A White Paper from the Experts in Business-Critical Continuity™

Comparing Transformerless to Transformer-based UPS Designs

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Executive Summary

There is growing interest in utilizing transformerless UPS modules in high power, three-phase critical power backup applications. These UPS systems use some of the latest technology and provide benefits at certain operating conditions; however, most of the units available in the marketplace compromise system availability to varying degrees.

Today, large transformerless systems are constructed of smaller, modular building blocks that deliver high power in a lighter weight and more compact package. The modular design with higher component counts, extensive use of fuses and contactors, and with lack of system isolation can result in lower Mean Time Between Failure (MTBF), higher service rates, and lower overall system availability.

For high-power enterprise data centers and other critical applications, a state-of-the-art transformer-based UPS still provides the highest availability. Transformers within the UPS provide fault and galvanic isolation as well as providing useful options for power distribution that should be considered when designing a UPS system. Technology developments and configuration options allow the latest transformer-based designs to operate at higher efficiencies compared to previous designs, making them more comparable to the transformerless models in the marketplace.

Transformerless UPS models should be considered a viable option for lower power, small and medium business applications where achieving the highest availability isn't the top concern and space and weight restrictions inhibit the use of traditional transformer-based designs. These applications can benefit from the high efficiency at full loads and excellent input power conditioning through active components offered by transformerless designs.

Introduction

Transformerless UPS products have been introduced into the market to meet the need for lighter, more compact three-phase UPS systems. This paper addresses the factors that should be considered when deciding between transformer-based and transformerless UPS designs.

Both approaches use a double conversion process (Figure 1) to provide power protection for mission-critical applications.

The double conversion process utilizes an input rectifier (RECT) to convert AC power to DC power, which is used to maintain the DC power storage source (BATT) and power the DC-to-AC inverter (INV). In turn, the inverter provides AC power to the critical load. In the event of an AC power outage, the inverter continues to provide conditioned AC power from the DC battery.

The primary difference between the two technologies is the use of transformers in the design. A transformer-based UPS may use a transformer before the rectifier and requires an isolation transformer after the inverter to derive the voltage being delivered to the critical load.

Transformerless UPS designs utilize developments in power and control electronics technology to eliminate the need for an isolation transformer on the output of the inverter. Advancements in power semiconductors and control have also allowed the PWM (Pulse Width Modulation) switching frequencies to increase, allowing the use of IGBT (Insulated Gate Bipolar Transistors) within the rectifier stage.

Both approaches can be designed to maintain adherence to key UPS power quality performance objectives, such as availability, maintainability and adaptability. However, an engineer designing a large data center needs to carefully consider the costs and benefits of utilizing transformerless technology as they relate the overall performance criteria of the facility against the proven performance of transformer-based systems.

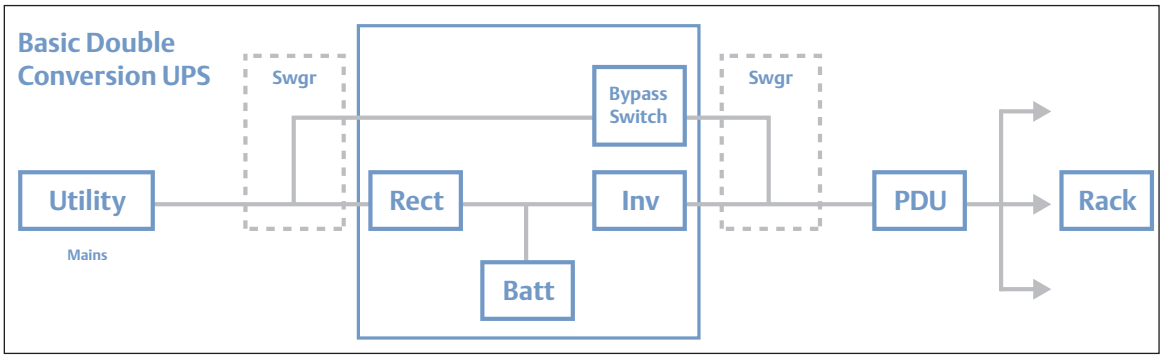

Figure 1. Basic double conversion UPS functional diagram.

Transformer-Based UPS

Figure 2 illustrates a simplified block diagram of a state-of-the-art transformer-based UPS. The key components of this design include:

- A passive filter (inductors and capacitors) on the rectifier input to reduce input current distortion and improve the power factor.
- A six-pulse (or optional twelve-pulse), SCR-based rectifier assembly on the input. Optionally, an additional transformer provides AC-DC isolation for the rectifier input voltage.
- A DC energy-storage system (typically a battery) connected directly to the DC bus between the rectifier and the inverter to provide AC output power ride-thru capability during a loss of AC input power.
- An IGBT-based PWM inverter on the output.
- An isolation transformer on the inverter output to derive the appropriate output voltage also provides a convenient and solid point for referencing the AC output neutral to ground. This neutral ground connection provides excellent common mode noise rejection.
- A passive filter on the inverter output to provide a very low distortion voltage supply.
- An automatic bypass switch (static switch) using power semiconductors (SCRs) is included to provide instantaneous switchover to an alternate source if a UPS output disturbance occurs.

This system offers more flexibility in system voltage matching or voltage step-down applications and is typically located closer to the infrastructure electrical service entrance in dedicated facility power rooms. Input/output voltages may be in various combinations of 600, 480 and 208 VAC.

The rectifier AC input source does not have to be the same as the bypass AC input source, which increases systems availability by decoupling UPS failures from the bypass path. Large systems are typically manufactured based on removable subassemblies and are available available in discrete units rated up to 1100 kVA.

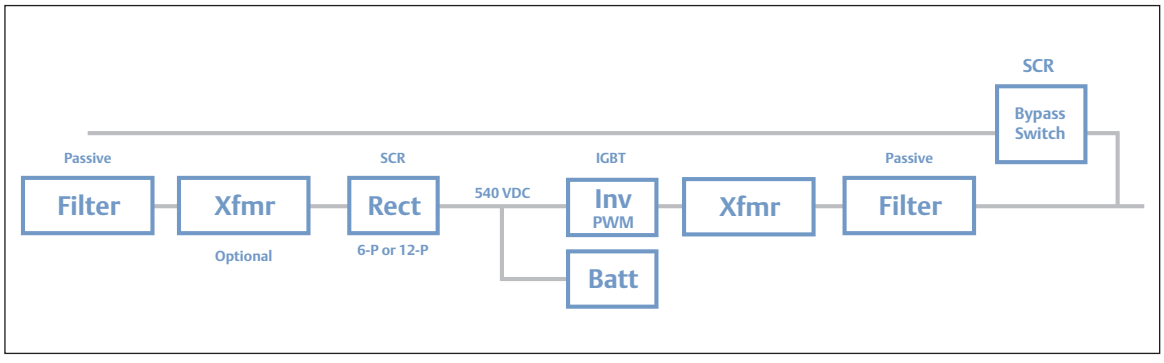

Figure 2. Transformer-based UPS block diagram.

Rectifier Section Detail

Transformer-based UPS rectifiers are technically elegant, well-proven and robust. They use passive input filtering techniques to produce relatively low levels of input current distortion and a relatively high input power factor. The lower power rated, transformer-based models typically incorporate a six-pulse SCR (Figures 3 and 4). Higher power rated units (greater than 500 kVA) normally use the 12-pulse design as standard (Figure 5).

The SCRs are naturally commutated with the line voltage and present a very efficient and robust application. SCR phase-control inherently provides a power-walk-in (soft-start) function at turn-on without additional power control components. The output DC voltage is regulated for both inverter input and for battery charging over a wide input source voltage range.

A natural operating characteristic of a six-pulse rectifier is the generation of harmonic currents on the input source. A six-pulse rectifier will generate a total harmonic current distortion (THD) of greater than 30 percent. Therefore, in most applications, a passive (capacitance plus inductance) input filter is included to reduce this current distortion under 10 percent while improving the input power factor.

A twelve-pulse rectifier with filtering will reduce the current distortion to less than 5 percent and further improve input power factor.

At light UPS loads, a passive-input filter can force the UPS input current to a leading power factor (capacitive load appearance) and must be considered with engine-generator controls. Most UPS manufacturers offer options to eliminate leading power factor conditions at light loads.

With these models, input power factor changes with load, and input kVA is greater than input kW under all conditions.

DC Bus – Energy Storage Detail

The DC energy storage system (BATT) in the transformer-based design is connected directly to the DC bus connecting the rectifier output to the inverter input (Figures 3, 4 and 5), which contributes to reliability. This circuit formation provides excellent performance during loss of utility power as the charged battery is intrinsically and immediately available. However, since the battery is connected to the output of the rectifier and the input to the inverter, it will be subjected to ripple currents and voltages. Although these ripple currents are mitigated via a DC filter capacitor assembly, they still exist to a small degree and may have some effect on the battery, especially at higher ambient temperatures.

Inverter Section Detail

Transformer-based UPS inverters are relatively simple, well-proven and robust. These units employ an IGBT-PWM inverter (Figures 3, 4 and 5) that operates at a lower DC bus voltage. They use passive output filtering techniques to produce relatively low levels of output voltage distortion over a reasonable range of connected load characteristics. Inverter AC output power flows through a three-phase delta-wye isolation transformer that provides flexibility in UPS input/output voltage combinations.

The three-phase output of the inverter is fed into the primary of a delta-wye isolation transformer. The UPS output 4-wire voltage and neutral configuration is established by the transformer secondary wye winding. This ensures magnetic isolation of the DC battery system from the UPS AC output (and from the AC input when a transformer is used with the rectifier).

A passive output filter works with the transformer impedance to provide a low harmonic sine-wave voltage (< 5 percent THD) for all load operating conditions. With an output transformer, the AC output voltage of the UPS does not need to equal the rectifier or bypass input voltage.

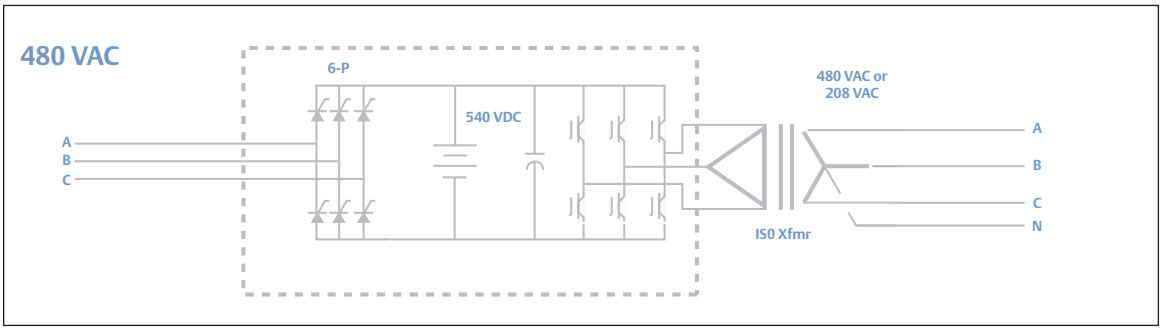

Figure 3. UPS with SCR-based rectifier and output isolation.

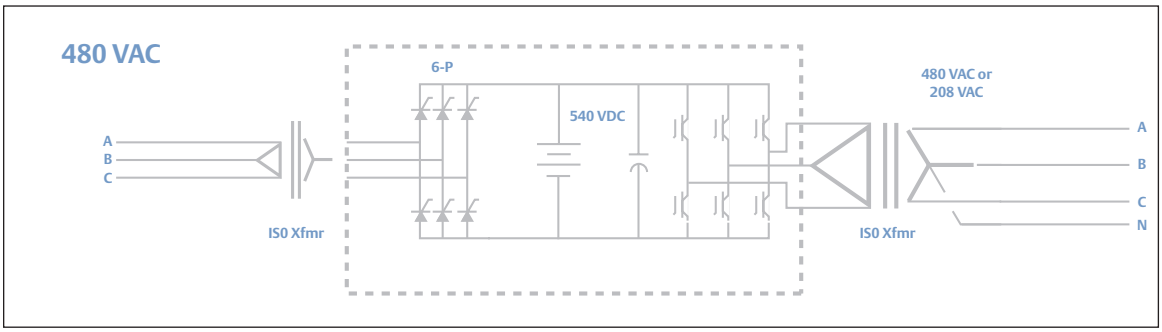

Figure 4. UPS with Six-Pulse SCR-based rectifer and input/output isolation.

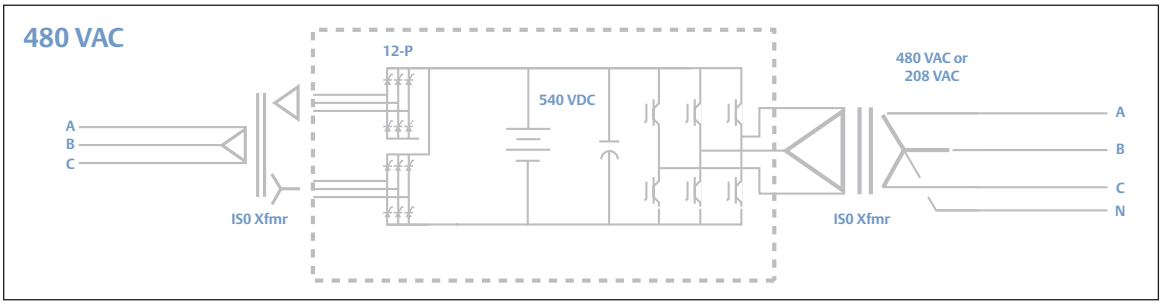

Figure 5. UPS with Six-Pulse SCR-based rectifer and input/output isolation.

Transformerless UPS Design with PWM Rectifier

Transformerless UPS topologies replace simple passive magnetic voltage transformation functions with complex, solid-state circuit solutions. Figure 6 illustrates a simplified block diagram of a transformerless UPS design. There are a number of key differences between this circuit and the unit depicted in Figure 2.

Utilizing PWM power conversion techniques, transformerless UPS rectifiers are physically smaller and produce low input current harmonics with near unity input power factor.

Typically, the UPS battery in transformerless applications is connected to the internal DC bus through an integrated bi-directional DC/DC converter. This puts an additional, complex element in series with the battery.

Using similar PWM power conversion techniques, transformerless UPS inverters are physically also smaller and produce low output voltage harmonics over a wider range of connected load characteristics.

The bypass function is similar to the transformer-based design. However, without external transformers added, the bypass AC input must be the same voltage as the inverter AC output and the same source as the rectifier AC input.

Transformerless UPSs are typically designed and styled for computer room in-row lineups but are usable in equipment rooms as well. Manufacturing methods are usually based on removable, functional modules with the power conversion modules currently rated less than 300 kVA. Complete transformerless UPS systems are an assembly of standard frames and functional control and power modules.

A transformerless UPS is lighter and smaller than the power-equivalent transformer-based design with both physical volume and footprint being less. However, other external transformers may be required for isolation purposes, safety benefits or to provide distribution flexibility. With the addition of external transformers, the overall facility weight and footprint totals may be higher than the traditional transformer-based UPS design. It is therefore important to consider the entire critical power design within the facility when choosing UPS technology.

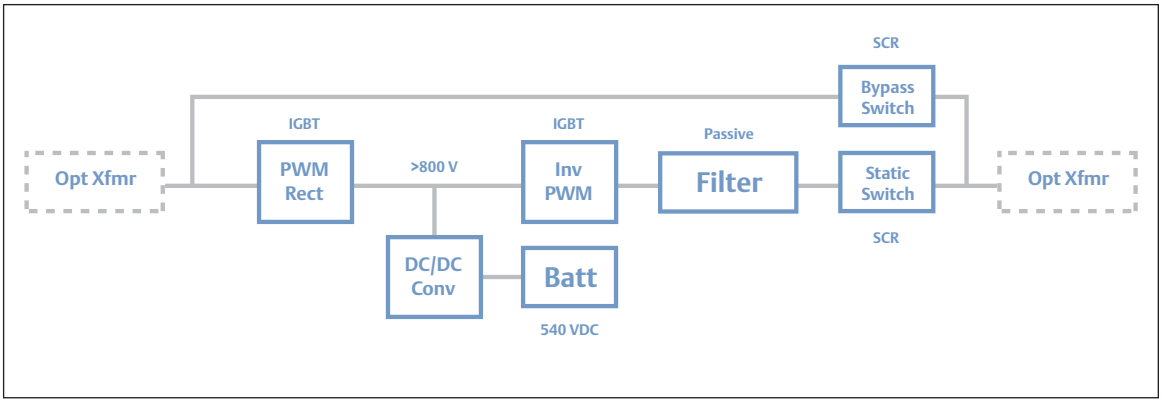

Figure 6. Transformerless UPS block diagram.

Rectifier Section Detail

In a transformerless UPS, the SCR Rectifier is replaced with a PWM IGBT three-phase power-factor and current-waveform-corrected rectifier. This more complex combination of converter functions requires even more components to provide the power walk-in function. The operation and control algorithms expand the basic functions of rectification and DC regulation to include control of the input current waveform.

In addition to its primary function of rectification of AC power into DC power, the rectifier now has the ability to regulate the input current to near unity power factor and input current distortion below 3 to 5 percent over the full load range. Therefore, the larger passive input filter as employed in the transformer-based design is not required. Since the power factor is not changing with load, input kVA is approximately equal to input kW under all conditions, allowing a lower input circuit breaker rating and closer engine-generator size matching.

DC Bus – Energy Storage Detail

The transformerless design applies the battery differently than the transformer-based design described in the previous section. The battery is not connected directly to the DC bus, but maintains its charge from supplemental battery charging (DC/DC Converter) (Figure 7). This isolates the battery from incremental aging effects of the rectifier/inverter DC harmonic currents.

During utility outages, the battery must be discharged through the DC/DC converter assembly, which acts as a boost regulator during battery discharge. This boost regulator will result in reduced DC/AC conversion efficiencies and increased battery size for transformerless units. The additional components of the DC/DC boost converter and DC/DC battery charger reduce the overall system MTBF.

Note that there is no AC input or AC output magnetic isolation in this configuration. If galvanic isolation is required to prevent DC faults from propagating to the input feeder or output critical bus, transformers would need to be added externally on the rectifier input or the inverter output.

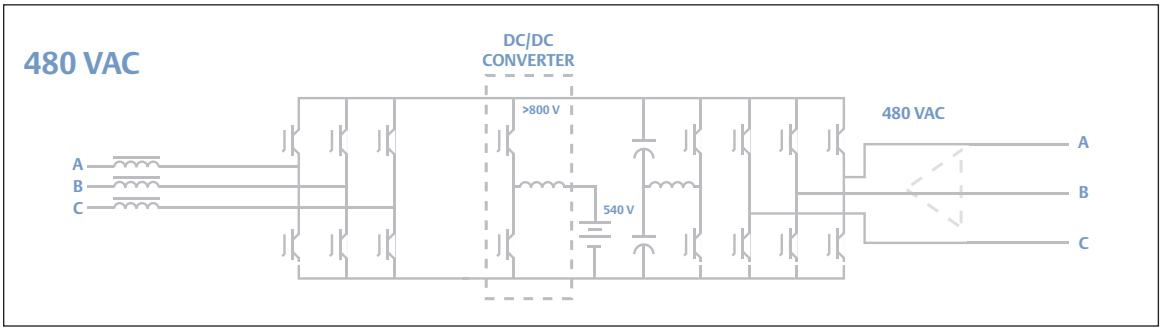

Figure 7. Three-wire transformerless UPS.

Inverter Section Detail

The three-phase PWM inverter output is passively filtered and presented to the UPS output terminals without flowing through an output transformer. This three-phase inverter provides a three-wire output (Figure 7). A fourth inverter switching leg is required to balance the DC bus voltage around zero volts or if a four-wire output (three phases plus neutral) is needed (Figure 8).

It should be noted that in this transformerless implementation, the normal output is three-wire and requires the input, output and bypass AC voltages to be the same voltage. This also requires that the input and bypass circuits come from the same source.

With a three-wire inverter output, a step-down to a distribution-level voltage (e.g.: 208/120 Volts) would be provided downstream within a Power Distribution Unit (PDU). The PDU requires an isolation transformer that would also provide for neutral formation and a local grounding point. If a neutral (e.g., a four-wire wye output) is required on the inverter output, it will require a full-capacity neutral run through from the AC input source to the rectifier (or bypass) and on through to the inverter output and connected load.

Technical Features and Performance Differences

While accomplishing similar performance goals, transformer-based and transformerless UPS units use somewhat different approaches to getting the job done.

Transformer-based units integrate passive magnetics with active power conversion components resulting in a relatively simpler, more robust UPS unit. Transformerless UPS units utilize all active, but more complex, power conversion techniques. This section reviews some of the performance, techniques and tradeoffs utilized in the various rectifier, DC energy storage, inverter and static bypass functions.

In UPS system applications, transformers provide fault isolation, arc flash mitigation, noise reduction, a solid neutral reference and some degree of fault current limiting. In choosing between transformer-based and transformerless UPS solutions, a system designer needs to determine where transformers are best utilized and whether they should be internal and/or external to the UPS in view of physical and electrical distribution requirements and tradeoffs.

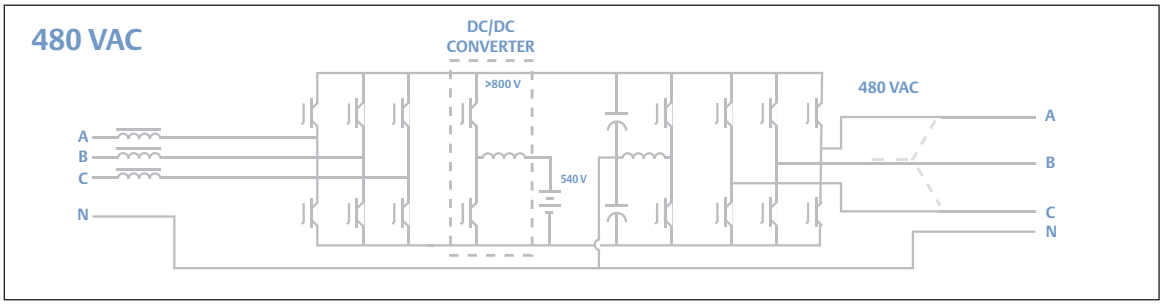

Figure 8. Four-wire transformerless UPS.

Site Planning and Adaptability

Many users find transformerless UPS equipment provides greater flexibility in accommodating less-than-clear growth plans. Transformerless designs are usually smaller in size than an equally power-rated transformer-based design, providing opportunities to locate the UPS physically closer to the point of power usage or on a more lightly rated (pounds/sq. ft.) raised floor.

Applying a transformerless UPS to a critical power distribution system does not mean that all transformers in the power path can be eliminated, but does allow the system designer to place transformers only where they are needed.

Isolation transformers, which are integrated into transformer-based UPS, still are needed to perform certain necessary functions within the critical power distribution system, such as:

- Establish a separately derived, 4W-plus-neutral source from a 3W input
- Provide local points for neutral-to-ground bonds
- Establish local grounding points for safety as well as common mode noise reduction
- Permit rectifier and bypass input sources to be separate
- Allows input voltages to be different than the UPS System output voltage
- Provide additional source impedance for fault-current and arc-flash reduction
- Reduce neutral-ground voltage transients for resistance grounding schemes
- Handle unbalanced wye-connected loads when applied to 3W distribution
- Improve the performance of overcurrent protective devices (fuses and circuit breakers) by reducing fault-current path resistance.

Once it is determined where transformers may be needed in the system, transformerless UPSs may permit more optimal placement in the power distribution path. However, it must be remembered that transformer-based UPSs have some of these functions internally integrated as part of the system design, a potential reliability benefit.

Reliability and Availability

Transformer-based UPSs have an inherently higher reliability due to a much lower parts count, robust N+1 redundant configurations, and simplified maintenance. They also benefit from technology innovations and an installed base of thousands of machine-years of experience and refinement.

The newer design of the transformerless UPS achieves its high-availability performance through power conversion technologies, redundancy, modularity, active fault management and lessons-learned from transformer-based designs. Transformerless UPSs in high-power, enterprise applications have yet to withstand the test of time; however, all major UPS manufacturers produce both topologies for mission critical applications. In order to compensate for the lack of field experience, these new topologies rely on intensive testing to predict future reliability.

Most UPS manufacturers understand the absolute criticality of the availability of mission-critical power and have incorporated techniques to maximize mission MTBF (Mean Time Between Failure) and lower MTTR (Mean Time To Repair) for both designs.

The control strategies and expanded power conversion processes within the PWM rectifier of the transformerless UPS will compare somewhat less favorably in predicted Product Mean-Time-Between-Failure (MTBFp). The simple fact that transformer-based UPS power units are available in discrete units up to 1100 kVA, whereas the largest transformerless UPS modules are less than 300 kVA, illustrates the potential limit on availability of the highly paralleled components within a transformerless UPS when more than one (1) module is required to meet capacity.

Transformer-based UPSs utilize a combination of passive and active fault management systems, while transformerless systems use a more complex active–only design. However, in analysis of the Mission Mean Time Between Failure (MTBFm), (i.e., sustaining the critical load) and availability of the mission-critical power, both product executions will be similar.

Robustness

In general terms, robustness is an expression of a qualitative level of abuse that a UPS system can handle beyond its 0-to-100 percent ratings while still meeting its availability requirements. Both transformerless and transformer-based UPS can provide excellent and similar dynamic overload capabilities for phase-to-neutral or three-phase dynamic load events. These units provide automatic handling of temporary overloads and faults on the downstream distribution network and can provide on-the-fly paralleling with the AC bypass in support of overload and load fault management. Transformer-based UPSs add the benefit of some degree of passive fault handling through internal transformers and filters.

Most transformer-based designs use circuit breakers at key disconnect points (Input, Output, Bypass and Battery). These circuit breakers provide protection and allow for greater fault clearing capabilities.

Transformerless units typically use a contactor and fuse combination which can present problems during certain conditions. Specifically, an inverter IGBT can fail short which may cause the contactor to weld and introduce a DC current onto the critical bus. In addition, most contactors will be unable to open during DC fault conditions or high AC Interrupting Current situations which can be easily handled by a properly sized circuit breaker. Also, in a transformer-based UPS, the DC fault current cannot pass through the transformer. As a result, the input feeder and the critical bus cannot experience any DC fault conditions, nor cascading DC faults.

DC Energy System Isolation

Internal or external transformers can enhance the reliability of the DC link in several ways. Transformers add a degree of impedance to the power circuit, serving to incrementally reduce the magnitude of fault currents. An output transformer associated with the inverter will further serve to isolate the AC output from DC faults. Similarly, an input transformer will isolate the AC input source from DC faults. If both AC input and AC output transformers are included in the power system, the AC input and AC output will be unaffected by DC faults to ground, DC ground fault sensors will operate better, and maintenance/service procedures will be significantly safer.

VRLA (valve-regulated, lead-acid) and wet cell batteries (typically 180 - 240 cells) are usable with both UPS designs. However, caution should be used when designing a transformerless UPS system with the open rack configuration of wet-cell battery systems due to the higher potential of DC ground faults during maintenance or operations, directly affecting the critical bus.

Engine-Generator Interface

The input filter on the transformer-based design is large enough in kVAR to cause the input power factor to become leading (capacitive) when the UPS is lightly loaded (something less than 40 percent). This has been known to cause engine-generator control issues if not taken into consideration during the engine-generator/UPS integration design phase. The added kVAR of the filter also requires that the engine-generator be oversized when compared to the UPS power rating. In view of these conditions, most UPS manufacturers offer an option to eliminate the light-load, leading power factor if needed.

The transformerless design, with its near unity power factor and very low input current distortion over the full output load range, circumvents these characteristics and allows a closer matched engine-generator set to be applied to the system. The engine-generator set may still need to be oversized to some degree to handle the full critical load plus battery recharging.

As a side note regarding system design, be sure to confirm that the engine-generator as well as any other power distribution components can handle the critical load power factor and AC current distortion separately from the UPS. From time to time, the UPS will be on bypass, with the critical load powered directly from the AC input source or engine-generator (or other alternate AC source).

UPS Output Considerations

The output transformer in the transformer-based UPS design provides flexibility in output voltage, phasing and grounding. The delta-wye transformer can be configured as a three-wire, no-neutral 480 Volt or 208 Volt system. It can also be configured as a four-wire, 480V or 208V wye system allowing parity-rated neutral currents (Figures 2, 3 ,4 and 5). The wye provides for adherence to the National Electric Code separately derived neutral definition. With an output isolation transformer, the UPS can be connected to two separate AC sources (rectifier input and bypass input). It also permits the neutral to be grounded and a local distribution reference established.

Transformerless UPS design is typically executed as a three-wire in-and-out-only system with the output voltage the same as the input voltage (Figures 6, 7 and 8). Neutral establishment (i.e., four-wire wye output) for distribution occurs farther downstream in an isolation transformer, whether stand-alone or within a Power Distribution Unit (PDU).

If a neutral is required in a transformerless UPS, a fourth leg is added to the inverter (Figure 8). The created neutral does not have magnetic isolation and will be referenced to the input through multiple impedances. This lack of isolation can create challenges where managing the neutral voltage on a line-to neutral load is required. Physically, a full-capacity neutral conductor cable needs to be run from the AC input source to the downstream load, an additional cost consideration.

Fault Current Availability

A key requirement for all UPS products is an ability to manage internal fault currents while preventing disturbances to critical load operations. Transformer-based units handle this requirement through the combination of internal magnetic impedance (current limiting effects) and active fault control techniques. Transformerless units, with a lower level of internal impedance due to the lack of internal magnetics, must depend on faster-acting, more robust and complex active means to achieve a similar level of fault management.

Site design should include an analysis of available fault currents at different locations along the critical power path from service entrance to actual critical load. Since the transformer-based UPS has one or more series transformers included within the product, output fault currents will be partially limited by the impedance of the internal transformer(s).

The transformerless UPS has, in general, the ability to pass more fault-current through its structure and into its faulted circuits since the limiting impedance may only be a function of the rectifier and inverter power semiconductors.

The transformer-based UPS is typically located in a power room and has long power distribution cable runs, adding additional impedance. The transformerless UPS can be located much closer to the actual critical load resulting in the potential for higher battery fault-current availability which must be considered in the selection of circuit breaker fault-current ratings.

Arc Flash Energy

Arc Flash is a consequence of a limited impedance short circuit fed by one or more paths of source energy. There are many factors that must be considered when estimating arc flash energy: source voltage levels, potential fault current magnitudes, source impedances, number of contributing paths and circuit breaker trip characteristics.

UPS design and physical location within the infrastructure critical power path will also influence the available energy that may be realizable at the fault location. In general, the impedance of the included transformer(s) within the transformer-based UPS will lower the available fault energy within the downstream distribution system. With a transformerless UPS, a system designer may find that an external transformer(s) must be added downstream of the UPS to assist in limiting fault currents, and therefore arc flash energy levels. This may mean the difference between requiring Level 1 PPE (Personal Protective Equipment - a flame resistant cotton coat) and Level 4 PPE (an insulated, Arc flash protective suit, gloves and helmet) during maintenance procedures.

Isolation

Aside from fault current handling and arc flash mitigation, electrical distribution systems must include provisions for sectionalizing feeder and branch circuits for the following:

- Ground and neutral conductor management
- Limiting fault and neutral current loop lengths
- Providing safety ground paths
- Limiting common mode electrical noise

Other functions may include voltage-transformation, delta-wye transformation, neutral formation, AC-to-DC-to-AC circuit isolation, and reducing risk during maintenance procedures. Line-frequency transformers are the typical method to provide these many functions. The internal transformer(s) within a transformer-based UPS provides comprehensive, integrated magnetic solutions for essentially all of these functions. They are designed-in and tested as a complete package. If other local neutral/grounding points are needed, they can be added using additional, external transformers.

The more compact, transformerless design, while providing size and weight benefits, is not able to provide the aforementioned electrical distribution and isolation functions internally. The benefit for the system designer is the ability to place transformers only where they are determined to be needed and not duplicated, potentially saving costs, space and weight.

These benefits must be balanced against the fact that the UPS units and third party isolation transformers cannot be designed and tested as a system in the factory, creating the possibility that something in the system design is overlooked, such as dual AC input source isolation requirements or arc flash mitigation needs.

Maintainability

Maintainability is a reflection of the convenience, safety, speed, accuracy and risk of performing maintenance and service on the UPS system components. The transformer-based design provides a longterm history of ease of maintainability and a history of safety for service personnel. The magnetic isolation and impedance provided by the integrated transformer(s) is an asset when planning maintenance actions. Most transformerless UPS systems may be reliably serviced in sections while maintaining critical load operations with minimal risk.

Total Cost of Ownership

When considering the total cost of ownership for a UPS system, it is important to consider both the initial upfront costs (CAPEX) as well as the ongoing costs to power, maintain and service various options (OPEX).

- Initial Costs (CAPEX): Due to the removal of transformers, most transformerless UPS modules will be less expensive than the traditional transformer-based models. They will also have a reduced footprint which reduces the need for additional space in the data center. The cost/benefit of these systems can be deceptive however, if an engineer determines that an input or output isolation transformer(s) is required. The addition of transformer requirements outside of the UPS results in higher overall purchase costs, increased total footprint, increased labor to install and wire the additional equipment. Plus, the external transformer may not be as well-coordinated as with a transformer-included design.
- Operating Costs (OPEX): Both the transformerless and transformer-based UPS modules have similar high efficiency and full-load performance factors. Both designs typically feature Economy mode options, meaning that the critical load can operate in the UPS bypass mode, transferring to the UPS inverter when the input source has an out-of-limits disturbance.
- After years of optimizing performance, transformer-based UPS systems have achieved a relatively flat efficiency curve from 30 percent to 80 percent loading where typical Tier 3 and Tier 4 data centers operate. At this loading, the efficiencies of both systems are nearly identical and there may be minimal operating advantage to the transformerless UPS models. If an engineer requires an isolation transformer,

the efficiency of the transformerless model is reduced by 1.5 percent or more, potentially making the transformer-based model actually a more efficient and cost effective system.

Conclusion

Figure 9 (see back page) provides a summary of top-level performance attributes for the two designs.

Transformer-based UPS AC output availability has steadily improved over the decades as component, design, control and manufacturing techniques have been refined and proven. Performance has significantly improved while component count has decreased. These designs, intended primarily for equipment room installation, have consisted largely of an assembly of replaceable/repairable subassemblies. As the key power source for mission-critical applications, their field observed availability numbers have climbed to remarkable levels.

However, contemporary, rapidly changing IT installations have driven the requirement for more flexible alternative solutions for those situations where future critical power requirements are difficult to forecast.

Transformerless UPS topologies have emerged as a solution for the demand for efficient, flexible, smaller footprint, lighter weight UPS systems to accommodate today's quickly changing IT requirements. The price of these performance feature improvements has been the replacement of a few robust but physically large and heavy passive components (e.g., transformers, inductors, capacitors) for functional equivalents implemented using many more components packaged in field-replaceable, modular subassemblies. It is reasonable to expect that, while achieving system output availability values that approach those achieved by transformer-based designs, the transformerless designs will have service call rates higher than their transformer-based counterparts.

Transformers are necessary to establish circuit isolation and local neutral and grounding points, as well as to providing voltage transformation requirements. Transformers permit power systems to incorporate multiple AC sources by providing separately derived neutrals and grounds rather than be powered from a single AC source. With transformers, the UPS input voltage level does not have to be the same as the UPS output voltage level. When utilized in conjunction with the UPS's internal DC link, DC-to-AC output and AC-to-DC input isolation can be provided, reducing or eliminating the risk of DC faults propagating upstream or downstream of the UPS.

For the absolute best in robust, high availability UPS solutions, it is hard to beat transformer-based UPS designs for the foreseeable future. However, as transformerless modular UPS design and manufacturing techniques prove themselves, some transformerless design techniques may find their way into transformer-based systems, further improving the utility of the transformer-based designs.

	Transformer-based	Transformerless
Size & Weight (smaller is preferred)	+	+++
Location Flexibility	+	+++
Initial System costs	++	+++
Fuzzy growth plans	++	+++
Adaptability/scalability	++	+++
System Efficiency	++	++
Input waveform management	+	+++
Input/Output Configuration flexibility	+++	+
Input / DC / Output Isolation	+++	+
Availability	+++	+
Fault management	+++	+
Component count	+++	+
Reduced need for paralleling for capacity	+++	+
Robustness	+++	+

Best = +++ Better = ++ Good = +

Figure 9. Summary comparison of transformer-based and transformerless UPS design.

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