UPS design: Transformer-free vs transformer-based

The function of the transformer in a UPS

Why do uninterruptible power supplies have transformers? The answer lies in one of the most common uses of a transformer: to step up output voltage.

The new power converters brought in around the beginning of this century brought not only significant customer benefits but also removed the necessity to have a transformer. The age of transformer-free UPS was thus born. Subsequent evolution was rapid: Thyristor-based designs – with six-pulse, then later, 12-pulse, thyristor bridges - quickly gave way to today's topology, which is built using IGBTs (insulated-gate bipolar transistors). Now, virtually all double conversion UPSs have IGBT power converters and are transformer-free.

Transformer-based UPS

In a transformer-based UPS, when the mains supply is available, the power flows through the rectifier, inverter and transformer to the output to supply the critical load. This working mode is called double conversion mode. In double conversion mode, the battery is constantly kept fully charged. During power outages, the battery feeds the inverter, which then supplies uninterrupted power to the critical load through the transformer.

The static bypass acts as an emergency path that is switched in when there is a problem on the double conversion path such as an overload, over temperature or output short circuit. As its name suggests, the maintenance bypass switch connects input to output and allows the UPS to be bypassed. Other switches then allow the unit to be isolated and serviced.

Transformer-free UPS

The working principle of a transformer-free UPS is the same as that of a transformer-based UPS except that - because the IGBTs can handle high voltages there is no need for a step-up transformer after the inverter. This boosts energy efficiency - typically from 90 to 96 percent - which is the industry-standard. Furthermore, transformer-free UPSs are lighter and have a smaller footprint – reducing investment and running costs.

Because of the higher voltage involved in transformer-free UPSs, an additional converter is introduced between the DC bus and the battery. This converter allows a constant and precise control of the batteries and provides a clean DC voltage with no ripple, which maximizes the battery lifetime.

But the advantages do not stop there. Total harmonic distortion is reduced dramatically and the input power factor (PF) is resistive thanks to active control of the input currents. This means that the devices upstream of the UPS (eg, generators) do not have to be oversized by a factor of 1.5 (or even more) as is usual with transformer-based UPS.

Some other differences can be identified. The output impedance and the dynamic response to unbalanced loads are better with a transformer-free UPS thanks to the direct control of the output sine wave and the fact that each phase is controlled independently. The output short-circuit capability of the inverter is also better than a transformer-based UPS.

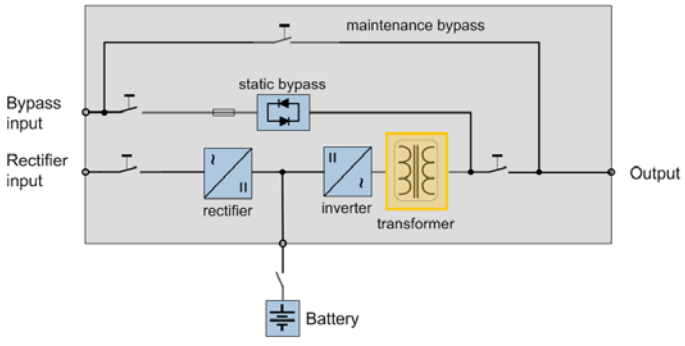

Figure 1: single-line diagram of a transformer-based UPS

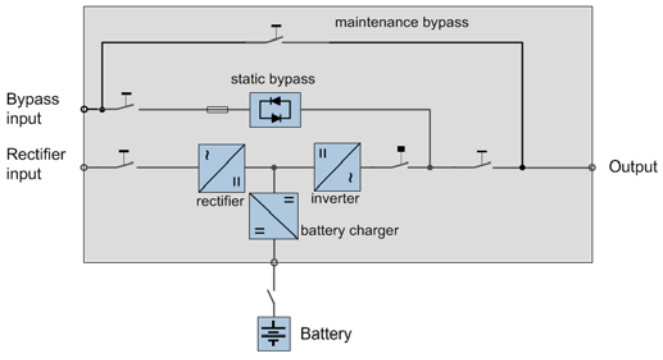

Figure 2: single-line diagram of a transformer-free UPS

Major technical specification differences (typical)

Table 1: summary of the major technical differences between the two topologies.

#		Transformer-based	Transformer-free
1	Efficiency on double conversion mode	90-92 percent	95-96 percent
2	Efficiency on eco-mode	99 percent	99 percent
3	Current total harmonic distortion (THDi)	30 percent (6-pulse thyristor-based rectifier) 12 percent (12- pulse thyristor-based rectifier) 3-4 percent (IGBT rectifier)	3-4 percent
4	Input PF	Low on partial load	0.99 – 0.97 at full and partial load
5	AC ripple on battery	Without battery charger more than 5 percent with battery charger 0.2 percent	0.2 percent
6	Allowed number of battery blocks in series (12 V)	Fix (typically 40)	Variable from 30 to 50
7	Output impedance	High (worse)	Low (better)
8	Output fault clearing capability on inverter	Typically up to 5 x In	Typically up to 3 x In Up to 4-5 x In or even higher may be option with more cost
9	Output fault clearing capability on bypass	Up to 10 x In	Up to 10 x In
10	Dynamic response	Poor, unbalanced loads affect output voltages	Ideal, direct control of the output sine wave, each phase is controlled independently. Thus, unbalanced loads do not affect the output voltages
11	Weight (one 500 kVA unit)	2.2 – 2.6 tons	1 ton

Major differences for the customers (effect on the customer benefits)

Table 2: summary of the major differences between the two topologies for the customers.

#		Transformer-based	Transformer-free
1	Investment cost	$$$ due to higher UPS cost, higher installation cost (oversizing of the system upstream of the UPS) and larger footprint.	$$
2	Operational cost	$$$ due to lower efficiency means higher energy costs for both UPS and cooling.	$ Higher efficiency ⊠ reduced power losses and less cooling. Over many years, the saving is significant.
3	Environmental impact for production and transport to final location	Higher than transformer-free due to more components (transformer) and bigger mechanical size for the unit	Lower than transformer-based thanks to the same arguments
4	Environmental impact for operating the product	Lower efficiency means higher power losses thus more energy needed for cooling.	Higher efficiency means less power loss and less energy needed for cooling
5	Battery life (lead-acid)	May be reduced due to AC ripple	Up to 12 years

UPS performance criteria will never be perfectly matched in practice and the best solution will be the best compromise. The type of application, the criticality of the business dependent on the power supply, the user's business model, etc. will determine which compromise is selected. From the comparisons above, it is clear that the transformer-free UPS design is better, which is why it now dominates the market. However, both designs provide the fundamental functionalities of a double conversion UPS, maintain the key characteristics such as availability and reliability and they have equal lifetimes.

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