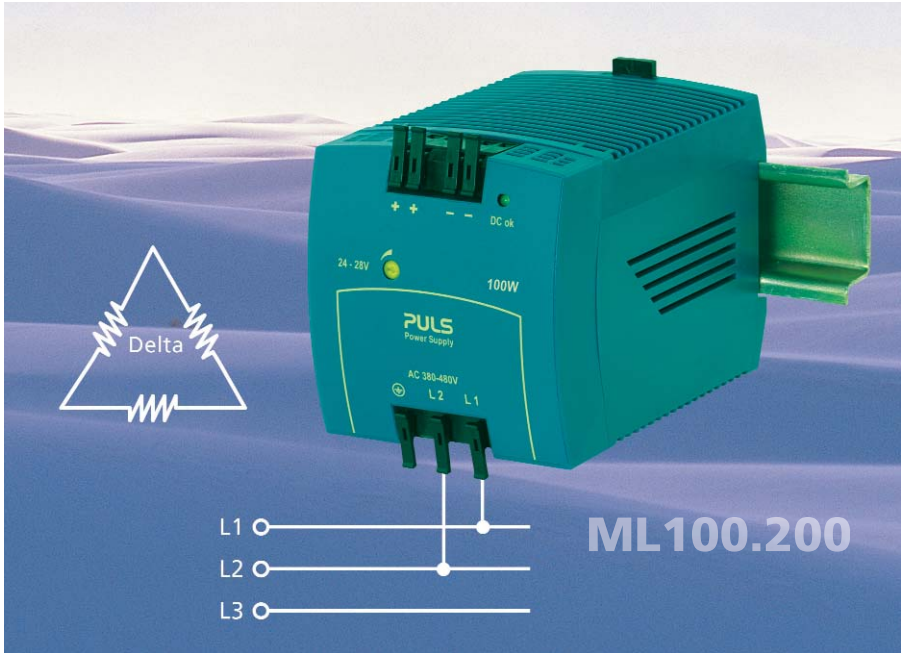
Power Supplies for Mains Without a Neutral Wire

Michael Raspotnig

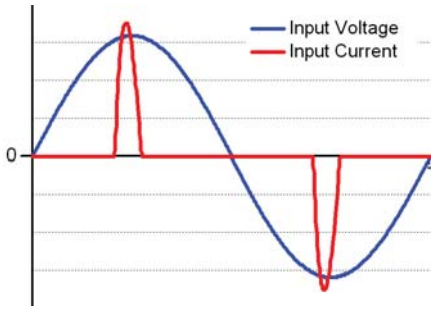
To avoid overloading of the neutral conductor, machine builders, panel builders and system integrators often use a Delta-system which has no neutral wire. Some machine builder standards, such as the EN 60204-1 for example, restrict the use of a neutral wire.



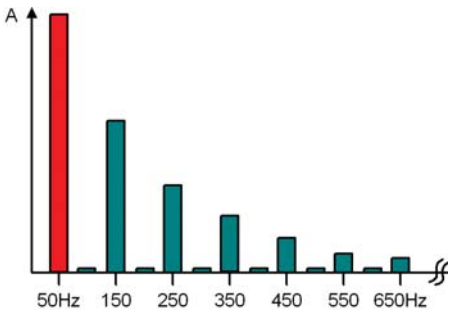
Controls, sensors and actuators frequently require a 24 Vdc auxiliary supply voltage that must be generated by a power supply.
Previously, only transformer power supplies connected to two outer conductors or three-phase switched mode power supplies were available for this. Especially for outputs up to 100W, PULS has now developed a cost-effective and lightweight switched-mode power supply in a plastic housing that can be connected between two phases and does not require a neutral conductor.

What causes a neutral conductor overload?

Modern devices such as power supplies, servo amplifiers or frequency converters now use exclusively switched-mode technologies for the conversion of energy. This type of equipment converts the AC mains voltage to a DC intermediate bus voltage using a bridge rectifier and large electrolytic capacitors. This DC intermediate bus voltage is then converted to the lower control voltage such as 24V. The periodic charging current that flows into the electrolytic capacitors, causes a distortion of the input current, which then deviates significantly



Distorted waveform of the input current of a typical consumer (without PFC measures)

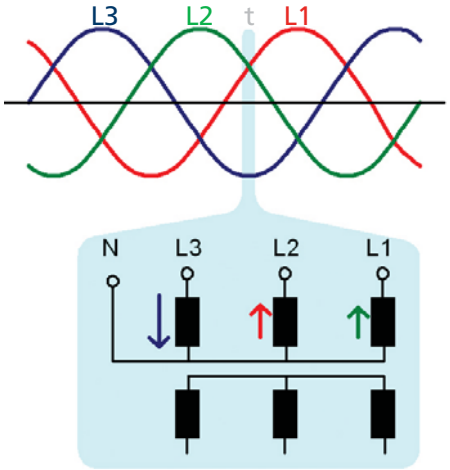


Fundamental and harmonic wave levels of the input current of a typical consumer (without PFC measures)

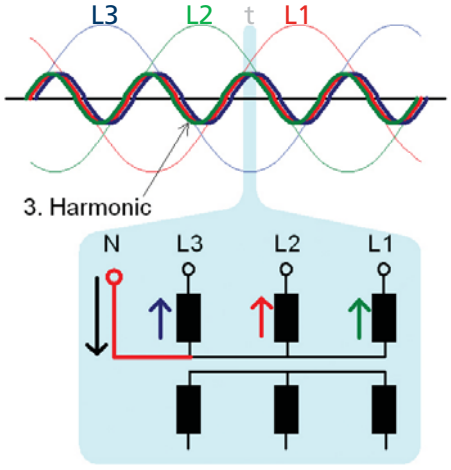
from the sinusoidal waveform. The distorted waveform can be mathematically transformed into a fundamental wave and harmonic waves (multiples of the fundamental wave) by a Fourier transformation. Strict limits on the extent of the harmonic current apply in public networks. In private networks such as industrial networks, the system operator is responsible for safe operation.

Overloading of the neutral conductor has various causes and one frequent cause can be explained with the following example.

Under a symmetrical load and a sinusoidal input current, no current is supposed to flow in the neutral wire. The waves of the three phases have an phase-offset of 120° and therefore the current in the neutral wire cancel each other out.
If the input current is not sinusoidal and there is for instance a high amount of the 3rd harmonic current, one can see that the harmonic currents no longer cancel each other but are added together on the neutral wire. This can result in dangerously high currents in the neutral wire. A similar situation applies to the 6th, 9th, 12th, etc. harmonic waves. The energy content decreases significantly in higher harmonic waves, making the 3rd harmonic wave particularly important. The even-numbered harmonic waves arise only as insignificant amplitudes due to the wave shape of the current. In addition to the neutral wire load, an elevated load also arises in the supplying transformer which can be corrected with compensation windings. Since the current in the 3rd harmonic wave flows in the same direction in all phases, a magnetic field is generated in the iron core of a transformer that no longer cancels itself out but must close over a parallel connection (e.g. via the transformer housing) if no compensation windings are present in the transformer.



The total of the phase currents is zero and does not result in a load in the neutral wire



The currents of the 3rd harmonic wave of all three phases are added together in the neutral wire

Selection of the correct auxiliary power supply

Single-phase switched-mode power supplies are generally excluded in some applications due to the lack of a neutral conductor and the application. These would be used in a wide variety of output lines and by many manufacturers, but they are not suited for the voltages of three-phase systems. Switched-mode power supplies with a three-phase input do exist but only for higher power levels and lower wattage units in the 100W range are difficult to find. This leaves only transformer power supplies with secondary regulation and exhibit serious technical and practical disadvantages as will be shown below.

The ML100.200 switched-mode power supply developed by PULS especially for control applications is a cost-effective solution for generating a stabilized 24Vdc voltage from a three-phase mains voltage. The 100W output power is sufficient for many control tasks and at 24Vdc, the ML100.200 supplies up to 4.2A output current. A similar product ML90.200, also satisfies the American NEC Class 2 requirements.

With the ML100.200, it is still possible to make use of the benefits of switched-mode technology for low power without the need to spend a fortune. In comparison with the transformer power supplies typically utilized for this application, the ML100.200 offers numerous advantages. At only 370 g, the device is extremely lightweight compared with transformer power supplies, which weigh roughly 4.5 kg, and can therefore can be easily mounted on the DIN-rail along with the other control components. Switched-mode power supplies have a significantly broader input voltage range and service the typical 3x400V and 3x480V networks without changing the tap connections. The internal electrolytic capacitor bridges short mains failures and keeps the output voltage stable. This prevents failures or unnecessary restarts in the application. The effects of input transients and other faults in the network are suppressed by the internal filter in switched-mode power supplies. The considerably lower power dissipation results in less heating in the cabinet, thereby prolonging the service life of the entire machine and plant operation.

ML100.200	switched-mode power supply	Transformer power supply*)
Installation type	DIN-rail	Flange
Weight	360g	4500g
Size	73x75x103mm	110x172x161mm
Volume	0.56 litres	3.05 litres
Input	320-552Vac	360-440Vac
Efficiency	90%	63%
Power dissipation	11W	58W
Mains bridging	typ. 20ms	typ. 3ms

*) Typical model of a European manufacturer

Advantages of a switched-mode power supply over a transformer power supply with in-phase regulation, taking 100W devices as an example

2-Phases instead of 3-phases

Intuitively, one tends to always connect devices on all three phases which avoids an uneven load balance on the supply system. However, if one considers the relative power consumptions of control circuits verses power circuits, generally control circuits have a much lower power need. An "unbalancing" of the mains system is therefore not expected when control power supplies are connected to only two phases.

Connecting to only two phases has many advantages. Up to a power class of roughly 150W, the power supplies can be more compact and require less space in the cabinet, less wiring and installation time. Additional savings is also achieved with regards to the safety device as only two legs have to be protected. For power greater than 150W or if continued operation is required after failure of one phase, a three phase power supply is recommended.

Potential cost savings

In addition to the reasons already mentioned in this article, the ML100.200 power supply can save money not just with its attractive pricing but also due to the possibility of a smaller cabinet, lower transportation costs and installation labor are significantly reduced. Lower energy costs as well as less need to cool or ventilate the cabinet with simple installation also adds to the cost savings.