Switching power supplies - What does the future hold

Over the past 40 years, the evolution of the switching power supply from a 50 Hz transformer to a high-frequency switching power supply was primarily driven by the development of ever faster semiconductor switches. The development advanced from the relatively slowly switching thyristors to bipolar transistors, first with a small and later with a high blocking voltage. This allowed the realization of switching frequencies up to the 60kHz range. The field-effect transistors were technically sophisticated in the 1980s and were available on the market with a decent price/performance ratio. This made it possible to raise the switching frequencies again, this time to several hundred kHz. Of course, the continual increase of the switching frequency in switching power supplies does not serve an end in itself; due to the physical properties of magnetism, it leads to increasingly smaller power transformation devices and correspondingly much smaller switching power supply designs. On the one hand, power transformation devices are required to achieve insulation from the dangerous mains voltage; on the other hand, they adapt the output voltage level to the consumer. However, a higher switching frequency leads to switching losses, which conflicts with a smaller design, unless additional cooling methods are employed. For this reason, more complex switching topologies are used today, where the switching elements are switched on and off either in a voltage- or current-free state. Should this not be possible based on switching technology, extremely fast-switching gallium-arsenide or gallium-carbide switching elements are also used today for diodes and transistors. Compared to the MOSFET technology, these components are still rather expensive; however, the prices show a slow downward trend and are thus increasingly suitable for industrial applications. The developments and challenges associated with a further increase in switching frequency will be explained in detail in the following.

Impact of switching frequency on the size of power transformation devices

In the 1970s, switching power supplies with 50Hz transformers were still being used, which were correspondingly large and heavy. A 250 watts power supply weighed approx. 10 kg and was larger than a shoe box. The power transformation device continues to be a significant component in every power supply unit, thereby greatly affecting the switching power supply‘s size. The transferable energy in a power transformation device primarily depends on the cooling, the transformer core’s volume, and the winding and rate of change of the magnetic field, and thus the transfer frequency. Thus, if it is intended to increase a transformer‘s transferable power or decrease a transformer‘s size while maintaining the same power level, the transfer frequency needs to be increased. Disregarding the insulation requirements, a power transformation device‘s transferable power in first approximation is inversely proportional to the transfer frequency‘s square root. For this reason, in modern switching power supplies the 50Hz mains voltage is initially rectified, and an alternating voltage is generated from the direct voltage by means of electronic switches. For example, if the frequency of this alternating voltage is 50kHz, the required power transformation device is approx. 30 times smaller than at 50Hz, which naturally also affects the volume and weight of the switching power supply.

At frequencies of 500kHz, the size of a power transformation device can be further reduced to a third. This means that any additional increase in frequency can only lead to a moderate reduction in the size of the power transformation devices.

Impact of switching frequency on the size of the buffer and filter capacitors

Capacitors are used in switching power supplies to buffer voltages during breaks in the current flow, smooth residual ripple of currents and voltages, or filter high-frequency interferences. The size of these capacitors can also be reduced linearly with the frequency, which in turn leads to a decreased volume of the switching power supplies. However, this excludes buffer capacitors at a switching power supply's input, with or without power factor correction, since these must be operated with direct current, i.e., at 100Hz. This is also the reason why the size of switching power supplies cannot be decreased arbitrarily, unless buffer times are omitted.

Impact of operating temperature and cooling on the switching power supply's size

It is frequently ignored that the maximum transferable power of a switching power supply mainly depends on the maximum permissible operating temperatures and the cooling of the components in the switching power supply, if the power output is not restricted by a current or power limit. The manufacturer often makes ambitious statements that can lead to problems on the user's side, if the intended cooling is not available. It is therefore better to consult the degree of effectiveness or the power loss indicated by the manufacturer when selecting the switching power supply. If one manufacturer allows significantly higher operating temperatures on the components than another, more conservative manufacturer, the switching power supply's stated nominal power may be significantly higher; however, the reliability during permanent operation will be much lower. In general, it can be said that the switching power supplies today are already minimized under switching technology aspects to such a degree that any further volume reduction can only be achieved by additional cooling via heatsinks or additional air cooling. However, additional cooling leads to increased expenditures, and the use of air cooling, in particular, is problematic due to unwanted noise and potential contamination.

Impact of the degree of effectiveness on the size of switching power supplies

As described above, any additional volume reduction in switching power supplies by increasing the switching frequency has been mostly exhausted already. Much more promising are efforts to further increase the degree of effectiveness, thereby reducing the level of self-heating to increase the transferred power.

In the 1980s - the early days of the switching power supplies - industrially used switching power supplies had a level of effectiveness around 70%, which increased noticeably by the 1990s to more than 80%. In the past ten years, switching power supplies in the 90% range have become the technical standard.

Measures to further increase the degree of effectiveness in switching power supplies

Today, the power transformation devices used in switching power supplies are mainly supplied with the input voltage by resonantly switching FETs. These are inexpensive and have a very low rate of loss due to being switched on or off at the point of zero voltage or zero current, which makes them well-suited and sufficient for power supplies with approx. 800 watts. Today, boost converters are regularly used on the input side of switching power supplies over 100 watts, which achieves a significantly higher power factor (over 95%) than is possible when only using a rectifier. An additional inductance must be integrated in this circuit component. In order to keep this as small as possible, it is not simply possible to switch the associated high-frequency circuit breaker on or off in a current- or voltage-free state. Innovative, very fast-switching semiconductor switch circuit breakers are well-suited in this regard. In particular, this concerns semiconductors on the basis of gallium arsenide (GaAs) or silicon carbide (SiC). The transit frequency of these switching elements is about ten times higher than that of traditional silicon semiconductors. This is associated with significantly faster transit processes (switching processes) when switching on and off. Compared to silicon MOSFETS, these switching elements are still very expensive; however, their price is decreasing, thereby significantly influencing the further price and performance development of switching power supplies.

Current switching power supply topologies

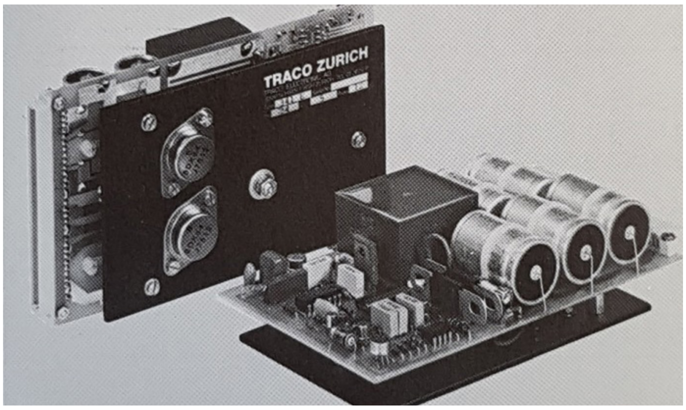
To ensure that a high power factor can be achieved at the switching power supply's input in accordance with the permissible limit values, modern switching power supplies with a performance over 100 watts usually have a two-stage design. A converter generates a preregulated direct current, that is regulated in such a way that the input current of this converter is nearly sinusoidal. A second converter, usually designed as a resonance converter, transforms the voltage to a lower level and separates the input voltage from the output.

Further development

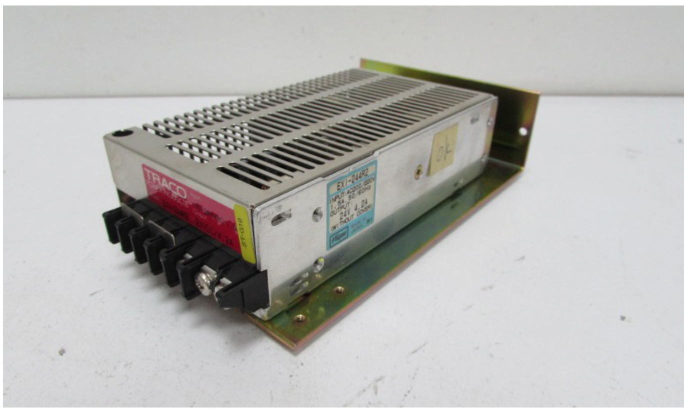
Switching power supplies will continue to become smaller to a moderate degree, and the power density will continue to increase, albeit no longer to the degree seen during the past 10 to 20 years.
More than in the past, the limiting factor will be the power loss discharged in the form of waste heat, which will be increasingly harder to discharge with a continuing reduction in size.

Recommendation

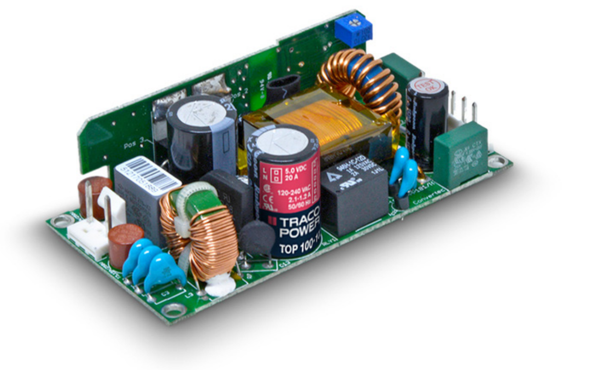
The user is well advised to correlate and compare the performance data of switching power supplies, in particular the power loss information, with the stated design volume. Obvious differences should always be clarified and questioned in the interest of a reliable application. Small is beautiful only applies when the resulting power loss during operation is correspondingly small as well!



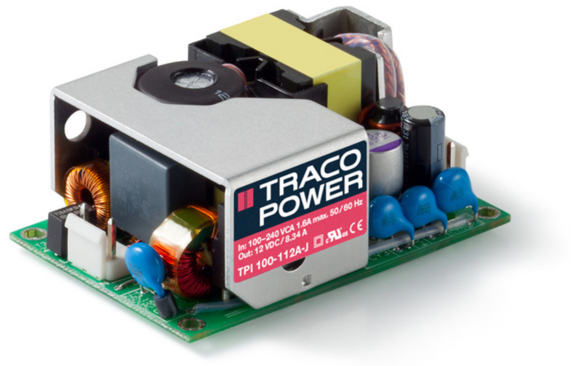
AC/DC switching power supply on a Eurocard from the year 1977 80 watts (format 160x100mm, illustration without power transformer)



AC/DC switching power supply in a metal package from the year 1990 100 watts (160x93mm)



Open frame AC/DC power supply from the year 2005 100 watts (101x51mm)



Open frame AC/DC switching power supply from the year 2015 100 watts (76x51mm)

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