Benefits of transformer-free UPS topology: myth or reality?

Abstract

The aim of this application note is to focus our attention on the characteristics of Transformer-Free UPS (i.e. without unnecessary magnetic components) and to compare them with UPS with inverter transformer (a transformer between the inverter and the output). In module power ranges up to 200 kVA, increasing numbers of UPS manufacturers are introducing a Transformer-Free design for VFI double conversion (Series on-line UPS). The reasons which lead UPS manufacturers to develop an IGBT topology with a Transformer-Free (T-Free) configuration can be summarized in what follows.

User demands:

- **Higher efficiency** to reduce carbon footprint and running expenses (operating expenditure or OPEX), allowing also a quicker payback of the initial investment.
- **Lower heat losses:**
  - Copper losses of the transformer are eliminated;
  - Load harmonic heat losses are eliminated;
  - Lower capacity cooling system is needed.
- **Lower capital expenditure.** With non T-Free technologies (in the power range up to 200 kVA) additional optional devices were needed to match the same input performances (i.e. additional passive or active filters) of a T-Free UPS, therefore the initial purchasing expenditure is reduced.
- **Smaller module volume and footprint, taking up less valuable floor space.** Provided that compact dimensions are sometimes very useful in installations, in general, if an UPS takes up a certain space per kVA regardless of manufacturer, then the market accepts that footprint as the "norm". Of course, the first compact unit onto the market resets the users' expectations and the old "norm" becomes "uncompetitive".
- **Lower weight, which lead to:**
  - 40% of the unit weight;
  - Handling, transportation and installation savings;
  - Lower floor load, lighter construction plinths/raised-floor, etc…
- **High input power factor** to avoid DPF correctors/filters.
- **Low input current harmonic distortion** to reduce the harmonic pollution in the upstream distribution.

Technological incremental innovations:

- **Better PWM inverter algorithms** for high fidelity sine wave output, avoiding the control loop lag across the transformer.
- **Increased** ruggedness and reliability of IGBT devices.
- **Faster switching IGBT** with lower losses.
- **Refinement of IGBT rectifier solutions, which are suitable especially in the 80-200 kVA power range,** avoiding additional input filters altogether.

1. Input performances and improvements in T-Free UPS

There is a surprising link between the UPS topology without transformer and the development of the UPS input rectifier stage in the power range from 80 kVA up to 200 kVA.

The pressure on UPS rectifier topology has increased as there is an increasing number of building M&E service types that include non-linear electrical loads (variable speed drives in ventilation fans, compressors, pumps, lifts, lighting, etc…).

The demand for very low input current harmonics has increased, from practical considerations, the pressure of statutory constraints on harmonic limits and the risk of surcharges on electrical consumption with poor power factor or high harmonic current components.

The harmonic distortion of the current represents a negative aspect for the electrical systems upstream of the UPS. This is because it causes various parts of the system, such as lines, transformers, generators, etc to overheat. The harmonic distortion of the voltage is also key:

- It can lead to malfunctions, for example in the case of high equivalent internal impedance generators, such as diesel generators;
- It involves all the loads not connected to the UPS.

Traditional solutions involve the application of either 6-pulse or 12-pulse fully controlled SCR bridges, with or without capacitor filters to address the dominant harmonics in the bridge topology (5^{th} for 6-pulse, 11^{th} for 12-pulse) and to typically reduce the input THD from 33% (6-p without filter) to 5% (12-p with 11^{th} filter).

In order to limit the effects of harmonic distortion, especially for high rate UPS, it is important that a 12-pulse rectifier is used in order to limit lower harmonic current rejection.

Traditional solutions have some drawbacks:

- The resultant THD percentage increases with reducing load (although the harmonic currents do reduce in absolute terms);
- Power Factor varies with load and usually peaks at no higher than 0.85, unless the UPS features a high-PF mode, like 90-NET;
- The capacitors, when used for filtering purposes, can act as a sink for other network-borne harmonics with resultant transient resonance or overheating problems. These capacitors can then become "wear items" and need routine inspection and replacement regimes. That's the reason why 90-NET features only 12-pulse rectifier with THDi<5% without AC capacitors (non-resonant filters);

On the upside, these SCR-only rectifier arrangements have proven to be simple, rugged and highly reliable in service, especially for higher rating above 200 kVA.

The "perfect" rectifier would have a sine wave current input (regardless of load), no capacitor filter network and a power factor very close to unity. Such performing solution can be achieved using IGBT technology in the rectifier.

2. How IGBT in rectifiers can also be used to eliminate the inverter Transformer

Until few years ago there was little choice for a true series on-line (double-conversion) UPS module but to have an inverter Transformer.

Generally, a double wound transformer in the output stage of traditional design UPS modules is supposed to still provide various advantages for both the user and the designer:

CLAIM: Provides galvanic isolation between the inverter and the load, preventing DC voltage being fed to the load, in the event of an inverter switching device failure, preventing DC voltage from being fed to the load.

ANSWER: In the T-Free solution this risk is reduced thanks to the increased performance of IGBT's and the speed of protection devices/sensors which will cause the UPS to switch to very quickly bypass in case of anomalies.

CLAIM: Provides a separate neutral connection point for the load (star-point).

ANSWER: It is exactly the same as for T-Free configuration, which has a common neutral point in the inverter bridge.

CLAIM: Provides the opportunity to step-up and step-down the inverter or load voltage.

ANSWER: This is totally superseded by using the "booster effect" in the DC chain, either with a dedicated converter or by the booster (like in the Chloride 80-NET UPS product)

3. UPS with Input or Output Transformer: The Solution for Galvanic Isolation

Nowadays the inverter transformer can be avoided, mainly thanks to the well consolidated IGBT technology and the most common installation requirements up to 200 kVA.

The best results of the input or output transformer, which is used for galvanic isolation, can be obtained both in Transformer-Free UPS and in UPS with inverter transformer.

A double wound transformer, preferably with a screen, must be used to make a permanent modification to the neutral status. It can be electrically connected either upstream or downstream of the UPS.

The transformer has a constant flow through it to supply the load: this causes a reduction in overall performance, usually between 2 and 3 percentage points: this will cause the efficiency to go down to the value offered by an older inverter transformer UPS, so the real need of galvanic isolation should be carefully evaluated.

The advantages of the output transformer (**Fig. 1**) are:

- If the UPS functions in isolation, the line from the unit output to the transformer primary will function in an IT cycle;
- Provides a separate neutral connection point for the load (star point);
- Reduces the system electrical noise.
- The transformer secondary neutral can be connected to earth, for example to create a TN system. If this does not happen, an IT system is created downstream of the secondary. This system may be suitable for improving the continuity of the power supply system for critical loads which do not require the protection devices to be opened after the first earth fault.

Another possible solution for Transformer-Free configurations is to put a transformer upstream from the UPS (**Fig. 2**).

In this configuration the transformer has to be more powerful than the one connected at the output. This is because it has to be capable of supplying the rectifier when the batteries need to be recharged through the transformer, also taking into consideration the double conversion efficiency.

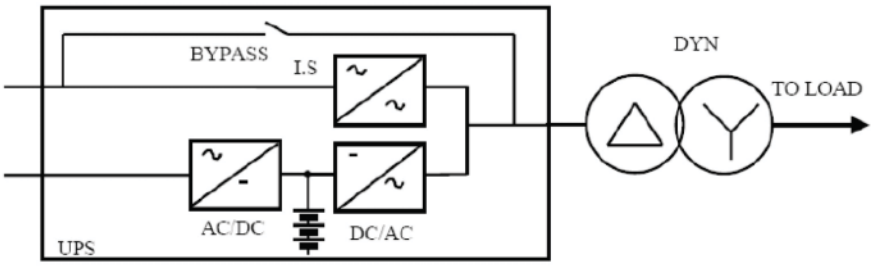

Fig. 1 - UPS with output transformer

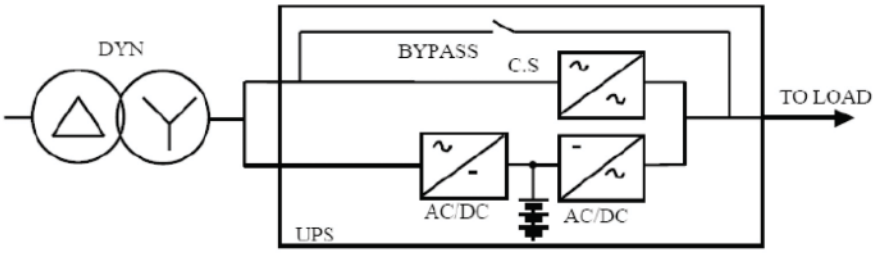

Fig. 2 - Isolation transformer on UPS input

4. PDU Isolation Transformers

It should not be forgotten that many parts of the world distribute three phase power in a 3-wire format, without a Neutral, and utilize step-down delta-star isolating transformers in the PDU at the point of consumption. The Neutral is created at the PDU by the star point of the transformer output winding.

This technique can also be employed in order to improve power quality (particularly in reducing Neutral to Earth voltage and Earth "noise" problems) as for instance in UK installations - with the added advantage of not distributing a (double rated) Neutral conductor.

The use of isolated PDU should in any case be very accurately evaluated, since the full effect provided by T-Free UPS of the increased efficiency cannot be gained entirely.

5. Conclusions

- From a UPS technological point of view, nowadays the inverter transformer configuration is no longer needed, especially up to 200 kVA;
- In order to reach galvanic isolation, whilst maintaining high efficiency values (with Transformer-Free UPS), an input or output transformer can be used. By using an upstream transformer, also the by-pass line of the UPS is connected to the secondary of the isolation transformer, ensuring galvanic isolation for the whole system;

As a further demonstration that Chloride always provides customers the best solution in terms of technology and value the 80-NET has been launched. This is available from 60 to 200 kVA and is compatible with a wide range of battery autonomies. Aspects of 80-NET's premium class performance are:

- T-Free technology that doesn't need the inverter transformer;
- IGBT double conversion technology;
- Full input Power Factor Correction (PFC) and extremely low current harmonic rejection (<3%);
- Total compatibility with any installation;
- High conversion efficiency (certified up to 98%), allowing reduction in operating costs, thanks to the Intelligent Double Conversion (the double conversion efficiency is certified up to 94%);
- Capability of powering state-of-the art IT loads irrespective of the PF (leading or lagging, up to 1).

About the author

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Emiliano Cevenini is Vice President Marketing as well as leader of Chloride's Product Marketing Team. He has product manager for 3-phase UPS since 2002; before, he had been given responsibility for Chloride Support and Consulting activities and had been part of the Research and Development Team first and of the Technical Support and Development Team later.

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