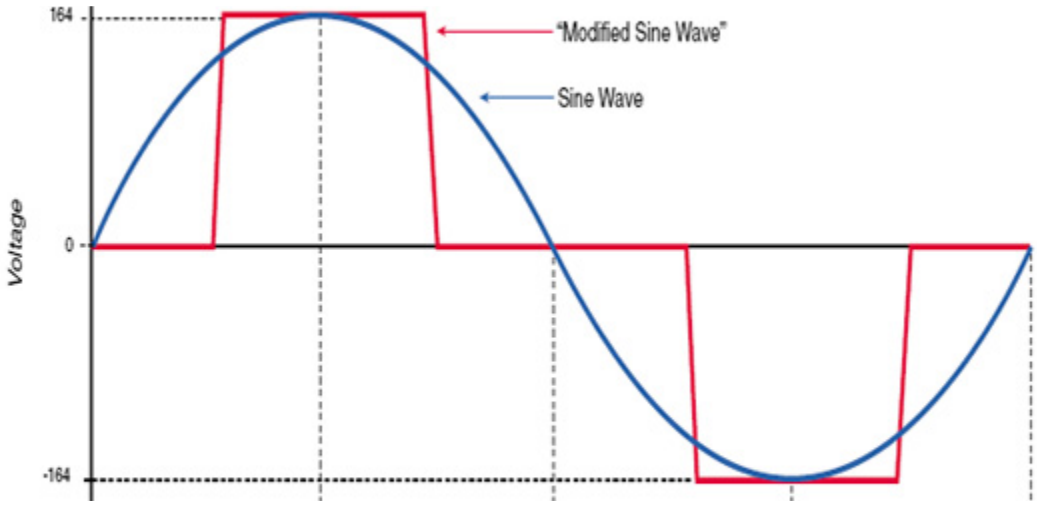
Static UPS Topology 101



Double Conversion

LINE INTERACTIVE

Standby / Off-line

By Robert J Walker

Executive Summary

UPS technology comes in many forms. The major technology differences start with either static UPS or rotary UPS. Within each of those categories there are multiple types of technology and significant differences in what the technology provides. One thing all systems called “UPS” have in common is some form of stored energy. For the sake of this paper please consider this an entry level understanding with a focus on “Static” technology UPS systems with some detailed information on the latest generation component advancements.

Who we are

Facility Gateway Corporation is not a manufacturer of any UPS systems; we specialize in Critical Infrastructure Data Center Design, Build, and Maintenance Asset Management Services. Our experience comes from working with many brands of UPS, Generator, Switchgear, HVAC and Monitoring equipment. We are product experts with a broad range of experience.

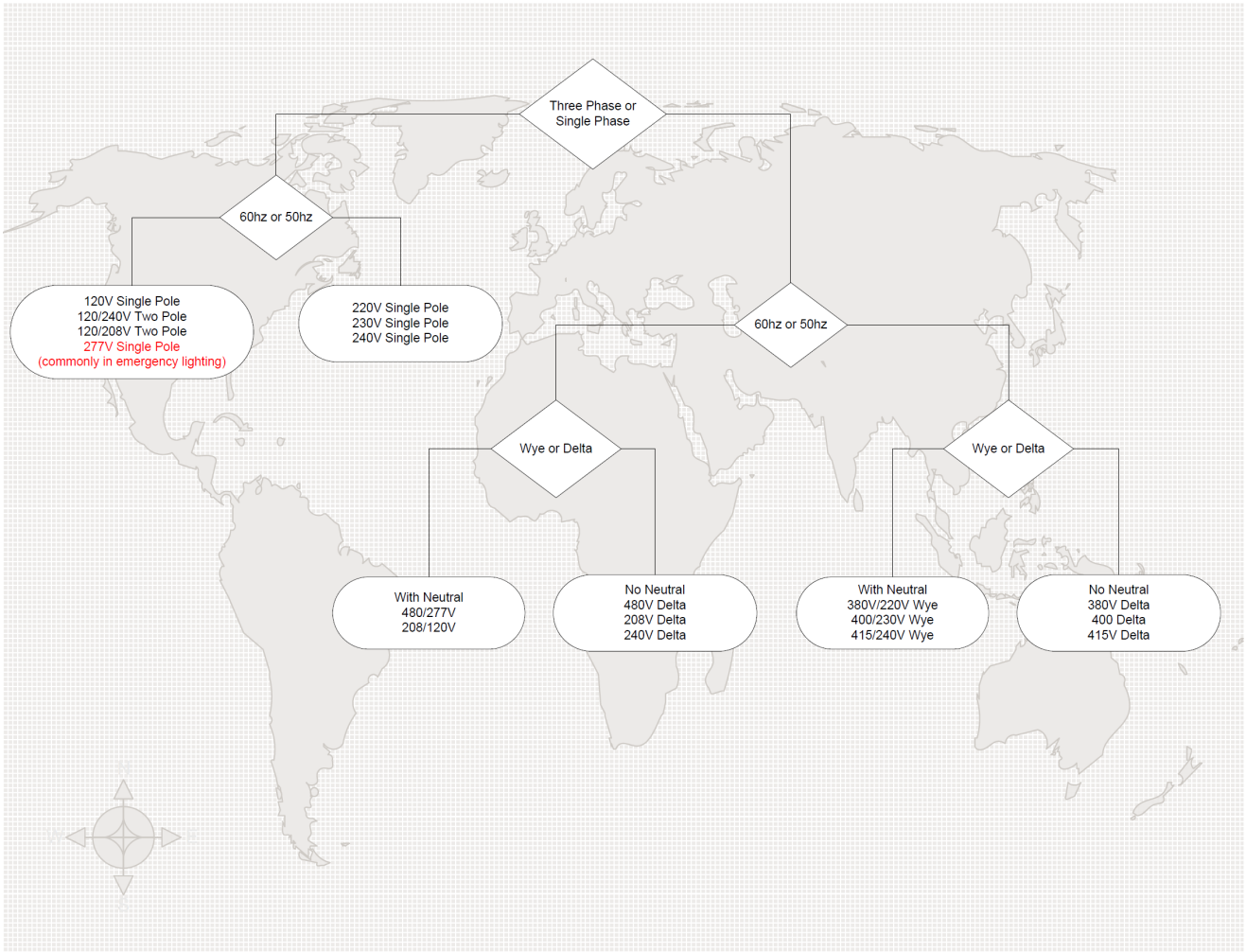
Introduction

Static UPS, the term Static refers to the use of semiconductor components that are used to convert power in a UPS back and forth between AC and DC power. Through the use of power electronics such as SCR's (Silicon Controlled Rectifiers) Transistors, and today IGBT (Isolated Gate Bipolar Transistor) we have seen this category of UPS become the dominant technology used in today's critical power applications. Due to the small foot print (which continues to shrink as technology advances) and the relative low cost these systems have proven to be very reliable, cost effective, and highly configurable.

Single Phase & Three Phase power overview

The two primary categories of Static UPS are defined by their application to either “Single Phase Power” or “Three Phase Power”. Single phase uses only 1 or 2 phases (legs) of power. Three phase indicating that 3 phases (legs) of power are used. The diagram below illustrates how we begin the selection of a UPS by first knowing the voltage. In addition to that the capacity of the system needs to be determined that value is published in kVA & kW. It is important to know both values when selecting a UPS.

Chart 1: Common Voltage



Single Phase

- Single phase systems usually provide backup for electronic devices such as a work station, server, or telephone equipment,
- Single phase UPS systems range in size from 250va up to 22kVA
- Single phase systems vary in technology from standby, line interactive and double conversion

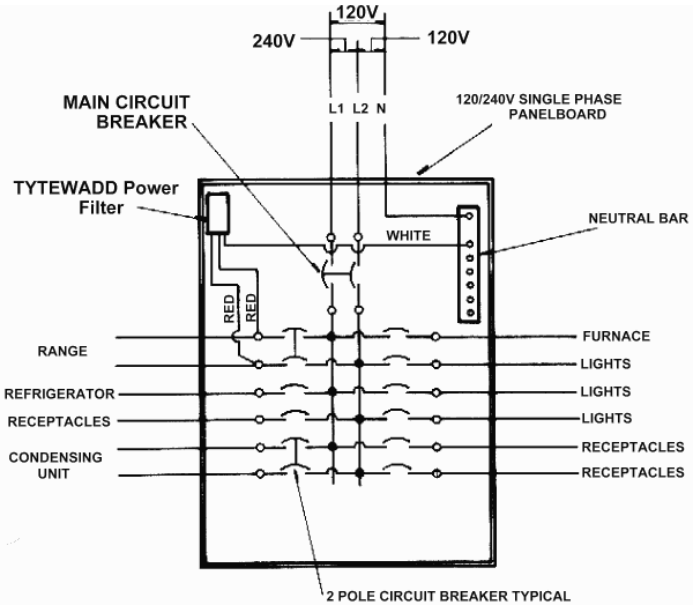


Fig 1. Typical Single Phase Panel board

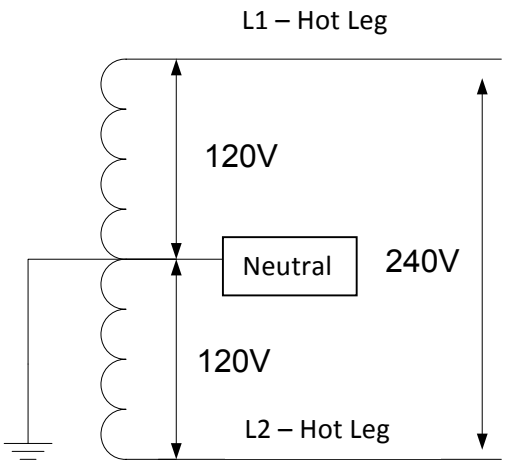


Fig 2. Typical Single Phase Transformer Output

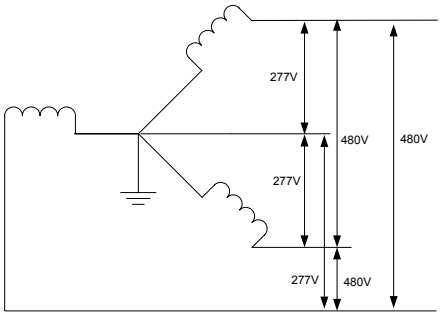
Three Phase

- Is generally more economical than one phase systems due to less conductor material used to transmit power
- Three phase systems typically fall in the range of 10kVA to 1MW modules that can be added in parallel to serve Multi-Mega Watt facilities
- The overwhelming majority of three phase systems are double conversion in technology

These are the most common types of three phase power used at the UPS level.

Fig 3. Typical Three Phase Wye used in America at 60 Hz. In many other countries this same configuration is used at different voltage levels. (430/250V 50 Hz, 420/240 V 50 Hz, 400/230 V 50 Hz & 380/220 V 50 Hz)

Three Phase Wye Power
480/277V 60hz



Three Phase Wye Power
208/120V 60hz

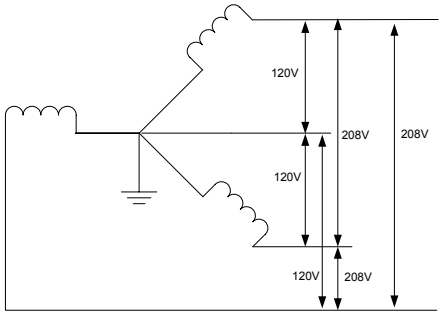
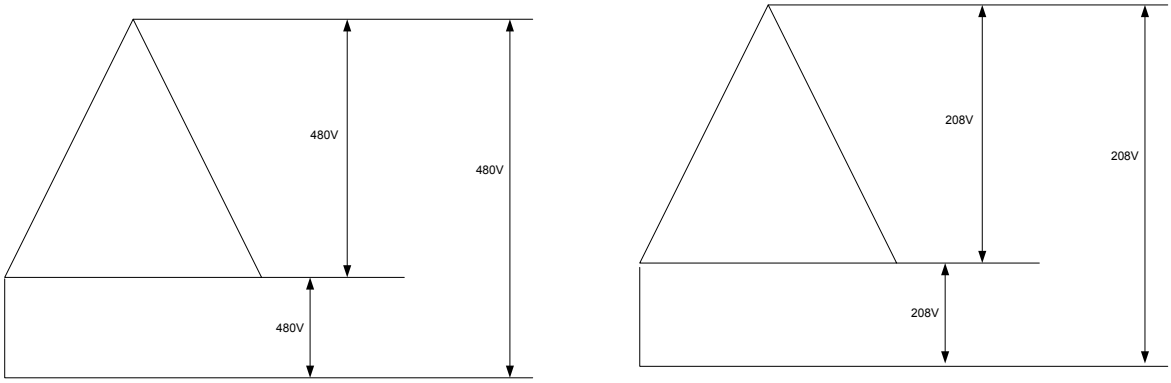


Fig 4. Typical Three Phase Delta used in America at 60 Hz.



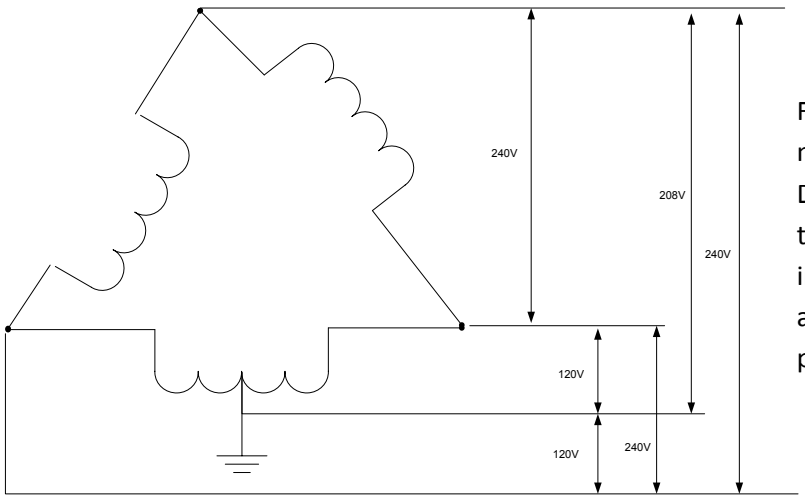
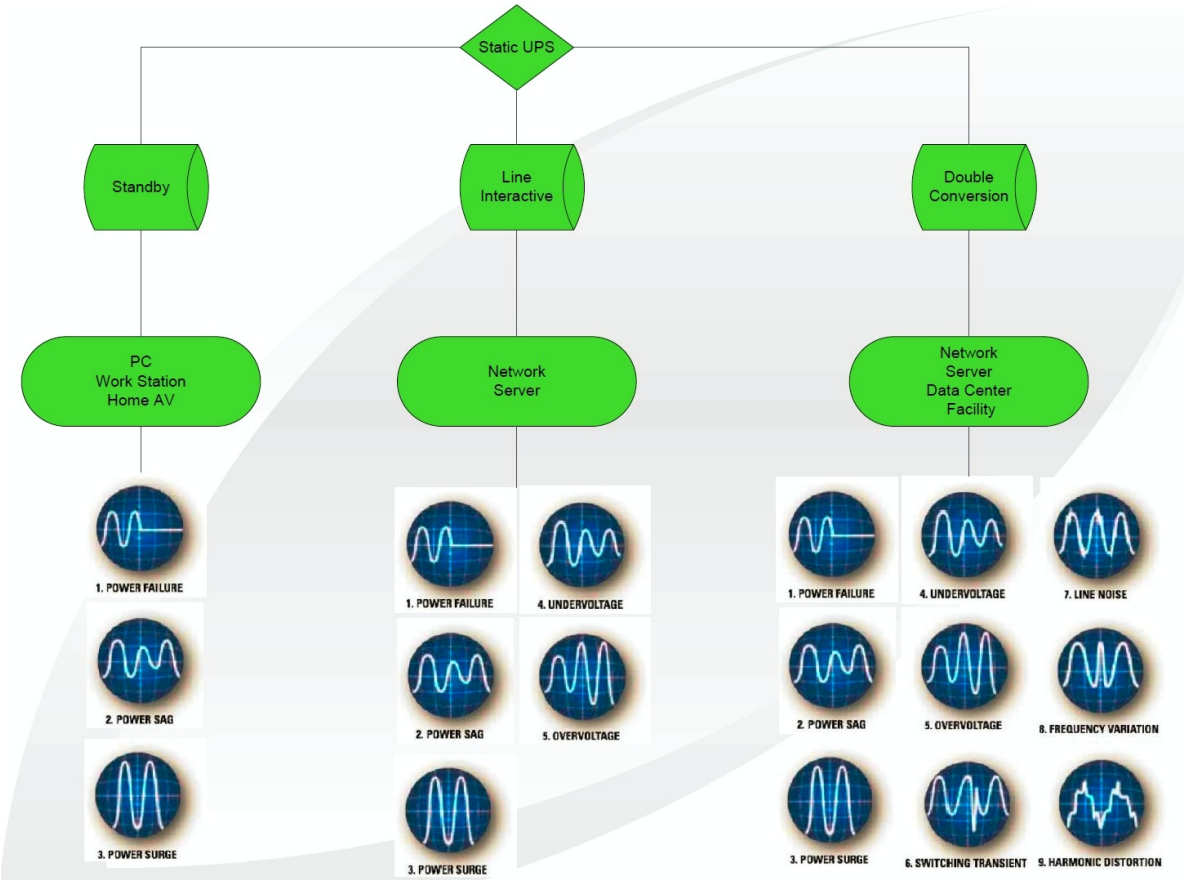


Fig 5. Not as common but still found in many parts of the USA is the 240V Delta with a High Leg. Most of the time, it is found in older electrical installations. This is an odd one to find a three phase UPS for since most three phase UPS systems are 208V or 480V.

Common Power Problems and Topology Basics

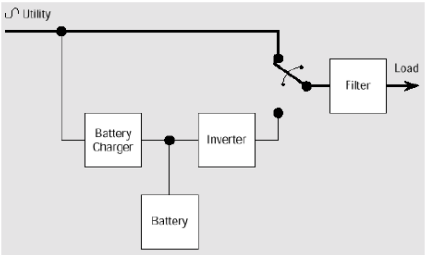
Within the single phase & three phase static UPS market there are 3 primary categories of UPS technology. The categories of “Standby”, “Line Interactive”, & “Double Conversion” are shown below in this flow chart that give a brief illustration of the common applications each type of technology is used within. In addition the illustration show which of the 9 most common power problems are corrected by each type of technology.

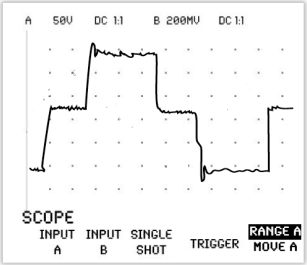
Chart 2: Static UPS Topology



Standby or off line technology (Most common in single phase UPS)

- The transition to battery power actually has a momentary break.
- This technology is typically reserved for single phase UPS systems
- This sine wave in Fig 7, was captured from the output of 650va Back-Ups standby / off line UPS.
- This is the power you are feeding your equipment when you are on battery power





Basic Solution: Protection from three potential problems.

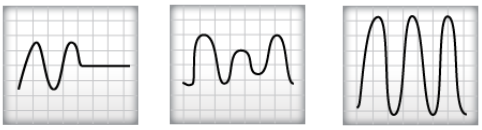


Fig 6. Standby One-line

Fig 7. Modified sine wave

- **Pros**
  - Inexpensive
  - Good for home PC and non-critical power equipment
- **Cons**
  - Short break in power 250m seconds or less
  - Square wave form which could damage sensitive equipment
  - Does not correct harmonic issues or frequency deviation
  - Must use battery to compensate for sag
  - Shorter battery life due to more discharges on the battery
  - Only Metal Oxide Varistor is used to suppress surge conditions
  - No static bypass

Line interactive technology (Most common in single phase UPS)

Moving forward to line interactive technology this is the next step up for better power protection. The key difference is that this technology has the ability to condition the output wave form without interruption to the power like the "off-line" technology does. This is done through a variety of technologies within this category of UPS. Most common is a buck boost bi-directional type of inverter/battery charger. This is the least expensive with the smallest foot print in this category. Line interactive technology provides additional power protection with the addition of two more problems that can be corrected for a total of 5 of the 9 power problems.

Another technology worth mentioning in this category would be Ferro resonant UPS technology. While a Ferro unit is technically line interactive, it actually has the ability to correct all 9 power problems. The Ferro based UPS is able to correct all 9 power problems due to the Ferro resonant transformer in the UPS which inherently provides a 250 to 1 spike attenuation, harmonic correction, and very good voltage regulation without the use of the inverter. As a result, the batteries see less discharges and the inverter sees less hours of operation which help make this a very reliable system. This is a much larger foot print UPS and more expensive due to the large copper transformer. This technology is typically reserved for only single phase UPS systems.

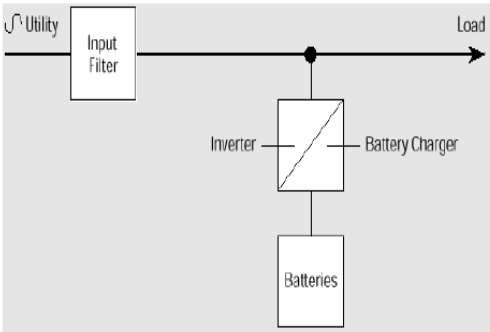


Fig 8. Line interactive one-line

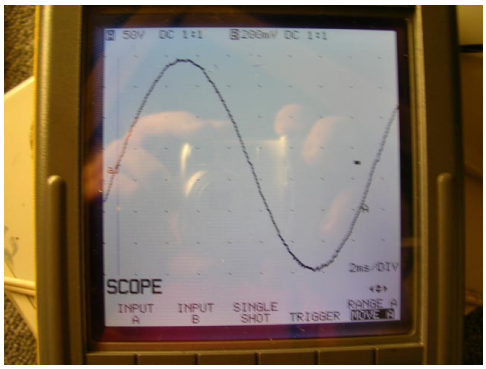
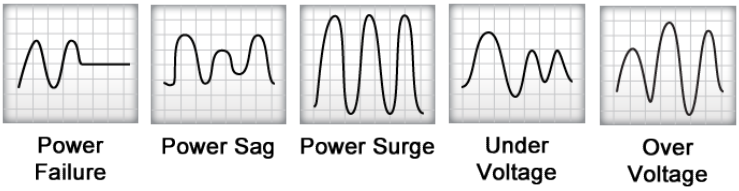


Fig 9. Line Interactive Output sine wave

This Output Wave Form was captured from a Line Interactive 700VA UPS system

Line interactive technology

Basic Solution:
Protection from five potential problems.



Pros

- Slightly better voltage regulations through use of a Buck/Boost Transformer
  - Boosts under-voltage, and bucks down overvoltage
  - If voltages exceed transformer capability, the UPS will use the battery to compensate for the condition
- Sine wave output
- Inexpensive
- Energy efficiency

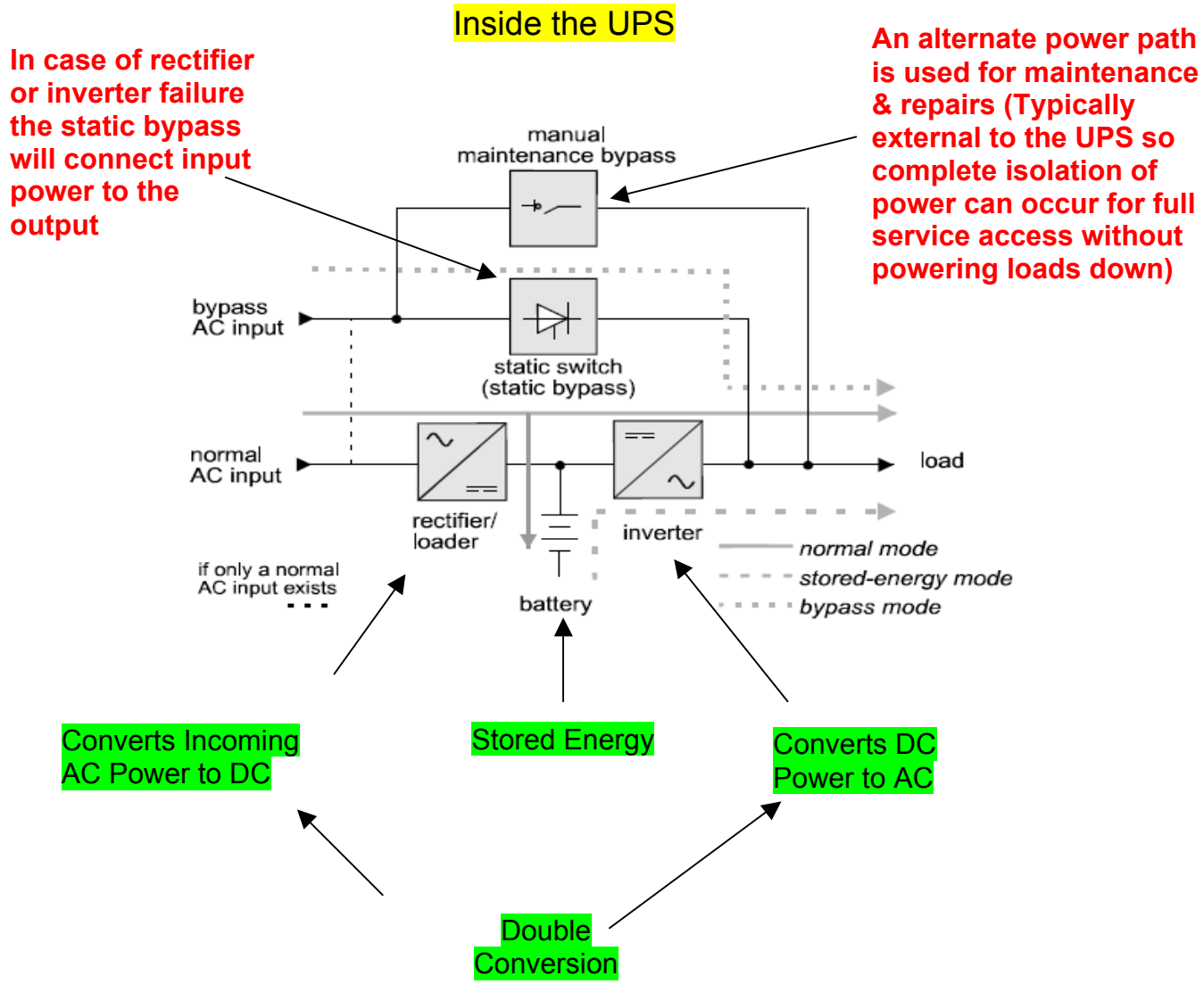
Cons

- Battery life is shortened due to their correction of power issues when on-line
- There is typically no static bypass in most models
- Does not protect against
  - Frequency deviation
  - Line noise
  - Transients
  - Harmonic distortion

Double conversion technology

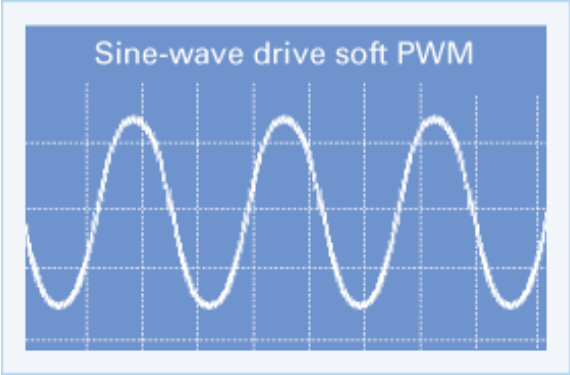
Double conversion technology is what most three phase UPS systems utilize along with your high end single phase UPS systems. The power is literally converted twice hence the name. The common components you will see in this technology regardless of brand name are the Rectifier, Inverter, and Static or Hybrid static bypass switch. Double conversion ensures that you have protection from all 9 of the most common power problems.

Fig 10. Double conversion one-line

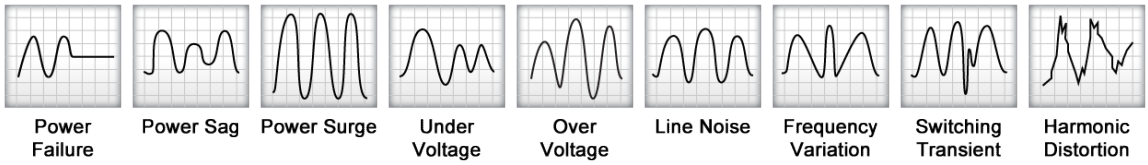


Double conversion technology

Typical Wave Form output of the Double conversion UPS with high quality Pulse Width Modulation IGBT technology.



Basic Solution: Protection from all nine five potential problems.



- **Pros**
  - Equipment is isolated from all types of power problems
  - Meets the 5% maximum harmonic requirement stated in major computer manufacturer specifications
  - Uses the battery less than other UPS technology which increases the reliability and life of the batteries
- **Cons**
  - Purchase cost is higher
  - Efficiency lower than line Interactive (Historically)

High Efficiency UPS technology

In recent years the push for better energy efficiency in the data center has had an impact on UPS manufacturers. They have been coming up with creative ways to make their systems more energy efficient. This has led to some competing ideas and technologies that deserve an overview. Our company works with multiple UPS manufactures and we have had exposure to each of these competing technologies. There are 2 primary differences that can help you categorize these high efficiency UPS's.

Energy Saver Mode

One category is often referred to as some sort of energy saving mode that takes a conventional double conversion UPS and in layman's terms operates it as a line-interactive UPS. There are slight variations with each UPS manufacturer that offers this option on their UPS systems. Essentially incoming power is passed thru the UPS to the critical load with minimal surge suppression as long as the power is within the programmed input tolerance. When input power falls out of that window the unit turns the inverter on and in many cases pulls from the battery to correct the power issue. In the event of an actual power outage there can be up to a 2 or 4 microsecond delay for the inverter to come on. The theory is that most of these systems that utilize this technology do so at 480V and have transformers downstream of them. There should be enough residual power in those transformers that the loads never see the power transition. Some of these UPS's come with internal transformers and some are transformer-less. Efficiency claims are 98% to 99% depending on manufacturer.

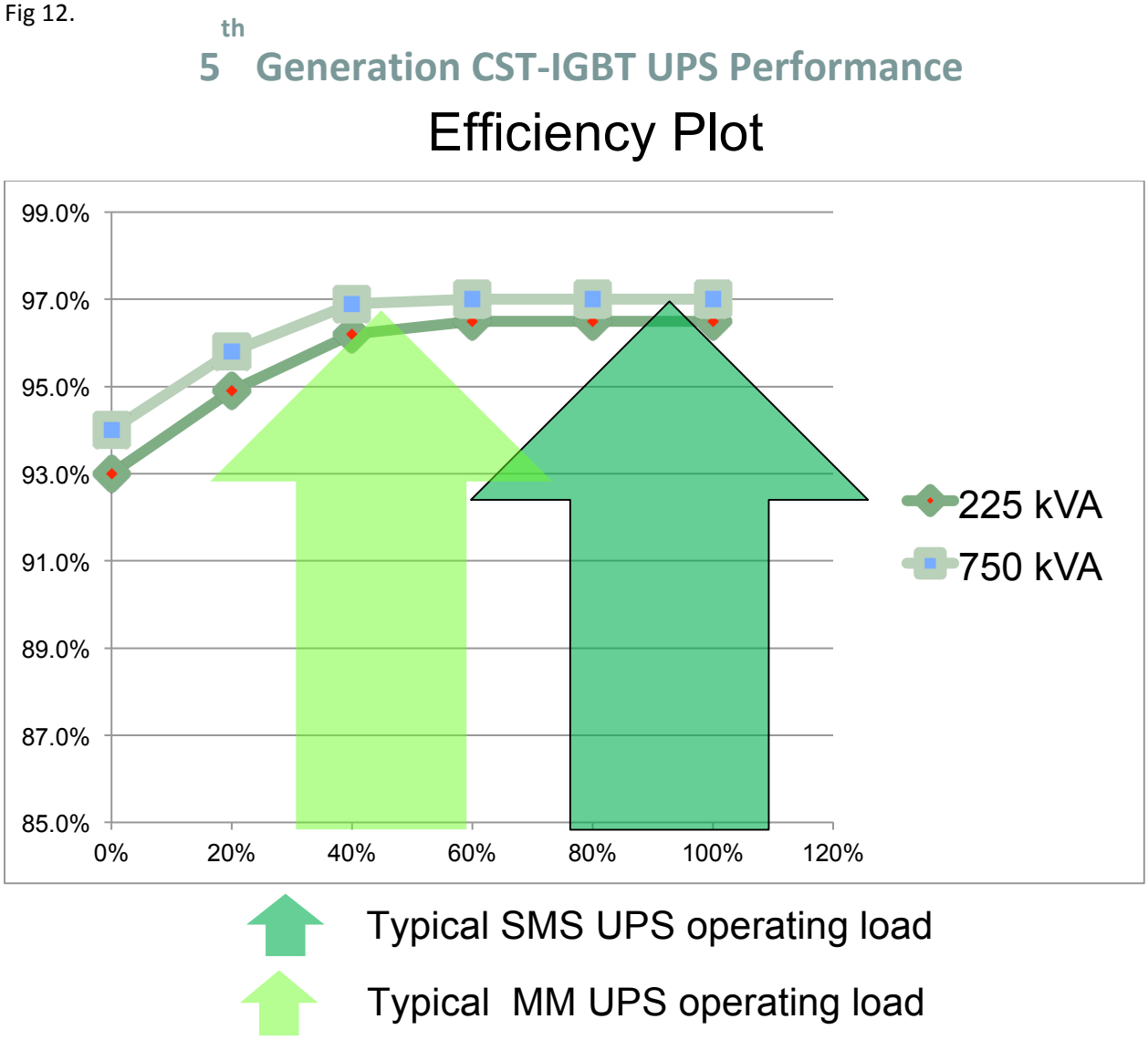
Transformer-less UPS with high efficiency double conversion

The other direction taken by a few UPS manufacturers is their ability to build a more efficient double conversion UPS through better power electronics. This group of manufacturers has the luxury of also being some of the world's top semi-conductor manufacturers. As a result they have developed purpose built components for their UPS systems. Some of this technology has bled over from the Variable Frequency Drive market that has seen great strides in more energy efficient electric motors.

The heart of the inverter on most UPS systems is the IGBT (Isolated Gate Bipolar Transistor). On your higher end UPS system this same component is also used on the rectifier of the UPS. The latest technology that a couple of UPS manufacturers utilize, is what they call the 5th generation CST-IGBT (Carrier Storage Trench). This latest technology allows the UPS to have a High frequency Pulse Width Modulation wave form that is extremely well regulated without the energy losses associated with normal IGBT's. This allows the UPS to operate in normal double conversion mode providing all the protection that a UPS is installed for. It does this while maintaining 97% efficiency in the on-line double

conversion mode. This system also has a very strong advantage in redundant designs since the UPS can achieve its highest efficiency with a partial load as low as 40%. Many tests have shown some models to achieve 93% efficiency all the way down to 15% partial load.

Fig 12.



CST-IGBT Transformer-less UPS Technology Benefits

- Smaller foot print – 30% to 50% reduction in foot print over previous generation
    - Less weight (floor loading concerns)
- Lower operating temperature & higher efficiency
    - 30% to 45% in many cases vs. their transformer counter parts with older IGBT technology. Not only saves you money on UPS efficiency but reduces cooling cost associated with UPS.
    - Full system efficiency achieved at 40% partial load with efficiencies remaining in the 94% range all the way down to 20% partial load. While operating in double conversion mode.
- Reduced parts count higher reliability
- <3% THD input 60%-100% load
    - <6% THD input at 25%-59% load
    - No input harmonic filter required
    - Again lower parts count and less operating cost by eliminating capacitors that need to be replaced in the future.
    - And lower energy cost due to low input THD
- 3 W + G install- reduce installation cost.
    - Most all data centers use transformers closer to load already to provide step down to 208/120V
- 100% step load without the use of batteries
    - Voltage Regulation +/- 1% for 0% to 100% Balanced Load, +/- 2% for 0% to 100% Unbalanced Load

Conclusion

It is a combination of needs and site limitations that ultimately dictate your UPS selection. This starts with identifying the loads and the value associated with keeping them protected. The type of load plays a big part in selecting the proper UPS technology. Within each of the categories we covered there were multiple differences between models. In this paper you were introduced to the difference between single phase and three phase UPS systems and the multitude of different voltage options. In addition to this the different UPS topologies were discussed and examples of common applications for each UPS type given. There were pro's and con's provided for each UPS technology and we dove into the latest in high efficiency designs. Last but not least, it is important to team up with an experienced partner during the selection and installation of a UPS system to ensure all critical aspects are considered.

About the Author,

Robert J Walker is the Senior Electrical Application Engineer for Facility Gateway Equipment Sales and Installation division. He is responsible for planning and design of data center critical power distribution, supporting the equipment sales team, critical facility management sales, turn-key installations and data center builds. He has 23 years of experience in power quality, power distribution and field service. His career in power quality began in 1990 at Best Power Technology, 1994 Rockwell Automation, 1996 Cooper Power Systems, 1999 Computer Power & Service Inc., 2006 JT Packard, 2011 Facility Gateway Corporation to present. His degree is in Electronic Engineering Technology from Herzing College (formerly Wisconsin School of Electronics). Additional courses from Milwaukee Area Technical College and Multiple UPS manufacturer's service school programs.