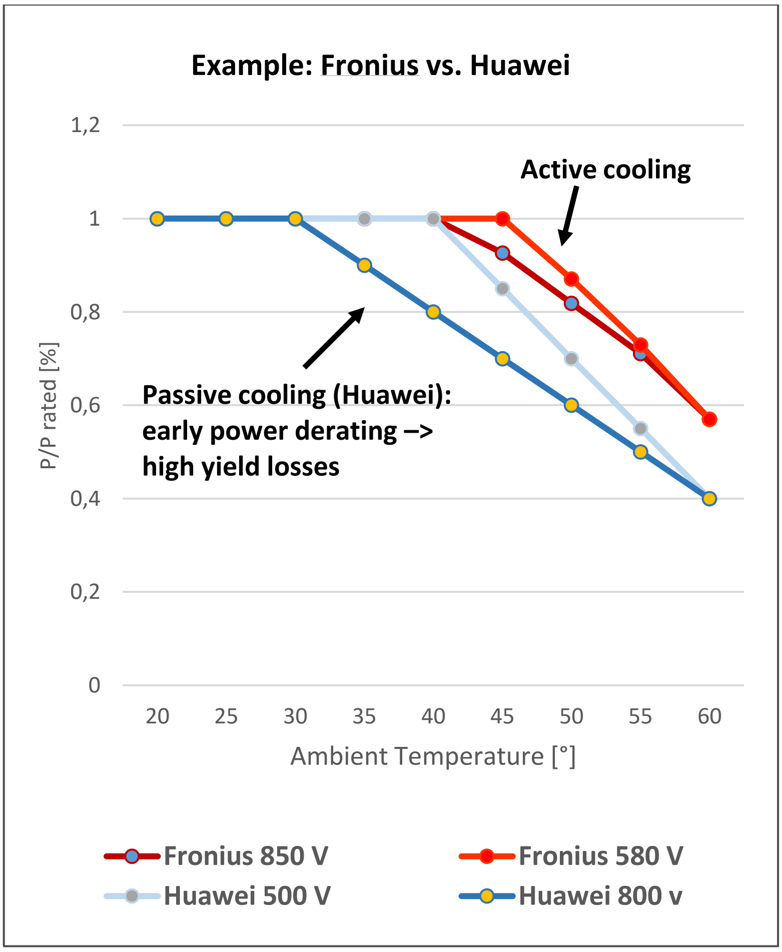

Figure 8: Power reduction in relation to ambient temperature [source: competitor data sheet]

As is evident from the graphic, the (800 volt) passively cooled inverter is already switching to power derating at ambient temperatures of **30 °C**, which can result in high yield losses. The (850 volt) actively cooled Fronius inverter, on the other hand, only starts power derating from 40 °C. By comparison, the passively cooled inverter is already **running at only**
80% of its power output at this ambient temperature!

5.1.1 Repercussions, using a reference system as an example

The impact of early power derating in passively cooled devices is analysed below on the basis of a system installed in Australia.

This reference system is a system in Australia (99.84kWp DC / 90kW AC) with actively cooled Fronius inverters. The diagram below shows a daily production curve of the AC output and the progression of the ambient temperature. Ambient temperatures of up to 50 °C occur in the Australian example system.

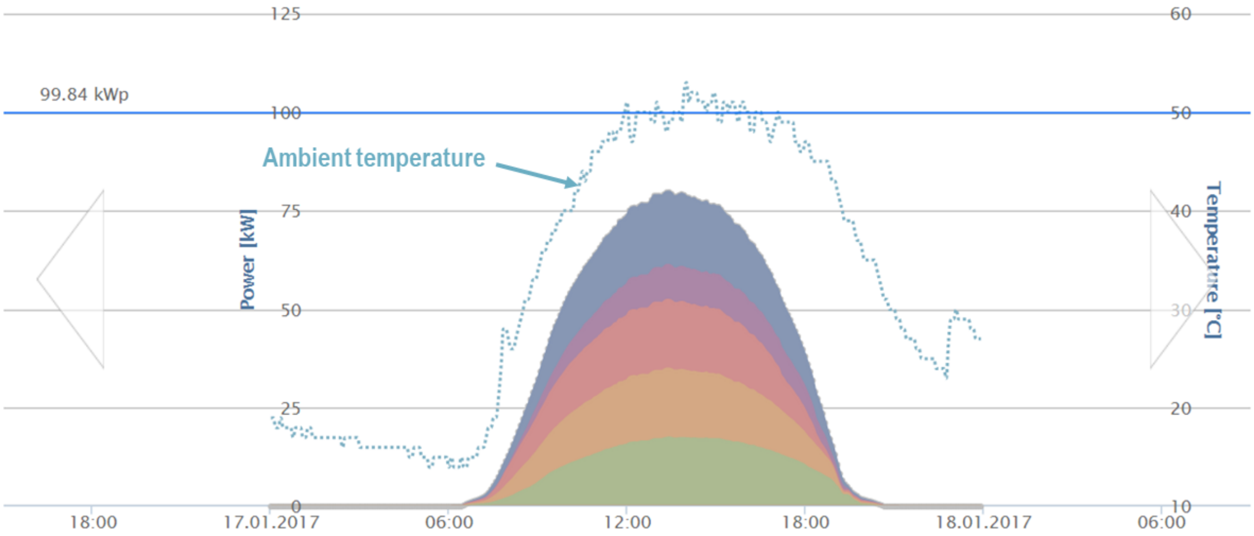

Figure 9: Daily yield curve and progression of ambient temperature
[source: Reference system in Australia (99.84kWp DC / 90kW AC), Fronius [3]]

In these temperature conditions, actively cooled Fronius inverters can achieve a yield of 647 kWh, which appears in the following graphic as a hatched area below the black curve:

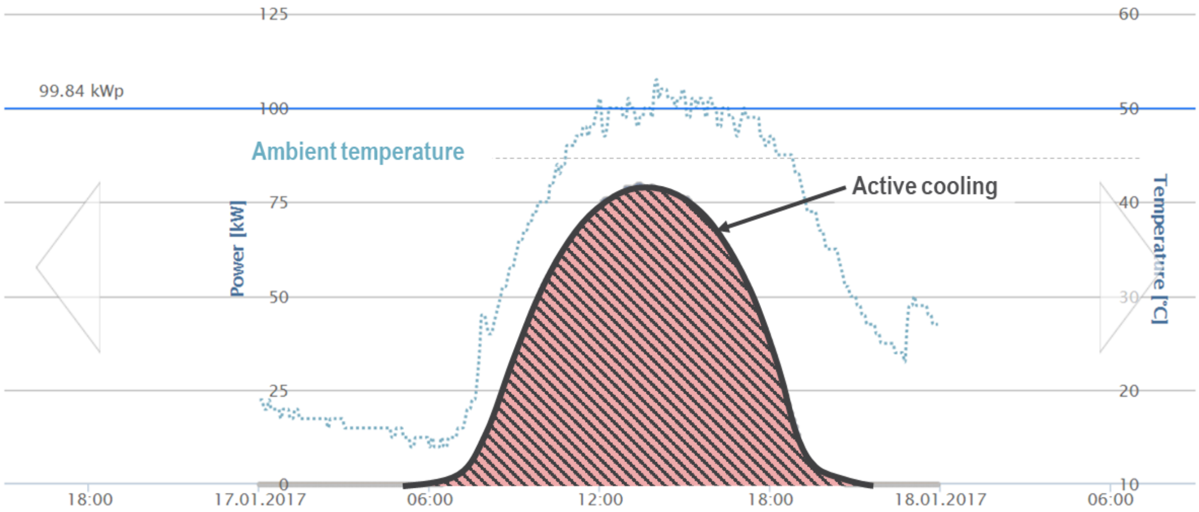

Figure 10: Yield with active cooling [source: Reference system in Australia, Fronius [3]]

To make a comparison with passively cooled devices under the same conditions, the derating behaviour of a competitor device, as measured in the previous section, was transferred to this system.

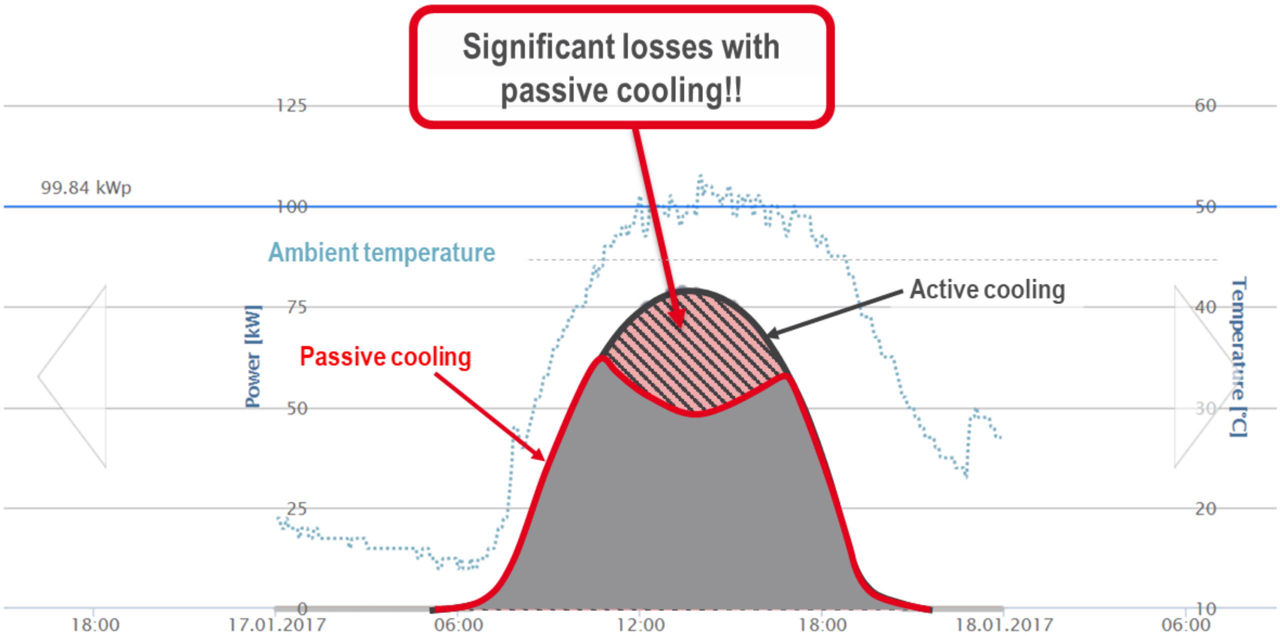

Figure 11: Yield or loss to be expected with passive cooling [source: Reference system in Australia, Fronius [3]]

Figure 11 shows the yield that can be expected if this system were to be implemented with passive cooling. Assuming that power derating starts at a temperature of approx. 35 °C, it would only be possible to achieve a yield of 551 kWh.

The calculated losses with passive cooling would be around 96 kWh (hatched area) – corresponding to a **loss in yield of 15%.**

6 THERMAL COMPARISON

The cooling system of an inverter is essential, especially for the electronic components inside the device. If it gets too hot inside the device, this can have harmful consequences for individual components, which in turn will affect the service life and total yield.

To compare the effect of passive and active cooling technology, comparative temperature measurements were taken from passively cooled non-Fronius inverters and actively cooled Fronius inverters. The results were then compared.

6.1 Behaviour of passively cooled devices

In the picture below, a thermal imaging camera was used to show the temperature distribution inside a passively cooled device at an ambient temperature of 55 °C. Under these conditions, an electronic component inside the passively cooled device is already at a temperature of 113 °C. But according to the manufacturer's specifications, the maximum permissible component temperature is 110 °C.

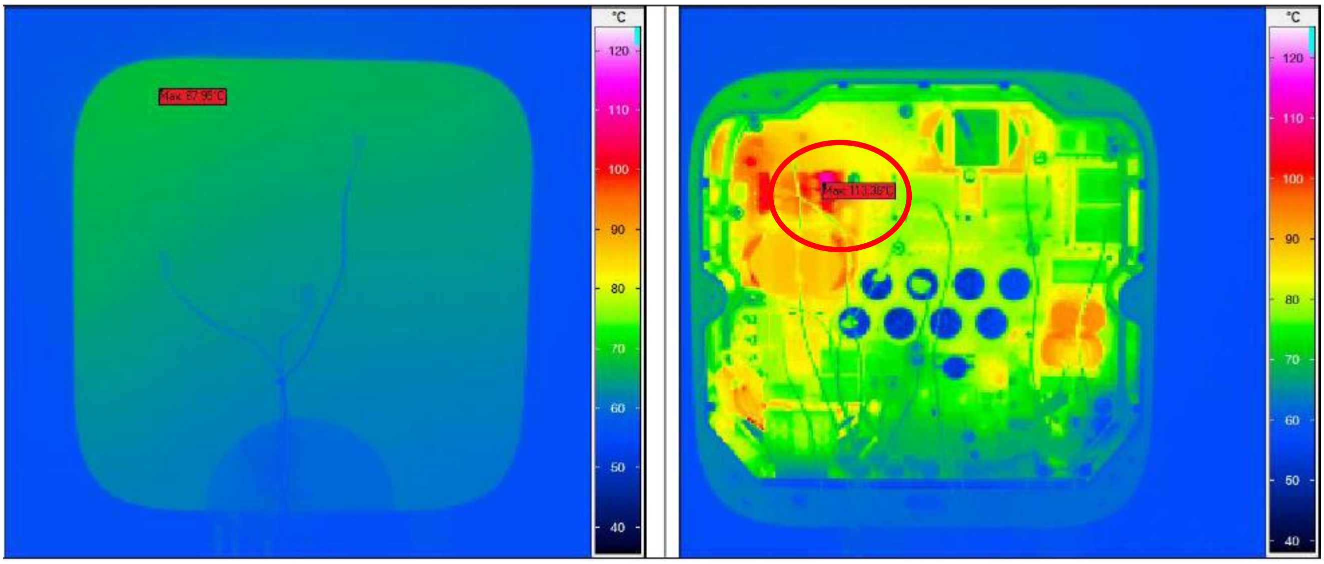

Figure 12: Distribution of heat inside a passively cooled inverter at an ambient temperature of 55 °C (PAC=5 kW, Umpp=260 V) [source: Fronius]

A temperature of 112 °C has already been measured at an electronic component in a passively cooled inverter from a different manufacturer with the same power category for an ambient temperature of 35-45 °C (depending on the DC voltage), as can be seen in figure 13 below.
Although an internal fan is installed in this device, its dimensions are too small, as temperature differences of up to 40 °C occur inside the housing between the upper and lower range of the non-Fronius inverter. There is therefore a risk of local hot spots, which could have a negative effect on the service life of the inverter.

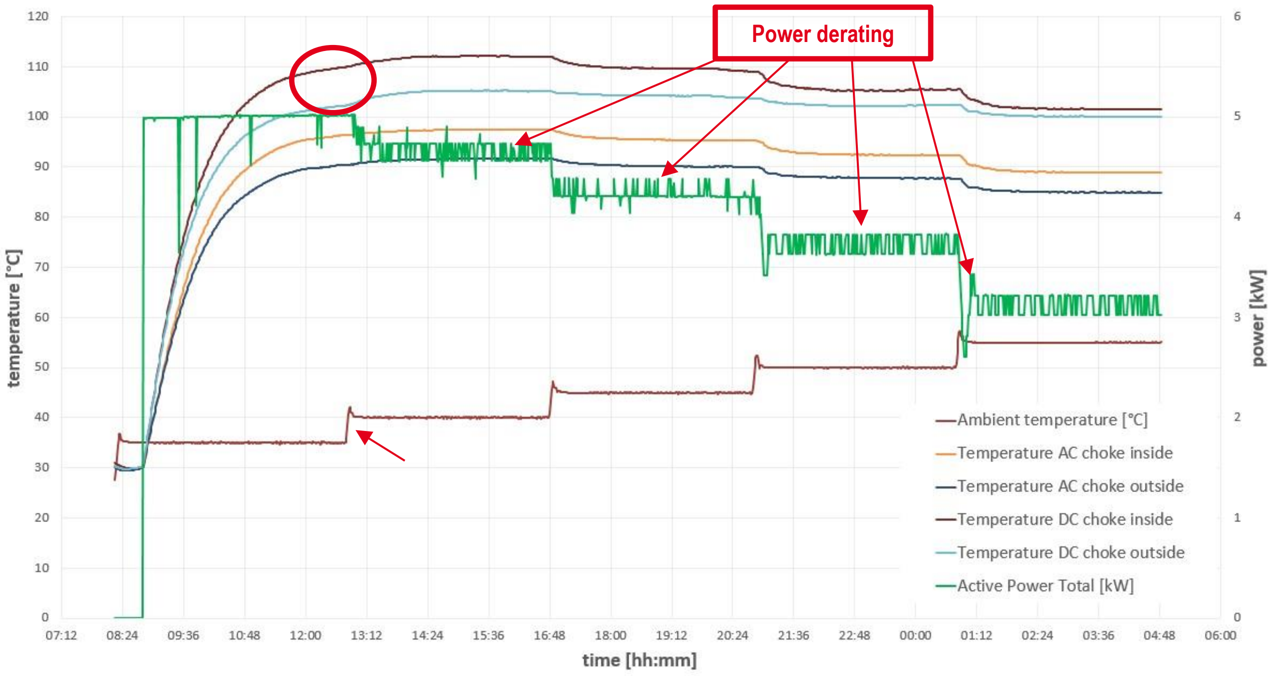

Figure 13: Progression of temperature and power for a passively cooled inverter (PAC = 5 kW, Umpp,min=175 V) [source: Fronius measurements]

As can be seen in the graphic, power derating starts from an ambient temperature of 35 °C. At an ambient temperature of 55 °C, this allows the component temperature (DC inductor) to fall to 106 °C. But the power at this point is still only 60% of the nominal output (see green performance curve in figure 13).

The thermal measurements revealed that power derating start times vary, depending on the DC voltage at different ambient temperatures:

- 35-40 °C (175 V DC)
- 45-50 °C (365 V DC)
- 45-50 °C (500 V DC)

The measurement results coincide with the manufacturer's specifications:

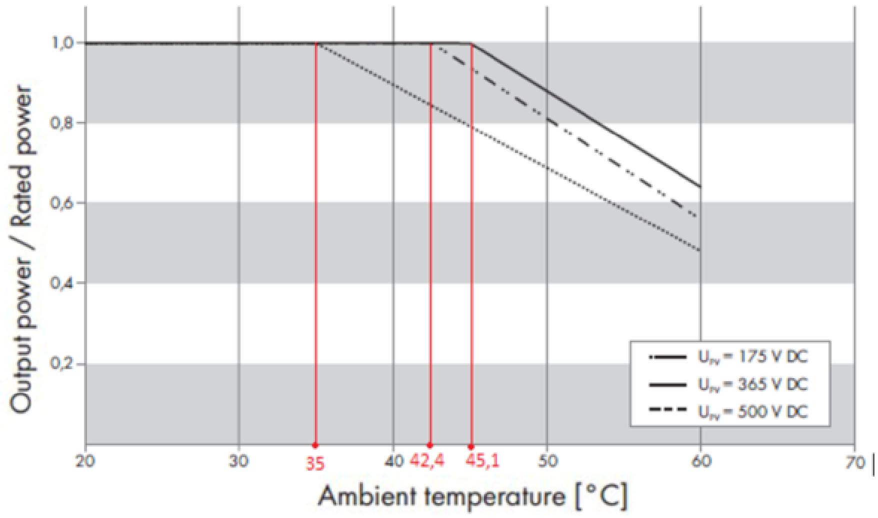

Figure 14: Power derating subject to ambient temperature at PAC,nom = 5 kW [source: competitor data sheet]

6.2 Behaviour of actively cooled devices

Component temperature measurements were also taken for an actively cooled Fronius inverter of the same power category as the passively cooled devices, at an ambient temperature of up to 55 °C. With the actively cooled devices, the maximum component temperature is 94 °C, that is, 19 °C lower and thus clearly below the maximum permissible component temperature of 110 °C (DC inductor).

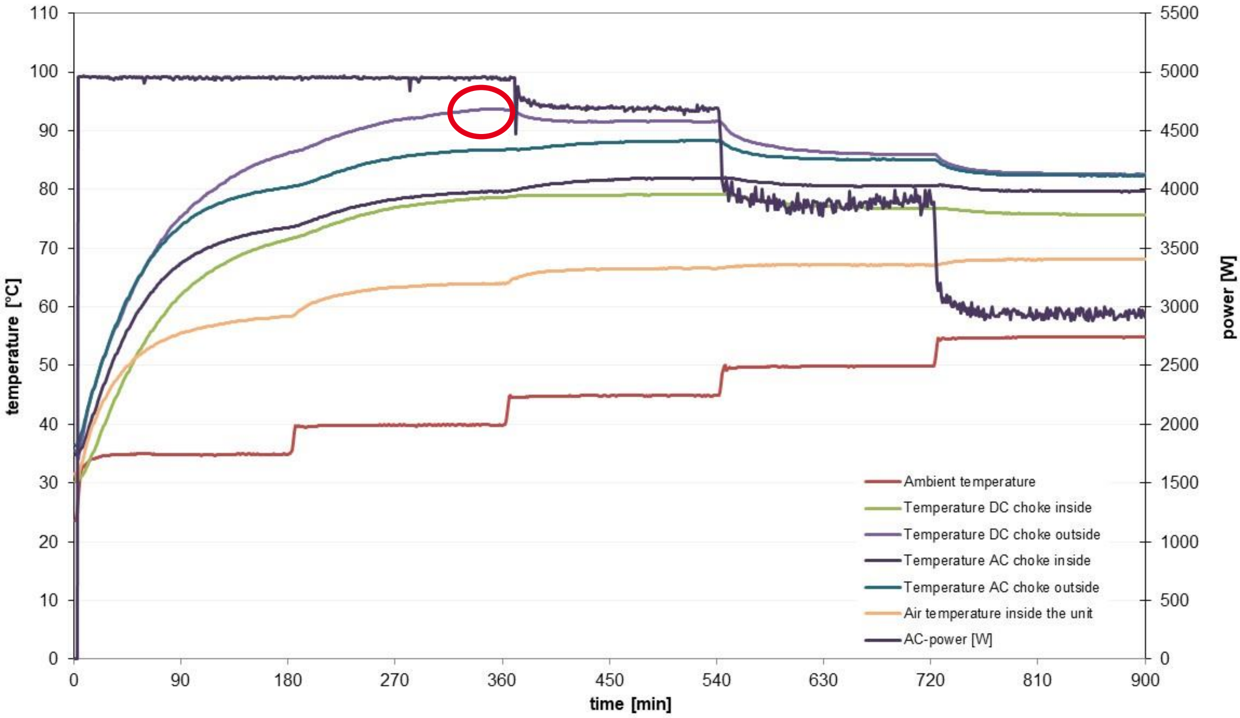

Figure 15: Progression of temperature and power for an actively cooled Fronius inverter (PAC = 5 kW, Umpp,=220 V) [source: Fronius measurements]

As is evident from the graphic, although the Fronius inverter is also power derating at 55 °C, the passively cooled inverter loses an exceptional amount of service life, due to the higher component temperatures. As explained in section 4, a 10 °C rise in temperature in this range means a reduction to the service life of 50%.

7 ASPECTS OF THE TWO COOLING SYSTEMS

7.1 Aspects of active cooling technology (Active Cooling)

7.1.1 Noise levels

Actively cooled inverters have more fans in the device compared to passively cooled devices, which can result in higher noise levels. Field measurements from real systems reveal that the fans of active cooling technologies run at full speed for approx. 10% of the entire operating time, even at high ambient temperatures (see section 4.1.1).

But there are advantages to having these fans inside the actively cooled inverter, as explained in the following section.

7.1.2 Lower costs over the whole product lifetime

Inverters with active cooling technology – as detailed in section 3 – do not usually require maintenance. This keeps the OPEX (= operational expenditures) to a minimum. On the other hand, maintenance costs are high for inverters with a passive cooling system. Six-monthly maintenance intervals are increasingly required, especially in very dusty environments. The ongoing costs for systems with passive cooling are therefore far higher than for devices with active cooling.

7.1.3 Lower weight means increased convenience

Inverters with active cooling technology are always lighter than those with passive cooling, as the heat sinks required for passive cooling are larger and heavier. With actively cooled devices, cooling is fan-assisted. So only a smaller and far lighter heat sink is required. Actively cooled inverters can therefore be transported and installed more easily and flexibly.

7.1.4 Longer service life

As the comparative temperature measurements showed, high temperatures are critical, especially for the sensitive electronic components in the inverter. The hotter they get, the greater the probability of failure. Even a temperature increase of just 10 degrees Celsius can halve the lifetime of the power electronics. Fronius uses active cooling, which means that the components are cooled by fans, so their temperature is lower than in devices with passive cooling technology. Fronius inverters therefore have a longer service life.

7.1.5 Greater flexibility in system design

Actively cooled inverters exhibit greater flexibility when it comes to designing systems. They allow system designs to be implemented that are far more asymmetrical than those using passively cooled inverters. Devices with active cooling technology are also highly adaptable when it comes to installation. They can be mounted vertically and horizontally. Mounting angles from 0° to 90° are possible. Devices with passive cooling, on the other hand, can only be mounted vertically on a wall.

7.1.6 Higher yield

To stop electronic components overheating, the inverter implements controlled power derating. This behaviour of inverters with active cooling has enormous advantages compared to devices with passive cooling systems. Due to the far cooler temperature in the housing, Fronius inverters exhibit optimum derating behaviour. This has a direct effect on yield. Devices with active cooling technology deliver far higher yields and reduce the payback period of the investment, especially in warmer regions.

7.2 Aspects of passive cooling technology

7.2.1 Noise levels

Inverters with passive cooling technology do not usually have fans, which means that noise levels are lower.

7.2.2 Efficiency

Fewer fans usually have to be powered in passively cooled inverters. They are therefore sometimes slightly more efficient. However, this positive effect is put into perspective at high temperatures by power derating (see section 5).

8 FURTHER DEVELOPMENTS IN ACTIVE COOLING

Fronius has been a driving force in innovation in this industry for more than 25 years and can rely on their own past experience and findings from research. The active cooling system has been proving its worth in Fronius inverters for many years.
The aim is to ensure that the system is always as efficient as possible, as being future-proof is a core value at Fronius. Future-proof means energy solutions that are so flexible and reliable throughout their entire useful life that they can also adapt to the changing requirements of the energy environment.
Over the years, Fronius has always managed to keep optimising the active cooling system and adapt it to new market conditions. This is why Fronius will continue to rely on this technology in future and will develop reliable, cost effective and sustainable energy solutions with active cooling – for today, tomorrow and the day after.

Nowadays, engineers try to develop advanced electronic devices that are tiny in size and low in volume, but also have the highest average power density, in order to reduce production costs and energy and make them easier to handle. This requirement is a major challenge for the cooling systems of electronic components.

8.1 Fronius GEN24 [Plus]

The key element in the development of Fronius GEN24 [Plus] devices was the need to design a flat yet highly efficient system comprising one heat sink and one fan to cool power electronics components. At the heart of this cooling approach is an individually proportioned fan housing, that is integrated into a recess in a diecast aluminium heat sink with specially arranged cooling fins (see picture below).

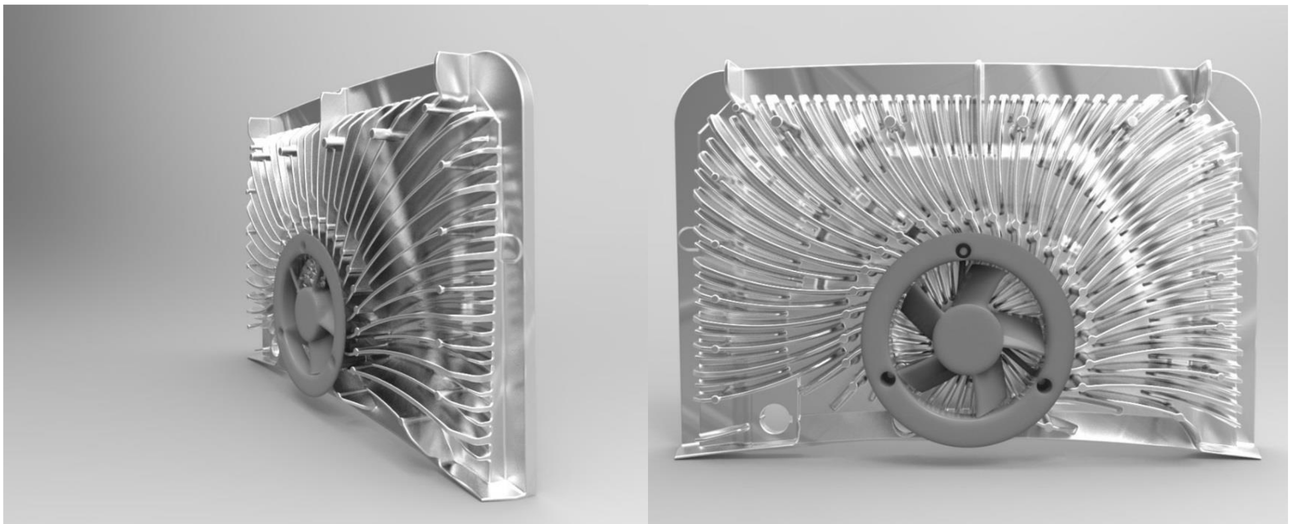

Figure 16: The innovative Fronius GEN24 [Plus] cooling system [source: Fronius]

This housing is able to create ideal pressure conditions for flow optimisation. The ambient air is drawn in, flows through and is deflected in the best way possible, resulting in effective cooling. Thanks to this innovative fan housing, inverters can be produced with a significant reduction in the depth of the housing.

8.2 Flow behaviour in the heat sink of the Fronius GEN24 [Plus]

A great deal of development work has gone into optimising the active cooling system so that it cools even better and more efficiently than in the past.

Compared to the standard fan (0.6 m³ / min), 250% (1.5 m³ / min) of the air volume can now be directed through the system. The high air volume flow makes it possible to remove heat from electronic components quickly and efficiently via the cooling fins, even at high ambient temperatures. This produces an extremely homogeneous temperature distribution at the heat sink (see figure 17).

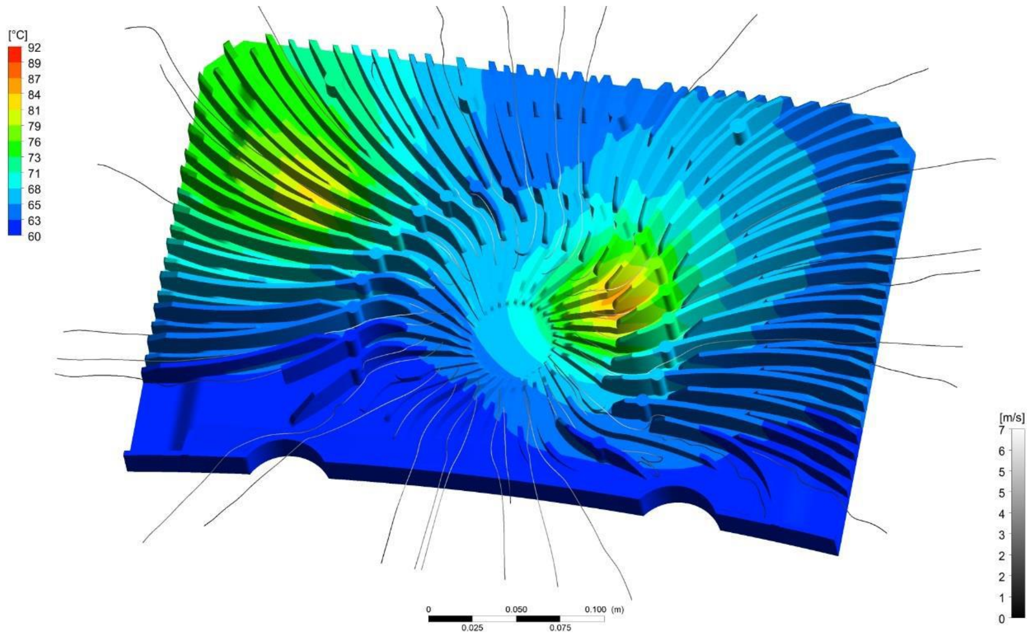

Figure 17: CFD flow simulation – rapid heat removal via the cooling fins [source: Fronius]

Due to the optimised flow approach, 20% less fan power is required. This means that a smaller fan is enough to provide the same amount of cooling as in conventionally actively cooled devices. This also results in better temperature distribution and lower noise levels. The device also benefits from less weight and a low installation depth.

8.2.1 Contributing to effective energy production

Large-sized housings are costly to produce and difficult for customers to handle. The installation sites for the inverters must also have more space. The system miniaturisation described here results in low-cost, simple photovoltaic inverters with few components. As the device may possibly be located in direct sunlight as well, no additional heat-shielding precautions need be taken for the inverter. No additional shading roofs or shaded devices are required, which in turn conserves resources and greatly reduces the customer's investment costs.

Due to the low power consumption of the fan, this optimised cooling system also makes a contribution to effective energy production. Thanks to the improved cooling capacity, the temperatures that occur inside the device are far lower, which increases the service life of the power electronics and the device and makes a sustainable contribution to environmental protection. As most of the functionalities of the inverter are contained in the aluminium mould, no additional plastic and iron components are required either. This innovation also helps to conserve resources.

9 SUMMARY

This document compares the active and passive cooling technologies of inverters. Numerous tests as well as bibliographic references clearly show the advantages of active cooling technology.

The forced air flow in actively cooled systems controls the temperature in the inverter perfectly and produces a longer service life.
Actively cooled devices are already an advantage for planning, in relation to the design and the manner of positioning. Because of their lower weight, devices with an active cooling system are also easier to install and transport, which saves time, effort and therefore money. Lower costs are incurred because there is little to no expenditure on maintenance. But above all, it is the extra yield achieved by better performance and the longer service life of the power electronics that justify using an active cooling system in an inverter.

10 BIBLIOGRAPHY

[1] "Calculating Useful Lifetimes of Embedded Processors", Application Report SPRABX4A–November 2014–Revised October 2017, Texas Instruments - http://www.ti.com/lit/an/sprabx4a/sprabx4a.pdf

[2] "The Effect of Temperature on The Life of Power Electronic Devices", CTM magnetics - http://www.ctmmagnetics.com/the-effect-of-temperature-on-the-life-of-power-electronic-devices/

[3] PV system Robinvale - https://www.solarweb.com/Home/GuestLogOn?pvSystemid=92147e5f-d215-4d8c-8737-a528007d3e2c