Working definitions of terms: Commercial vs. Industrial UPS Systems:

On-Line, Uninterruptible Power Systems (abbreviated: *UPS*) have been available for almost 40 years. The UPS market for On-line UPS covering capacities between: 5 – 150 kVA is still growing at 12% annual rate as Business and Industry become more dependent on the continuous flow of digital data.

According to Frost & Sullivan, almost 8 out of 10 UPS systems (>80%) produced now are designed for Information Technology applications. It is not surprising that Industrial UPS specifiers have a difficult time identifying the critical differences between Commercial and Industrial UPS equipment.
In general, the application universe for On-Line UPS systems can be broken into three (3) broad segments:

(1.) Information Technology (formerly called Electronic Data Processing) - The term *Commercial UPS* has become associated with Information Technology (IT) because the UPS and computer room are often purchased as a package from construction contractors. The bidding specifications for IT UPS equipment are not technically demanding and typically require only safety certification to UL or CSA. The Data Centers in banks, hospitals and insurance companies are examples of typical IT UPS applications. The interruption of AC power may disrupt data processing and telecommunications, but does not create an inherent risk of injury to people or property.

(Note: There are specific UL safety standards for safety-related UPS such as emergency lighting UPS or medical diagnostic equipment, but the UL standards are primarily safety focused and do not address UPS performance testing or designing for reliability.)

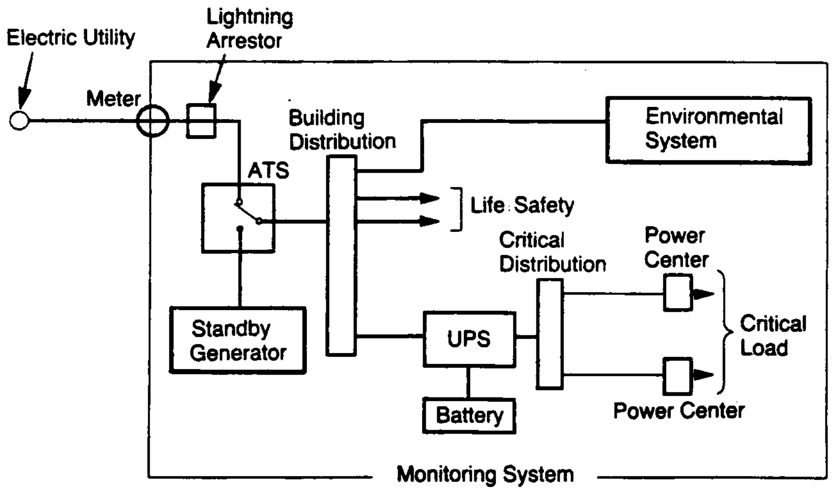
(2.) Critical Process Control - Over the years, UPS systems designed for Critical Process Control applications have earned the name: *Industrial UPS.* In these types of applications, the interruption of AC power may cause dangerous chemical process instability, or cause expensive damage to the processing systems. Petrochemical Complexes and Electrical Power Generation Plants are good examples of operations that use chemical or steam processes that can become dangerous if control power is interrupted. Because of the risk resulting from the loss of control power, UPS systems intended for Industrial applications must be designed and performance tested to a more rigorous level than commercial equipment.

(3.) General Process Control - There are applications that fall into a middle ground that we will label as *Light Industrial.* These types of applications have processes that are not inherently dangerous, even if AC power is interrupted during process operation. However, in these processes, the failure of the UPS to supply continuous AC power may result in loss of finished products or in hundreds of man-hours resetting the production equipment. Pharmaceuticals and the Food & Beverage Industries would be examples of Light Industrial classifications.

Some of the major application-driven differences between the IT UPS (Commercial) and Process Control UPS (Industrial) are summarized in **Table 1:**

Evaluation Factors		**IT – Commercial UPS**	**Industrial UPS**
A	**Electrical – Surge Levels & EMI/RFI**		
a1	On the AC Mains to Rectifier/Charger	Low Levels in IT Data Centers	Surge & EMI/RFI Levels can be high
a2	On the UPS Static Bypass Input	Low Levels in IT Data Centers	Surge & EMI/RFI Levels can be high
a3	On the DC Input - Battery	Dedicated Inverter Battery, no external connection	Power Gen. UPS often connected to Station Battery High DC Transients
a4	Input Isolation Transformer	Not usually specified for IT use	Usually Specified in Industrial setting
B	**Physical Environment – UPS Area**		
b1	Ambient temperature range	25 – 35 Degrees Celsius	15 – 55 Degrees Celsius
b2	Air Humidity	10 – 55 % RH	10 – 95 % RH
b3	Air Contaminants	Very Low Levels found in Office Buildings & Data Centers	Often very dusty, sometimes corrosive air contaminants also
C	**UPS Static Switch Design**		
c1	Full Electronic vs. Hybrid Configuration	Hybrid - electromechanical	Full Electronic – SCR devices in both Inverter & Bypass poles
c2	Sustained Load Fault Clearing on By-pass	Damage to static switch under fault at critical load	SCR devices are sized for worst-case bypass fault current.
D	**UPS Failure Contingency**		
d1	Static Switch Power Supply failure	May drop critical loads	Static Switch Fails to Bypass *Source*
d2	Control Microprocessor Failure	May drop critical loads	Static Switch Fails to Bypass *Source*
d3	Spare parts & Obsolescence	generally – 5 to 7 yr. Product Life	15 –25 yr. support required
E	**Manual Bypass Scheme**		
e1	Drum Switch vs. Circuit Breaker	Circuit Breaker Only	Drum Switch – zero break
e2	Independence from Static Switch	Needs Static Switch for zero-break transfer	Independent of Static switch
F	**UPS Battery**		
f1	Design Life	VRLA – 5 years	VRLA & Flooded – 20 years
f2	Support time Range	15 – 30 minutes	60 – 480 minutes
f3	Depth of Discharge / End Voltage	90% - 1.65 volts per cell	60 -80%, minimum 1.75 vpc
	Battery Re-charge Time to 90% of Original Capacity	Not usually specified, because battery time is less than 1 hour	Battery Chargers are sized to achieve 8 hour recharge
G	**100 % Performance Testing**	Not usually required. Type test data submittal accepted	Certified Test Data per NEMA PE-1, NEMA PE-5, IEE-944, IEC-146
H	**Equipment Design Life**	5 – 7 Years in IT Data Centers	10 - 15 Years in Petrochemical 15 – 30 Years in Power Gen.
I	**Inverter Technologies**	PWM Inverters Dominate	Split between Ferroresonant and PWM Inverters

EMI/RFI & Electrical Surge Levels – IT Applications vs. Industrial:

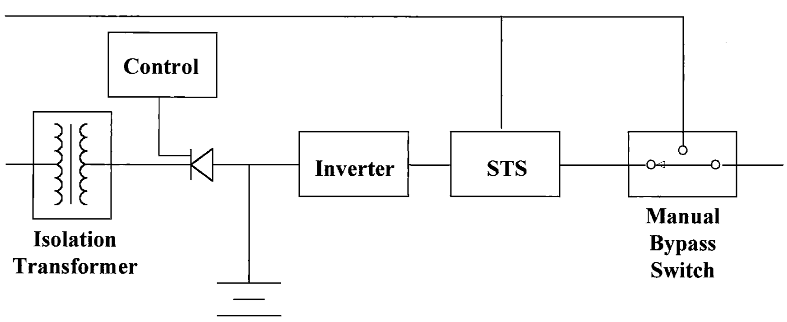


A typical IT Data Center is represented above in **Fig. 1**. We can see from the diagram that IT Data Centers are EMI/RFI-Surge protected environments. The IEEE Orange & Emerald Books recommend not only Lightning Arrestors, but also Delta-Wye transformer isolation on the UPS mains. The design of the Data Center's AC power distribution system protects the UPS from the effects of incoming EMI/RFI (electromagnetic & radio frequency interference) on the AC Mains and Bypass Input feeders.

The use of dedicated input power feeders, with the isolation transformers, not only reduces EMI/RFI, but also reduces the available fault current at the UPS AC mains. Competitive pricing pressure and the protected IT electrical environment sometimes justify the omission of the input isolation transformer in the rectifier section. The Specifying Engineer should carefully evaluate the UPS electrical environment, particularly in an industrial application, to make sure that a rectifier input isolation transformer is not required.

Fig. 2 below shows the Industrial UPS rectifier section with an input isolation transformer. In some Industrial applications, the UPS AC input power is fed from Switchgear or Motor Control Centers (MCC) and often shares bus connections with electrically noisy loads such as variable speed drives. An input isolation transformer may be necessary the Industrial UPS environment to protect the UPS from the effects of power feeder surges and RFI/EMI.

Fig. 2 - UPS with an Rectifier Section Isolation Transformer



UPS Environmental Considerations are often driven by the Application:

Many Industrial UPS environments, particularly those in Power Generation applications, have higher ambient temperatures, (i.e. > 30^{O}C.) and particulate contamination of the air. Industrial UPS equipment is designed to tolerate moderate amounts of non-conductive dust and high ambient air temperatures of at least 40 C. and usually has an optional design for 50^{O}C. ambient temperature.

Geothermal Power plants often produce as a process byproduct sulfur dioxide gas. Sulfur dioxide gas forms dilute sulfuric acid when combined with moist air. Industrial UPS systems designed for Geothermal Power applications will have epoxy-coated or nickel-plated copper bus bar, special anti-corrosion terminal connections, and acid resistant metal surface coatings. In extreme cases, the cooling air to the UPS cabinets is brought in from a clean (or scrubbed) source at a positive pressure and exhausted out of the cabinet tops to keep atmospheric pollutants out of the UPS interior spaces.

In contrast, the IT UPS environment is almost always temperature controlled at 30^{O}C. and kept very clean. The service life of any UPS system is reduced by operation in high ambient temperatures. The critical UPS component most affected by high ambient temperatures is the UPS battery, but other internal UPS components, such as DC bus filtering capacitors, may have their service life shortened by high ambient temperatures unless special high-temp capacitors are selected.

In the IT UPS applications, the UPS Specifier may not require long UPS service life, but in critical process control, a UPS service life of 15-20 years is often specified. Industrial UPS systems have built-in design margins to preserve the operation life in less than perfect environments. In addition, Industrial UPS equipment will also have predictive parts replacement programs to insure high UPS MTBF over the entire 15-20 year service life.

UPS Static Switch Designs – Hybrid vs. Full Electronic Static Switch Types:

Figure 3 A – An IT UPS with a typical Hybrid (Wrap-Around) Static Switch

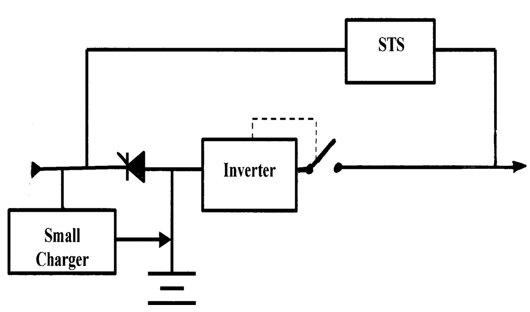


Figure 3 B – Detail of a Hybrid (Wrap-Around) Static Switch

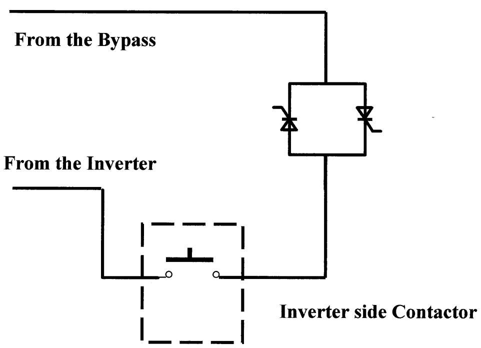


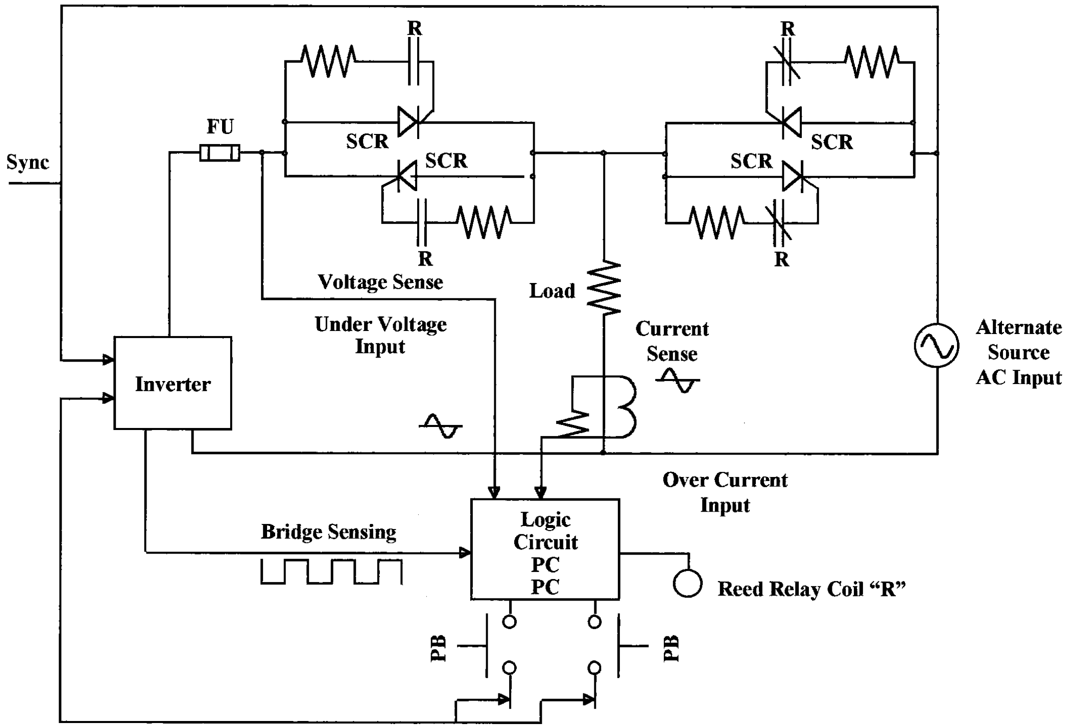
Fig. 3A on page 4, and **Fig. 3B** above, show the placement and construction a hybrid Static Switch (also called a wrap-around static switch). The hybrid static switch configuration is very commonly used on IT UPS systems. Only the Bypass pole of the static switch has the inverse-parallel SCR (Silicon Controlled Rectifier) pair for electronic power switching. The Inverter side of the hybrid static switch uses a power relay (contactor) with normally open contacts to disconnect the inverter from the bypass during the normal static switch critical load transfer operation. Contactors are not as reliable as SCR devices, especially if the Inverter is exposed to repeated load faults.

Under critical load fault, downstream of the UPS output, the short circuit current is limited only by the impedance of the bypass source. The high fault current levels can weld the contactor's electrical contacts closed. If the UPS hybrid static switch contactor contacts fail to open, the UPS output will be connected continuously to the bypass source. UPS Inverters, especially some PWM Inverters, are not designed to have their AC outputs back-fed from the Bypass for more than 30 – 50 milliseconds.

Industrial UPS systems use SCR devices on both the Inverter and bypass poles. Industrial UPS designs do not use the inverter side contactor, but instead use an additional inverse-parallel SCR pair. This modification to the hybrid static switch is, of course, a more expensive design feature, but the elimination of the contactor increases the static switch reliability. The MTBF (mean time between failures) of the UPS is linked to the reliability of the static switch because the static switch is directly in the power path between the Inverter and the critical load.

On the top of page 6, **Fig. 4,** is an elementary schematic of a fully electronic static switch. As we mentioned before, using SCR devices on both poles of the static switch creates a more reliable power path by eliminating the inverter-side electromechanical power contactor. An additional benefit is the switching flexibility added by the bypass-side SCR devices. Some Industrial UPS systems have two static switch transfer modes depending on the state of Inverter and Bypass phase synchronization. If the Bypass and Inverter are in phase synchronization, the static switch performs an overlapping (make-before-break) transfer. If the Bypass and Inverter are not phase synchronized, and the UPS load exceeds the Inverter capacity, the static switch will perform a 0.25 cycle break-transfer to prevent the creation of out-of sync circulating current. This type of dual mode static switch switching flexibility would be impossible without a fully electronic static switch.

Figure 4 – Fully Electronic, Industrial Static Switch



UPS Contingency Design Analysis:

Contingency Design analysis is the examination of how the UPS behaves when the unexpected happens? For example: Suppose the internal power supply to the static switch control board fails. Is the static switch fail safe? Specifically, will the static switch transfer smoothly to the bypass source upon a static switch control board power supply failure? In many IT UPS systems, the answer is: No! If the power supply fails, the static switch, if it is not a true fail-safe design, can not transfer the critical UPS load because the SCR gate drive no longer has the power necessary to operate correctly.

Few IT UPS systems use fail-safe static switch designs. Very commonly the SCR gating circuits in the hybrid static switch are triggered by opto-couplers which require external power to develop the SCR gate trigger pulses.

In a fail-safe static switch design, the static switch SCR devices derive their gating power from the load current. SCR gate drive reed relays with magnetic bias are set up so that the Bypass side SCR devices are gated on by the normally closed reed relay contacts. In a fail-safe static switch, a power supply failure will force the UPS to transfer the critical load from the Inverter to the Bypass.

It is common these days for UPS equipment to use microprocessor control. Unfortunately, unless careful thought is given as to how to limit the scope of microprocessor control, single point failure mode creates a problem if the microprocessor fails. In UPS designs that have not considered single point failure modes, the failure of the microprocessor results not only in the sudden loss of UPS output, but also the failure of the static switch to transfer of the critical load to the bypass.

In an Industrial UPS design, single point failure modes are carefully considered and eliminated if at all possible. In a well designed, microprocessor-controlled UPS, both internal and external watchdog circuits monitor the microprocessor's calculations continuously. If a microprocessor error is detected, the Industrial UPS, with its independent and fail-safe static switch, immediately transfers the critical UPS load to the Bypass.

The Manual Bypass Switch (MBS) gives the maintenance personnel the ability to place the critical UPS load on the Bypass source intentionally for UPS service. In an IT UPS, the manual bypass function is usually performed with a circuit breaker. The load to bypass transfer is first accomplished via the static switch and then sealed or jumpered by closing the manual bypass breaker. While this seems like a simple bypass method, it depends entirely on the proper operation of the UPS static switch. If the static switch is not operational, the manual bypass operation via the manual bypass breaker will not work as intended.

The Industrial UPS uses a make-before-break rotary drum switch. The manual bypass switching is completely independent of the static switch operation. In some Industrial UPS designs, the manual bypass switch has additional power switching contacts that isolate the static switch from the Bypass and Inverter to facilitate maintenance access.

UPS Batteries & Chargers:

In general, IT UPS applications specify valve-regulated, lead-acid batteries in the 10 – 30 minute ranges. Because the IT UPS Battery support times are usually not as long as those used in Industrial applications, charger capacity is usually not given much attention. The UPS battery chargers in the IT marketplace are typically sized to re-charge a 15 -30 minute lead-acid UPS battery to 95% capacity in 8-10 hours.

In contrast, in Industrial applications, the charger capacity often has to be much larger because the battery support times can range from 60 minutes to 8 hours or more. The UPS specifier needs to check to make sure the UPS system being considered has enough battery re-charge capacity built into the Charger, especially in Industrial applications like Power generation that typically use 4-8 hour UPS Batteries.

It is common in IT UPS applications to discharge the lead-acid UPS Batteries more deeply, usually to the end of discharge voltage of 1.65 volts per cell. In contrast, Industrial UPS systems will use a higher end voltage of 1.75 volts per cell. Discharging the UPS Batteries to a lower end voltage will remove more energy from the cells and result in a smaller UPS battery. Keep in mind that deeper cell discharge reduces the service life of the UPS batteries. Lead-acid cells, especially the less expensive 5-10 year service life cells, are very sensitive to depth of discharge. The UPS specifier needs to carefully weigh the consequences of reduced battery service life when lead-acid UPS batteries are discharged below 1.75 vpc.

Equipment Design Life – matching UPS service life to the critical process service life:

Industrial UPS equipment will have design margins built into its components so that the UPS system will have >100,000 hours of MTBF when operated in typical Industrial environments. There are components like cooling fans and DC capacitors that degrade with time, even with conservative design practices. Industrial UPS users such as Power Generation plants commonly specify UPS service lives in the 20 – 30 year life spans. Petrochemical UPS specifiers have a shorter time horizon usually in the 10 –15 year range, but, in general, the Industrial UPS specifier is looking for a longer UPS service life because the process drives the decision.

Industrial UPS suppliers will have documented component replacement schedules – components like cooling fans and DC capacitors – so that the UPS MTBF can be maintained over the 20-30 year service life. True Industrial UPS suppliers will have spare parts replacement programs that support older UPS equipment in the field. Industrial UPS suppliers, because they have to support their older UPS equipment, will have field data available to support their UPS MTBF figures in their data sheets.

Industrial UPS suppliers will keep UPS models around for longer intervals and tend to avoid product obsolescence because they are geared to support the older UPS systems in the field. Backward compatibility of UPS components is always an important design issue with an Industrial UPS supplier.

In the Commercial UPS marketplace, UPS models tend to become obsolete in 5 years. Today, the longevity of a typical Data Center -driven mostly by data technology change - is less than 5 years. IT UPS suppliers who know their marketplace very well, tend to concentrate their design efforts on making next year's model cheaper, smaller, and more efficient. Rapid IT UPS product obsolescence makes long term support of older UPS equipment in the field very difficult.

The Industrial UPS specifier should be aware of the long-term support issues when selecting a supplier. When one considers the life-cycle costs of a UPS, especially in large process applications, an Industrial UPS design, with a scheduled critical parts replacement program, is a much lower cost solution that UPS replacement.

Inverter Technologies – Ferroresonant & PWM

Ferroresonant Inverters have been used in Industrial applications for almost 40 years. These Inverters are still preferred for the really demanding UPS applications (such as in nuclear power) because of their power circuit simplicity and inherent fail-safe design. Please refer to the Solidstate Controls application paper: **Sizing a UPS System for Non-Linear Loads** for more information about Ferroresonant & PWM Inverter technologies.

PWM (**P**ulse-**W**idth-**M**odulated) Inverters have become more acceptable to Industrial UPS Specifiers over the last decade due to improvements in the reliability and switching speed of the IGBT power transistors. Please note that regardless of the Inverter technology selected, Industrial UPS equipment will always be more expensive than Commercial UPS equipment because their applications, as we have explored in this paper, are very different.