
UPS Systems in Industrial Applications



Solidstate Controls Incorporated
875 Dearborn Drive
Columbus, Ohio 43085
Tel : (614) 846-7500
Fax: (614) 885-3990

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Abstract

Uninterruptible Power Systems (UPS) have become an indispensable element of many data processing installations (EDP), from desktop PC's to mainframe computer systems. UPS systems provide a measure of insurance and security for the user who is concerned about data loss and hardware failures caused by power disturbances. The measure of insurance needed is proportional to the financial impact of the downtime caused by such an incident.

More recently, the introduction of computer based control systems in manufacturing and process control applications has prompted the need for UPS system in industrial facilities as well. Typical applications range from distributed PLC based controls to complete Distributed Control Systems (DCS) with power requirements ranging from 3 to 50 KVA. In addition to new plant construction, many older plants are upgrading both pneumatic and single loop control systems to distributed control, primarily to improve operating efficiency. Fundamental philosophical differences in system architecture indicate that industrial computer applications require different design parameters than their data processing counterparts and while UPS's in commercial applications have largely become commodity items, industrial UPS systems remain an engineered product.

Environment

What differentiates a commercial product from an industrial product? The first thing to consider is the useful design and service life of the equipment the UPS is expected to support. As any computer user will tell you, technology is evolving at such a rapid rate that the EDP computer system purchased and put into service today will likely be obsolete and in need of replacement within five years. Invariably, the UPS will be replaced with the computer because evolving technology results in more processing power with either lower or different power requirements. Because the computer equipment has a relative short useful life, ease of installation has been optimized by both computer and UPS manufacturers alike. The computer and UPS normally employ "plug and play" configurations to allow the old equipment to be rolled out and the new rolled in. Many computer racks or "towers" distribute the power to the peripheral equipment so the UPS is essentially connected to a single load, making the need for downstream power distribution and fault coordination unnecessary.

Another item of concern is the environment in which the equipment is to be installed. Most EDP computer systems are installed in designated rooms with tight temperature and humidity control or in air conditioned offices. Because a controlled environment is anticipated, critical components subject to thermal breakdown can be "downsized" to reduce cost. Also, the environment is relatively clean with little or no foreign material present to clog air filters, allowing forced air cooling to be employed. Like the computer equipment it supports, the EDP UPS will probably be under a maintenance contract with regularly scheduled preventive activity. The EDP computer's basic configuration and relatively short useful life, coupled with operation in a controlled environment allow design compromises in the EDP UPS that reduce initial cost while providing reasonable reliability.

On the other hand, the industrial computer system generally has a useful life equivalent to the plant design life (20 years or more). The cost to incorporate distributed control is extensive, whether it is new construction or an upgrade to an existing facility. Therefore, while software and field instrumentation upgrades may be incorporated over the useful system life, the basic architecture and power distribution will likely remain intact for at least 15 years and possibly longer. This means that design compromises are unacceptable. It also means that the UPS must be supported on a parts and service basis throughout its useful life. EDP UPS equipment is often discontinued within 7 to 10 years of inception making parts procurement difficult. Industrial facilities can also leave much to be desired from an environmental perspective. Most UPS's are installed in switchgear rooms or perhaps on the plant floor resulting in possible exposure to wide temperature variation, foreign material (dirt) and even corrosive gas and/or material. The industrial UPS needs to be capable of operating reliably under any of these conditions. Most industrial UPS manufacturers offer a myriad of options to address these situations, unlike EDP manufacturers; who primarily

offer standard “off the shelf” equipment. The UPS installation in an industrial plant is considered, permanent. There is fixed downstream distribution in the form of circuit breaker subpanels, conduit, and wire. Plant maintenance personnel are generally responsible for maintaining the equipment, therefore, ease of maintenance and troubleshooting are important considerations.

System Topology

The two most common topologies used in modern UPS systems are single conversion, which includes off-line/standby or line interactive units and double conversion which are considered to be true on-line machines. The standby power supply as depicted in **Figure 1** is most commonly used for small desktop computer applications, primarily due to its inherent low cost and small physical size. In this topology the primary power source is the fine or utility. A trickle charger is used to charge an associated storage battery which is connected in parallel to a static inverter. The static inverter is a solid state device which converts DC electrical power to AC by “chopping” the DC and synthesizing a sinewave electronically. The inverter is normally off, therefore, a control circuit is employed to detect primary power failure at which time it signals the inverter to turn on and pick up the load via a transfer device of some type. The previously mentioned advantages of this technology can be overshadowed by several inherent disadvantages. Since the inverter is normally off there is no line conditioning when the normal power source is present unless a filter and/or surge suppressor are integrated into the design. In addition, since the inverter is normally off there will always be an interruption in power when a power failure occurs.

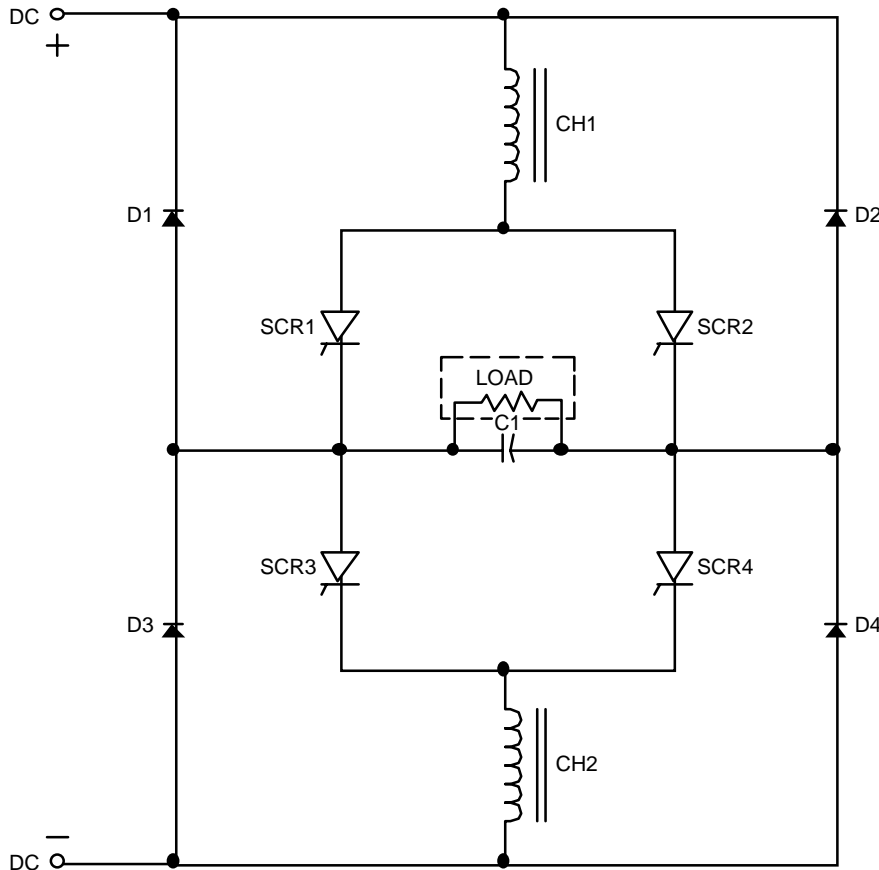


Figure 1 Common Inverter Bridge (Parallel Commutated Type)

Line interactive units operate much the same as the standby topology with the exception that a voltage regulator/line conditioner is incorporated in series with the utility input to address noise and voltage regulation under normal operation. Two common configurations are depicted in **Figures 2 & 3**. The configuration in **Figure 2** utilizes a constant voltage transformer (CVT) while **Figure 3** incorporates a solid state tap switching regulator to provide conditioning of the utility power. The CVT approach minimizes the power disturbance when the utility fails because it

stores energy for approximately one cycle due to its inherent resonant operating characteristics. Therefore, if the inverter comes on line in less than one cycle there should conceivably be no complete interruption in power.

The tap switching type uses a "bidirectional converter" rather than a stand alone inverter. The converter provides battery charging and fine regulation by buck/boosting the output transformer through a second primary winding while the utility is present. When the utility fads the converter essentially reverses and becomes a static inverter.

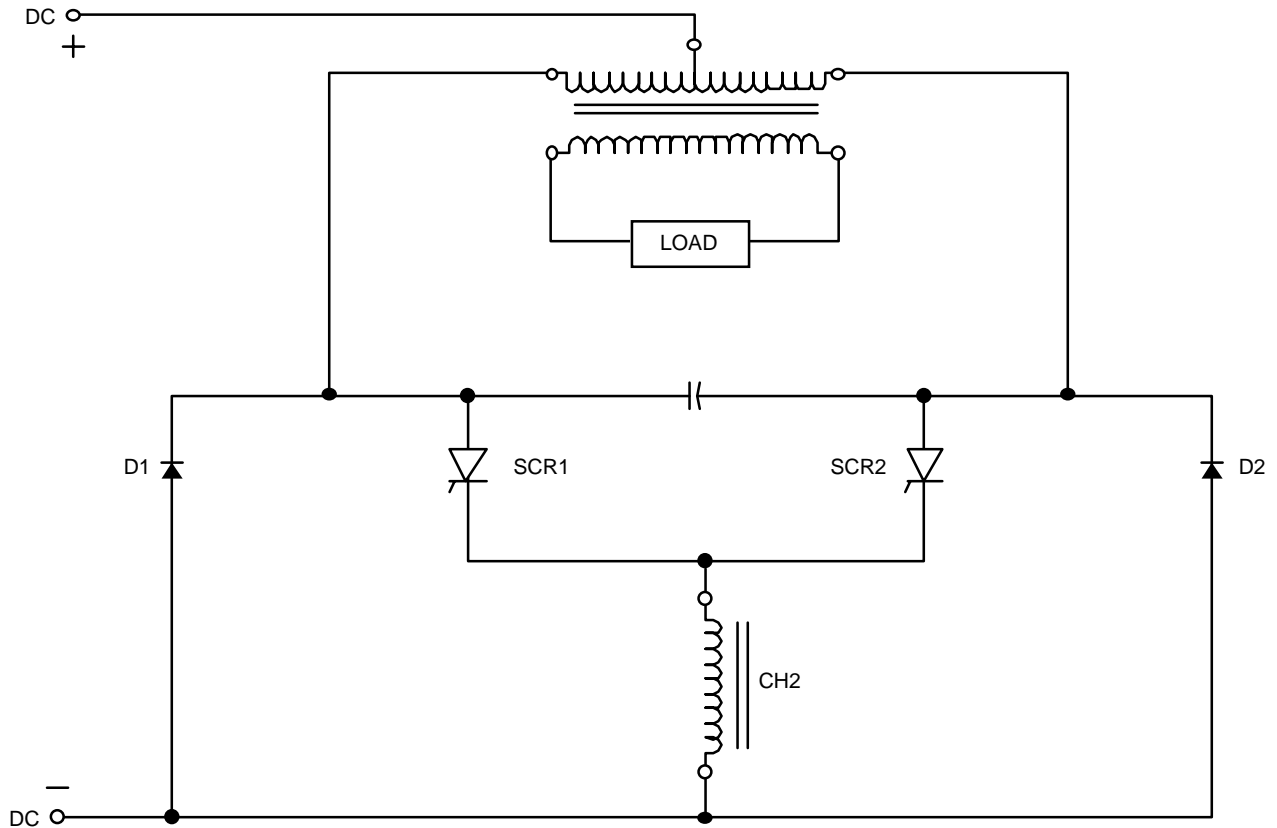


Figure 2 Center Tap 2 SCR Inverter

While both concepts offer the advantage of low cost, small size and high efficiency while the utility is Present, several inherent limitations preclude reliable operation in an industrial application. Since the constant voltage transformer is a high impedance, current limiting device it cannot deliver adequate fault current for downstream branch circuit coordination. This is not an apparent disadvantage when the UPS is dedicated to one load as would be typical of a computer room application, however, when multiple loads are connected via a subpanel there is a risk of the UPS going into current limit before a branch fault can be cleared which would result in the entire load being dropped due to undervoltage. In the tap switching approach, the transformer used is linear, with a much lower impedance so it can deliver much more fault current than its CVT counterpart. Since the semiconductors in series with the power path are fused with fast acting fuses, the integrity of the downstream distribution is stiff questionable due to possible coordination problems. There is no static switch to allow the unit to be automatically bypassed in the event of a system malfunction and since the optional manual bypass switch connects primary to secondary bypassing the power conditioner, in three phase applications a 30 degree phase shift will be introduced to the load when it is actuated due to the use of a delta/wye transformer. Even though these units utilize single conversion technology, they are often touted as "on-fine" which is a bit misleading.

Double conversion or "on-fine" UPS system eliminate many of the problems associated with the single conversion technologies. The typical double conversion UPS consists of a rectifier/charger, static inverter, static transfer switch, maintenance bypass switch and storage battery, as depicted in **Figure 4**. The rectifier/charger converts incoming AC voltage into DC voltage. This DC voltage is used to supply the load bus for the static inverter and simultaneously provide charge current for the battery. The static inverter synthesizes a regulated, computer grade sinewave from

the DC. This computer grade power is distributed to the load through a static transfer switch and a maintenance bypass switch. The static switch is a solid-state device that allows an unbroken transfer to the utility bypass line in the event of a downstream fault (the fault current available from the alternate source is only limited by the impedance of the upstream transformer, allowing effective panel coordination without the risk of stressing inverter components) overload or inverter malfunction. The inverter is synchronized to the alternate source so that an out of phase transfer does not occur. The maintenance bypass switch is a mechanical device to allow electrical isolation of the UPS when taken out of service for maintenance purposes. Since the inverter supplies power to the load at all times and the battery is in parallel with the inverter input, when a power failure occurs the rectifier/charger merely stops operating and the battery picks up the load instantly, resulting in no power interruption at all.

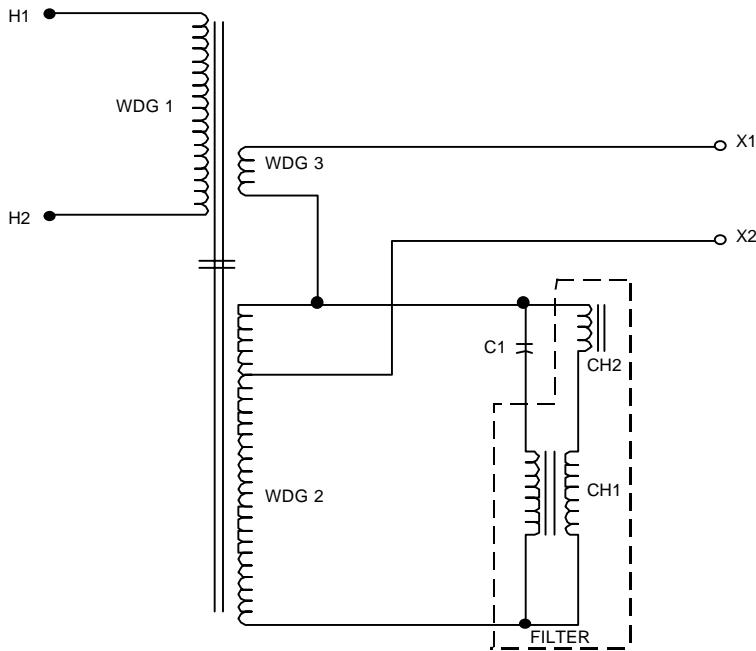


Figure 3 Conventional Sine-Wave Ferroresonant Transformer

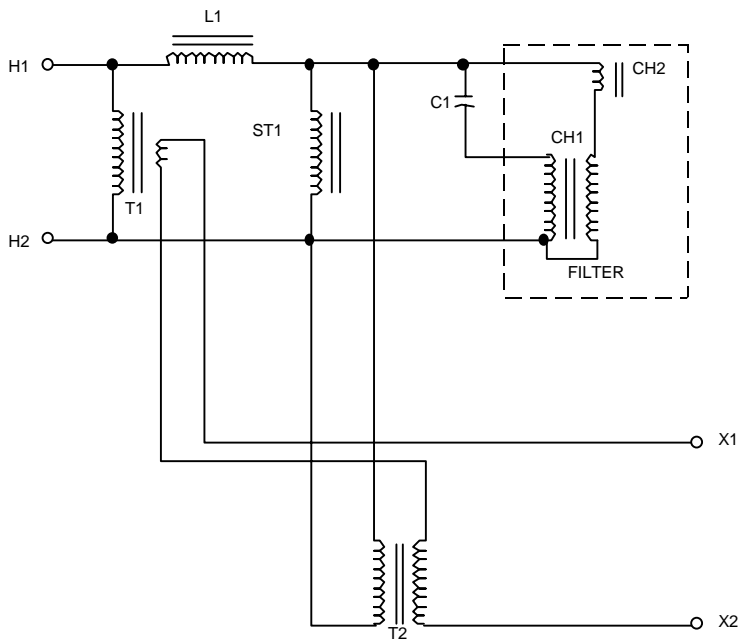


Figure 4 Complete Equivalent Circuit for Sine-Wave Ferroresonant Transformer

Breaking Down The Blocks

Even though all double conversion UPS systems contain the same basic components when depicted in block diagram form, the makeup of the individual blocks can be drastically different, which will impact whether the unit is more suitable for EDP or industrial applications. It becomes very confusing and difficult to evaluate the equipment beyond the block diagram format because most literature and descriptive information is not very detailed.

Rectifier Charger

Two rectifier/charger configurations, hybrid and phase controlled bridge are commonly used in reverse transfer UPS systems. The hybrid lends itself primarily to EDP or commercial applications while the phase controlled bridge addresses the industrial market. A hybrid rectifier/charger, as shown in **Figure 5** consists of a high power rectifier to supply DC to the inverter load bus and a separate trickle charger for battery charging. The high power rectifier will normally be an unregulated diode bridge, although, some manufacturers have been experimenting with power factor corrected (PFC) pulse width modulated (PWM) rectifiers. There are specific advantages and disadvantages with this approach when compared to the phase controlled bridge. Since both rectify directly "off the line", the diode bridge and PFC/PWM approaches eliminate the input isolation transformer. By removing the input isolation transformer and consequently its associated losses, a 3-5% increase in the overall operating efficiency can be obtained; an important consideration when installation will be in an existing computer room due to air conditioning requirements. The diode bridge rectifier further contributes to higher overall efficiency due to the low forward voltage drop across the devices when conducting. Similar efficiency gains can also be expected from the PFC/PWM rectifier resulting in system overall efficiencies that are 8-10% higher than their phase controlled bridge counterparts. Both approaches offer substantial cost reductions, obviously from the lack of an input transformer, and not so obviously from the lack of a control circuit (diode bridge) and the fact that smaller heatsinks can be used for heat dissipation due to the diode's 180 degree conjunction angle (failure of any semiconductor device normally results from thermal breakdown of the junction).

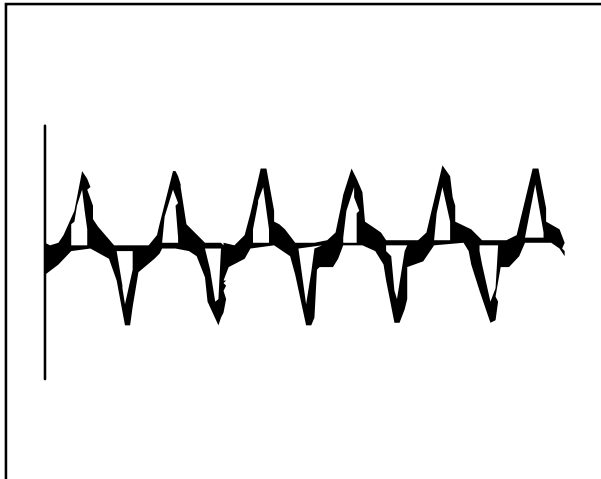


Figure 5 Typical Computer Load Waveform

At this point it is obvious that the advantages are low cost and higher efficiency so why would other solutions be considered? Because the design compromises made to address the cost and efficiency pressures of the EDP market also have an impact on long term reliability. The alternative phase controlled bridge rectifier/charger configurations generally includes a shielded isolation transformer on the front end as a standard feature. This offers the advantage of isolation from the input line and voltage conversion, allowing the DC bus voltage to be a selection rather than result in power plant applications in particular, the UPS can be designed to interface with the station DC system or supply the station DC, typically used for switchgear control voltage, protective relay control voltage and DC lube oil pumps.

Unlike the diode bridge rectifier, the phase controlled bridge can be controlled, allowing voltage regulation and current limiting capability. Regulating the DC bus to the static inverter improves reliability by limiting the inverter's exposure to low voltage excursions (since voltage and current have inversely proportional relationships, low voltage

on the inverter input means increased input current which can cause premature thermal failure of the semiconductors in the inverter bridge circuit). Because the industrial rectifier/charger employs constant current/constant voltage controls with automatic crossover, this technology also allows for "smart battery charging". A fully discharged storage battery will have a relative low impedance, a condition that will alert the charger controls to operate in constant current mode, delivering all current not demanded by the inverter to the battery. As the battery recharges, the impedance increases, and the charger automatically phases back, delivering less and less current until it reaches float potential where the charger reverts to constant voltage control. This allows efficient battery charging without overcharging and enables the use of temperature compensation if the ambient temperature becomes elevated. Since current limiting is a standard feature, the charger stands a reasonable chance of protecting itself in the event of a bus fault, which as a minimum would clear protective fuses in other designs. The cost factor can be significant between the two rectifier/charger topologies. Addition of the input transformer, SCR's vs diodes, the larger heatsinks required to adequately cool the SCR's, the inclusion of a control circuit and associated manufacturing costs make the industrial design much more expensive with the trade off being long term reliability.

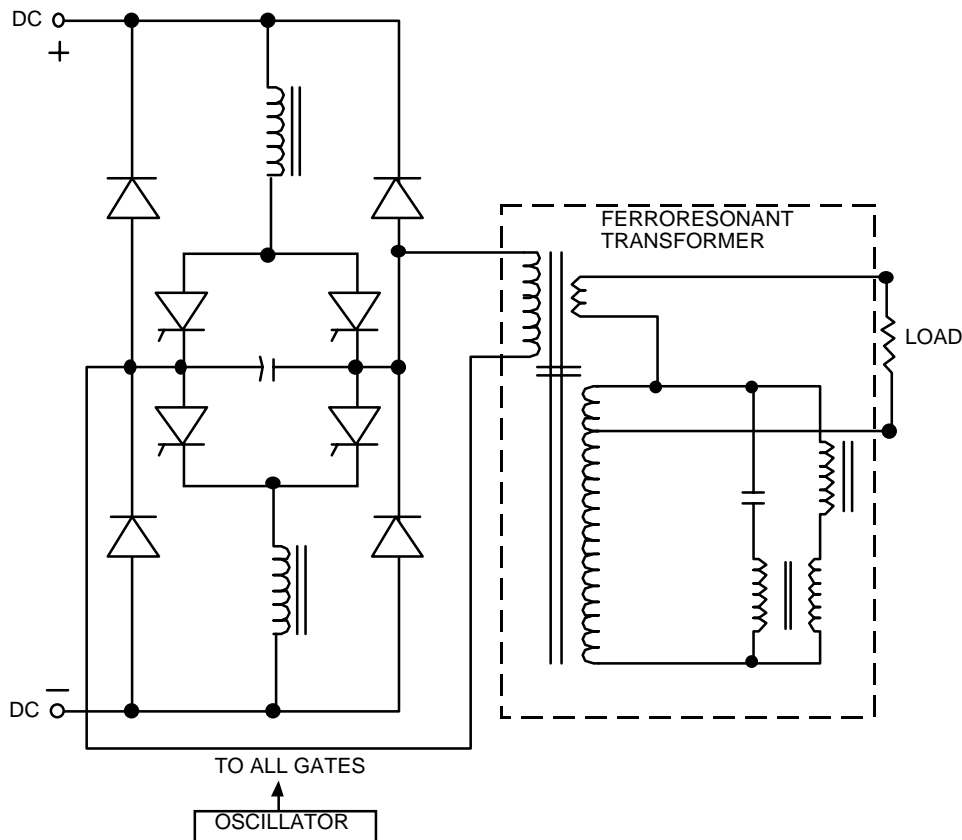


Figure 6 Ferroresonant Transformer Inverter

Inverter Technology

Inverter technology also plays a significant role in determining the UPS system's suitability for industrial applications. The two most common technologies used in modern UPS systems include Pulse width modulation (PWM) and Ferroresonant. Both technologies offer inherent advantages and disadvantages that are specific to their respective market focus.

The PWM inverter configuration, as depicted in **Figure 6**, is referred to as an active regulator. Voltage and current feedback loops gather downstream information and deliver it to a microprocessor based control circuit through a series of amplifiers. The bridge circuit in modern PWM technology normally uses IGBT's for power switching, although, SCR's could be used in high capacity, lower frequency applications. The IGBT bridge generates a positive

and negative pulse train at approximately 3 to 6 KHZ. The width of the pulses vary from narrow to wide and back to narrow in each half cycle; this pulse width being proportional to the transistor on time and to the equivalent rms AC voltage at that moment in time. The control circuit adjusts the transistor conduction time based on the information received from the voltage and current feedback loops to maintain output regulation. The driver network is a parallel power or darlington transistor array used to provide the current source necessary to drive the MEW& The positive and negative pulse train is then coupled from primary to secondary of a linear output transformer. A small LC filter with harmonic traps removes the odd order harmonics from the pulse train to create a sine wave.

PWM inverters offer many advantages when used in computer room applications, including high efficiency due to the use of IGBTs and a linear output transformer, small physical size, low cost and rapid response to transient load changes. Disadvantages include limited fault and short circuit current availability (due to the output transformer being linear, a downstream short will be felt on the primary and subsequently the IGBT's; the inverter will shut down to protect the transistors), complex circuitry, high parts count and intolerance to environmental extremes. These items can contribute to lower long term system reliability, which is a major concern in an industrial facility, based on user philosophy and load architecture. When used in a computer room application, the advantages outweigh the disadvantages because size, cost and heat dissipation are more critical issues than long term reliability, primarily due to the relatively short useful life of the computer equipment itself.

Ferroresonant inverters, as shown in **Figure 7**, are often referred to as a passive regulators. Instead of using active feedback and control, regulation and current limiting are an inherent characteristic of the transformer design. The Ferroresonant transformer (sometimes referred to as a regulating or constant voltage transformer) is the heart of the ferro inverter. The integrity of the transformer design and quality control associated with its manufacture have a direct impact on inverter performance and reliability.

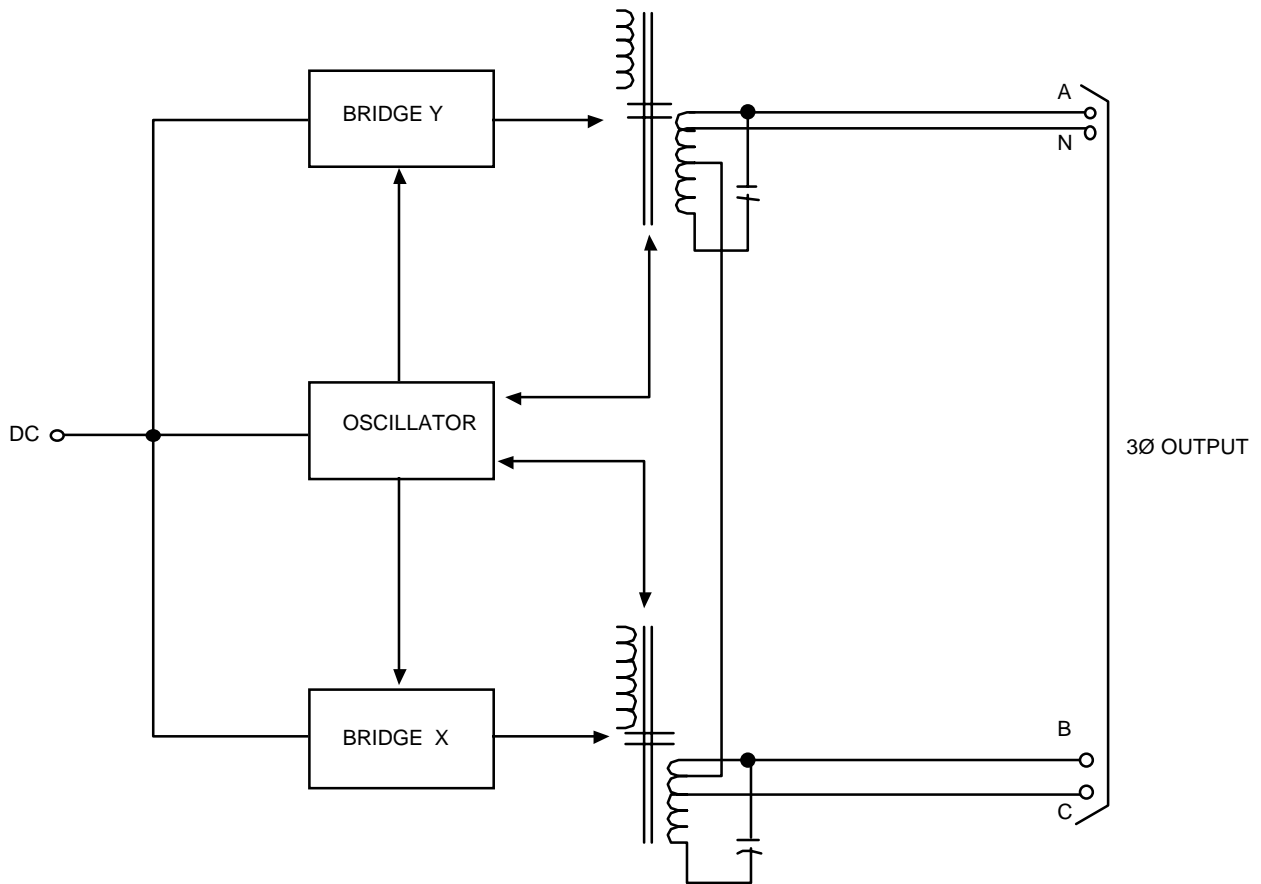


Figure 7 3Ø Scott Inverter using single phase ferroresonant transformers

The control and bridge circuits in the Ferroresonant inverter consist of a simple square wave generator, traditionally using SCR's, however, some designs now incorporate IGBTs. This square wave is then driven into the primary of the Ferroresonant transformer. The Ferroresonant transformer is non linear, designed to operate in the saturation range of its operating curve. The square wave produced by the bridge saturates the transformer core, therefore, the resultant leakage reactance rounds off the comers during coupling from primary to secondary, creating a "pseudo sine wave". A tuned LC circuit is then employed to maintain the transformer in a resonant state. Harmonic traps are designed to limit the 3rd, 5th, 7th, etc. odd order harmonics resulting in a distortion free sine wave A compensation winding is used to tighten the regulation of the transformer.

The primary disadvantage of ferroresonant technology is size and weight, and to some extent cost in the higher Power ranges. This is due to the mass of the ferroresonant transformer itself Historically, criticism has also involved audible noise and efficiency, although the new generation IGBT inverters have bridged that gap tremendously. Audible noise and efficiency are now approaching PWM levels.

Low parts count, hence, inherent high reliability and ease of maintenance make ferroresonant inverters a preferential choice for industrial applications in addition the tuned circuit in the transformer secondary stores energy which can be tapped into for downstream fault clearing (most industrial ferroresonant inverters can deliver 500% of their rating for 1 cycle prior to current limit). This energy can also be used to meet the demand for non-linear current, resulting in lower distortion in the output waveform when the loads are predominately non linear. Since the transformer is a current limiting device, it can continue to run when connected to a bolted short circuit. In summary, the transformer can tolerate a great deal of abuse, both operationally and environmentally without degradation in performance.

Single Phase Or Three Phase?

Most industrial inverter/UPS manufacturers offer single phase output systems to at least 50 KVA and some as large as 100 KVA. In the commercial arena, above 15 KVA the offering will undoubtedly be three phase. Since industrial control systems invariably constitute a 120 VAC single phase load, it makes sense to offer single phase inverters large enough to accommodate even the largest systems. Three phase UPS systems normally consist of three smaller single phase inverters connected in wye configuration with the 120 degree phase shift between phases derived from the control circuit. This can lead to downstream fault coordination problem, particularly at lower power ratings, when feeding single phase distribution because only a third of the inverter's total fault rating is available to any single phase branch fault. When a single phase inverter is used, its total fault rating is available, effectively lowering the source impedance.

Reflected harmonic current from non-linear loads can also cause problems for three phase inverters. Theoretically, in a balanced three phase system the neutral current should be zero, however, non linear loads can induce current in the neutral due to reflected harmonic current (primarily 3rd, 5th, 7th and 11th harmonic) even if the phase current appears balanced. This coupled with the high impedance of the inverter can cause voltage distortion in the output waveform. This effect can be significantly reduced through the use of a Scott '17' output connection rather than a wye because the triplen harmonics are in phase with one another and effectively cancelled, eliminating the 3rd harmonic as a problem.

Static Transfer Switch

The static transfer switch is a critical component with respect to load "uptime" as it allows an unbroken transfer of the load from inverter to alternate source and vice versa in the event of overcurrent, inverter failure or removal of the UPS from service for maintenance.

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Two types of static transfer switches are commonly employed in on-line UPS systems today. Many commercial systems utilize a static wraparound arrangement as depicted in **Figure 8**, where the load current is normally carried

by a conductor under normal operating conditions, This conductor is bypassed by SCR's with momentary ratings that conduct only while the conductor is moving from one point to the other. The alternative to this is a load rated static switch, depicted in **Figure 9**, where SCR's carry the load at all times. The primary advantage of the static wraparound configuration is &M it eliminates the losses that would normally be incurred due to forward voltage drop across the SCR's in the load rated version. This can contribute up to 2% in overall increased efficiency there is also a slight cost advantage, although the control complexity will be about the sane. The disadvantage is that since the SCR's in the static wraparound are rated to carry load current on a momentary basis, they are subject to premature failure due to thermal stress.

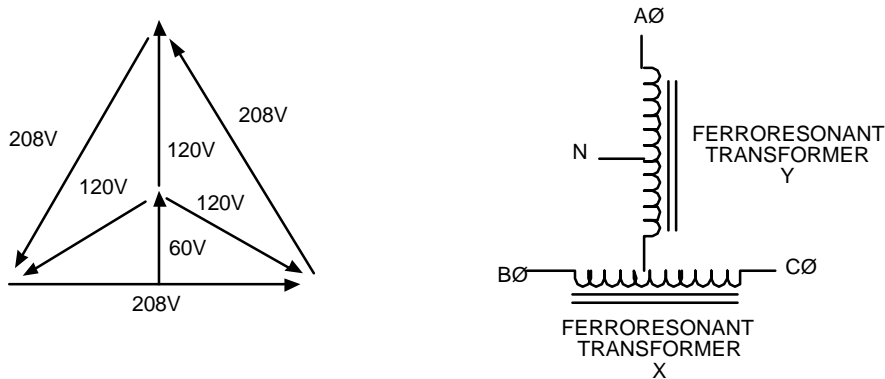
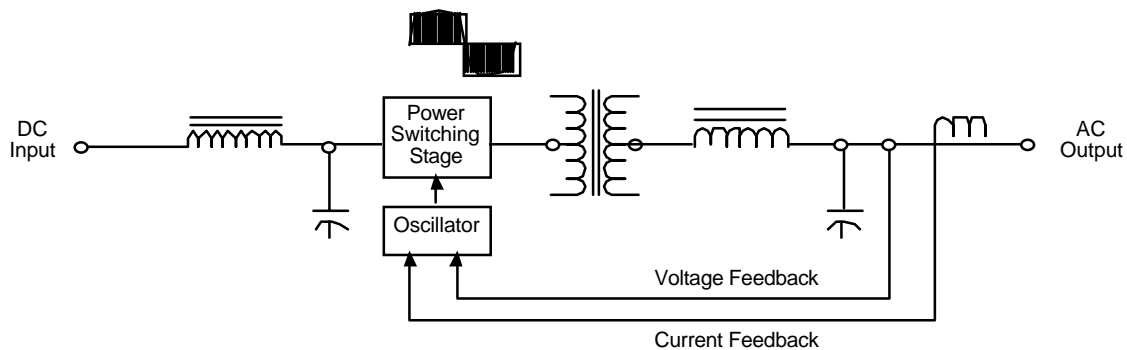


Figure 8 Scott Transformer Connections

Other items to consider in the static switch, which may or may not be addressed in commercial UPS systems, include:

- 1) Voltage AND current sensing for initiation of transfer. Some transfer switches are voltage sensing only, a less costly method but also can result in loss of the load on transfer.
- 2) Crest factor logic should be employed to prevent the static switch from being 'fooled' by the peak current induced by some non-linear loads.
- 3) The SCR gate drive circuitry should be isolated from the power circuitry, either optically or otherwise, to prevent misfiring of the SCR's due to noise.



Mean Time Between Failure (Mtbf)

Most UPS manufacturers publish System MTBF figures ranging from 100,000 to as much as 3,000,000 hours. It is important to note that System MTBF takes into account the static switches' capability to transfer the load to alternate source in the event of a problem. In laymans terms, it means "loss of the critical bus". What this implies is that if an inverter failure occurs and the static switch makes a successful transfer of the load to the alternate source, a failure really hasn't occurred. This is a meaningless specification as it is nearly impossible to prove. A much more

meaningful specification is Component MTBF, or reliability of the rectifier/charger, inverter, static transfer switch, battery, etc. as independent components. The System MTBF figures sound impressive, but if the load is on bypass due to an inverter failure, the operation is vulnerable. In reality, the highest failure rate can be attributed to the static inverter as it utilizes semiconductors in power switching circuitry, therefore, the UPS reliability becomes a function of the inverter reliability.

Battery

The battery system is also a critical component of the UPS as it provides the energy storage to operate the inverter during a loss of primary power. Several types of batteries are employed in UPS applications. These include nickel calcium, flooded cell lead acid and valve regulated lead acid.

Nickel cadmium batteries are quite expensive but perform well when wide operating temperature range is anticipated. Their use is normally limited to applications where operating condition warrant this capability. Flooded cell lead acid batteries are reliable and offer a fairly long service life (up to 20 years) with the disadvantage being that they outgas hydrogen, require routine maintenance and can be fairly large physically. Valve regulated batteries are very popular for UPS systems because they don't outgas, can be oriented in any direction (making installation flexible) and they are fairly cost competitive. The disadvantage is that they have a short useful service life and they don't tolerate high temperature well.

Commercial UPS manufacturer's favor the use of valve regulated batteries because for their physical size and installation flexibility as well as low cost. Unfortunately, the batteries are frequently installed inside the UPS cabinet, which dissipates heat and effectively shortens the battery life. Industrial UPS systems treat the battery as an external entity to minimize the temperature problem. Since the computer room UPS will be installed in a controlled environment and will likely be replaced at 5 years of age, they can provide adequate performance in that applications. An industrial UPS application that will be in service 15 to 20 years would benefit from the use of a flooded cell battery if it can be accommodated. Battery life and reliability can be enhanced significantly by controlling the temperature and providing adequate maintenance.

Summary

In conclusion, there are many things to consider when specifying a UPS for industrial applications, only a few of which have been covered here. We've learned that industrial UPS systems generally have a high initial cost than their computer room counterparts. They are also more reliable and will be serviceable for the life of the plant. A cost justification based on the 15 to 20 year plant design life will show the cost of ownership for the industrial unit to be considerably lower. If you factor in the possibility of one incident traceable to the UPS that causes plant down time it becomes a foregone conclusion that spending a little more on the front end can save a substantial amount of money in the long run.