

# Safeguards that Improve Your Bottom Line

The year 2001 will surely be remembered, as is 1941 when the US finally emerged out of the throws of one crisis with the Great Depression and into another with our entry into a devastating Global War. During 2001, we have gone from a spring/summer power crisis in our most populated state, California, to our national late summer/fall disaster of 9-11. Now we engage in another war, but unlike others during the last century, this crisis has affected our homeland with a direct assault and war front. Our emergency preparedness plans are being re-evaluated, especially preparedness for bioterrorism. However, we also have to assure that our laboratories will be able to function at all times. This means that electrical power preparedness is fundamental and becomes an even greater part of the lab's foundation for contingency planning.

It is quite likely, if the laboratory has not already done so, that the Laboratory Manager (LM) or Principal Investigator (PI) will update a number of critical operating procedures and install safeguards to assure the lab's: availability, reliability and survivability. This includes installing or upgrading supplemental electrical power devices, which is a wise choice to guarantee that the lab will not default on its contractual obligations to produce timely quality analyses and reports. While nearly all mission critical labs have emergency backup generators, these supplemental power systems are not really helpful if the analytical processing of samples, or the analyzers themselves, go offline due to a very limited time power interrupt (glitch) or total short term power loss, while transitioning to other backup sources. Improving the overall utilization and efficiency of the lab's electrical power is a bonus during preparedness upgrades. These investments will pay off by reducing down time and services costs associated with poor power quality that is being utilized by the lab's instrumentation systems.

**Assuring the availability, reliability of results and survivability of the laboratory is the primary emergency preparedness goal**

**Electrical power preparedness becomes an even greater part of the laboratory's contingency planning**

**Gaining increases in availability and ROI are the benefits**

The impact to the lab's operating bottom line for poor power quality or power interrupts is lost profit margins, increased operating costs, lost reporting time and possible damage to the instrumentation. But here's the rub, very few

labs and instrumentation manufacturers are in a position to determine and/or advise which is the best solution for improving power quality and integrity. Installing online uninterruptible power devices, that condition the lab's power, while providing supplemental (backup) power reserves is not as easy as adding a surge protector to a computer. The reason is simple; the instrumentation manufacturers like the laboratory are power users and not power consultants, so the lab is usually on its own to resolve its contingency planning and lab power management. As the old adage indicates, every "dark cloud" does have "a silver lining" and that is the good news. The bright side of this contingency planning dilemma is that installing a quality Laboratory Protection System (LPS) that is truly online (100% online – without a switch over lag to reserve power), with sufficient supplemental battery power reserves, will actually save the laboratory money. The LPS will improve power within the lab and aid in boosting its operating margin. Case studies indicate that the lab can expect an attractive ROI and Cost/Benefit ratios between 5 and 15:1. **What this means is that the investment in LPS units provides a positive bottom line return you can realize right away!**<sup>1, 2</sup>

This article's purpose is to assist the LM and/or PI in understanding laboratory power terminology and the differences between Watts, VA, VARs and TPF when evaluating their contingency plans for electrical power products and solutions. An additional goal is to guide the LM or PI in understanding how the terms are correctly and incorrectly used when specifying AC power protection interface and improvement devices. Nearly all of us are confused about the distinction between the Watt and Volt-Amp (VA) measures for external and interface Laboratory Protection System (LPS/UPS) load sizing, when the system manufacturer has not directly recommended or specified a "certified" instrumentation-grade LPS. This is an important issue, since the terminology in the literature is confusing and misapplied. The issue with power and power protection is that to truly understand AC power you do need a technical background in power/energy engineering. The problem is that you do not have the time for an extensive study and you need to put a contingency plan in place NOW!

Now that the LM and/or PI have decided to take positive action in reviewing their contingency plans, a new set of power terminology, associated with purchasing electrical power products, must be understood. The explanations and definitions within this article provide a basic understanding of how AC power is defined, for laboratory applications. The goal is to discuss the power environment, without becoming complex. Key technical terms have been highlighted. The reviewer will derive sufficient information from this article to better understand the engineering implications of inappropriately

sizing and applying AC power interface protection to instrumentation. Supplemental electrical energy/power source (backup) systems and LPS units are a necessity in any commercial, R&D and production lab. Truly, 100% online uninterruptible power protection is specifically required for key mission critical communications and instrumentation defined under Category II or III applications.

### Power Definition Background for all Alternating Current Applications<sup>3</sup>

While understanding “power” in DC applications is straight forward as: (DC Volts) x (Amps) = Watts, “AC power” is an entirely different matter. AC power drawn by analytical laboratory instrumentation, computers, telecommunications, digital controllers, and/or other general-purpose lab equipment is expressed in a number of unique terms identified in the table below:

Term	Abbreviation / Usage
Active Power	Watts, W, KW
Apparent Power	Volt-Amps, VA, KVA
Apparent Power Factor (without reactance)	APF or $\text{Cos } \phi$ or PF
Demand Power	VA
Displacement Power Factor (without harmonics)	DPF, $\text{Cos } \theta$ or PF
Harmonics (linear)	THD, Total Harmonic Distortion
Linear	Aligned Frequency of Volts and Amps (within phase)
Measured Power Factor	Ratio of measured Apparent Power Factor to the W for linear application (without reactance)
Non linear	Volts and Amps are out of phase
Power (general)	Work (Energy) per unit time
Power Factor (general)	PF, $\text{Cos } \theta$ , DPF, $\text{Cos } \phi$ , APF
Reactive Power	VAR (Inductive or Capacitive)
Real / True Power	W
Total Power Factor	Sum of DPF + APF, total measure of the efficiency of power utilization
Volt-Amps	VA
Volt-Amps Reactive	VAR, KVAR (Inductive or Capacitive)
Watts	W, Power to do useful work / t

Watts (W), Volt-Amps (VA), (VARs), Power Factor (PF, DPF,  $\text{Cos } \theta$  and APF) and Harmonics are the principal AC power terms. The power in **Watts** is the “real/true power”, also known as “active power” drawn by the instrumentation, laboratory device and/or other equipment (load device) of

interest. This is the power that produces useful work (energy), during a time period. By definition **Power = Energy / t**, but to truly understand electrical power in AC applications, you have to look at both **Power Factor** and **Harmonics** together, especially if the discussion involves instrumentation and its associated systems.

**Volt-Amps (VA)** is called the “apparent power” and is the product of the AC voltage applied to the load times the current drawn by the load. Additionally, magnetic and electrical energy (per unit time) is stored within the load device along with the “active power (which includes heat losses)” to form the total demand on the utility. “Apparent power” is also known as “demand power”, since this is the power the utility must supply to its customer. Demand (apparent) power will always be greater than the active (real/true) power required to do real work, within a given time period.

The only exception to this is where the load is purely resistive, without additional energy storage in the form of “reactive power” (magnetic fields induced by inductors and electrical fields generated by capacitance); and without “harmonic distortion”. In laboratory and instrumentation device applications, the load is never truly resistive or “linear” (where voltage and current frequency rise and fall together, i.e. within phase and without distortion) Therefore, there will always be some value of “apparent/demand power” and this value will be greater than the “active/real power”. Refer to Figure 1 for the Power Relationship triangle<sup>4</sup>.

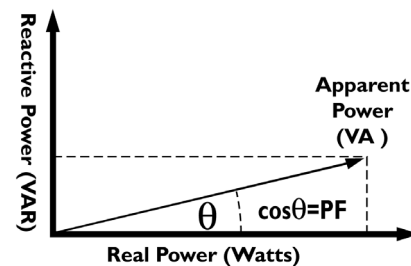


Figure 1: Power Relationships (W, VA, VARs & PF)

Apparent Power (VA) is the vector product addition of Real Power (W) and Reactive Power (VAR)

Apparent power is what you pay for and real power is what is used to do something useful. The energy/power that you cannot use because of low Power Factor is converted into heat losses in the wiring and circuitry

PF = 1.0 is an ideal situation, where:  
Apparent Power = Real Power

Both Watt and VA (VARs) ratings have an important use and purpose in electrical and energy engineering.

The W and VA relationship forms the key for appropriately specifying and sizing True Online Power interface protection devices for any lab application

The VA (KVA) rating is generally specified for the instrumentation system. What is equally important to know is the active power in Watts; and this information is not readily available within the laboratory

The relationship between the apparent and real (active) power is also known as the Power Factor (PF), which is also alternatively described as  $\text{Cos } \theta$ . Displacement Power Factor (DPF)<sup>5</sup> is the term used to describe and measure the effects of inductance (motors, ballast, coils and transformers) and capacitance on the efficiency of the AC distribution system, without harmonic distortion. Total Power Factor (TPF) is used to describe the total inefficiency of the load or distribution network, when linear harmonic distortion is introduced into the application. PF as a general term is now used incorrectly, or more so incompletely, in describing combined complex “analog” and “digital” systems, as a measure of efficiency and effectiveness of the load device. TPF is better term to use regarding the measure of the DPF of the classical analog **non-linear** loads (sinusoidal with a phase shift, due to inductance and capacitance) and the **linear** harmonic distortion of high speed switching equipment (controllers, processors and computers).

The Power Factor (DPF) relationship from Figure 1 can be expressed as:

$$VA = \text{Watts} / \text{Power Factor}$$

$$\text{Power Factor} = \text{Real Power} / \text{Apparent Power}$$

Power Factor (PF,  $\text{Cos } \theta$  or more specifically DPF) by electrical definition (IEEE)<sup>6</sup> is actually determined as the cosine of the leading or lagging phase angle ( $\theta$ ) of the fundamental of the current to the voltage. Equipment that stores energy, or requires a large ramp up to develop a square wave digital signal (infinite harmonics), such as a switched mode power supply (SMPS), in a computer or digital system, provides no real or useful work, but it does require appropriate sizing of the circuitry to handle the large current loads. “Apparent Power Factor”<sup>7</sup>, by definition, is the cosine of the phase angle ( $\phi$ ) of the measured line KVA, due to harmonics. Harmonic distortion and reactive current loads generate heat within the conductor and affect wiring

insulation temperatures. High insulation and wiring temperatures can cause a safety hazard and must be limited.

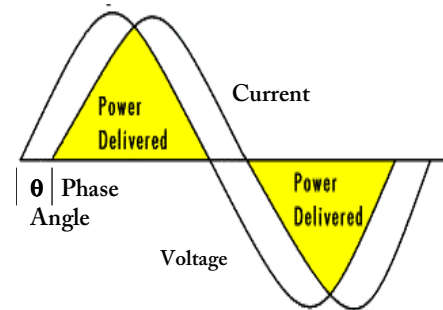
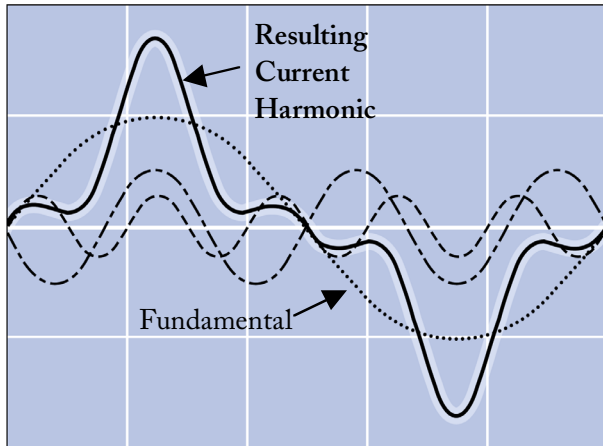


Figure 2: Active Power (Delivered Power) Resulting from Non Linear (Out of Phase) Loading

Figure 2 illustrates an example of a **non-linear** load with reduced real (active) power delivery. This type of device is storing a combination of principally magnetic and electrical energy (**reactance**) internally with no useful work being produced. The reactance energy/power is being converted into heat. Reactance is due to the phase shift of the true sine wave (undistorted) current to the voltage. Analytical instrumentation with large inductive loads such as, centrifuges, motors, coils, solenoids, lasers, fluorescence/UV flash lamps, etc. will exhibit reactive power delivery requirements similar to the area under voltage and current curves (yellow highlighting), shown in Figure 2. In the traditional or classical sense, with truly reactive power (VARs) and no harmonic distortion, power factor is simply the cosine of the phase angle ( $\theta$ ) between the voltage and current waveforms. This phase angle is correctable, as we will see shortly.

However, this is only part of the story affecting analytical instrumentation. The second phenomenon in bringing digital control, automation and robotics into the laboratory is the addition of the other form of power factor (apparent power factor) induced by digitally switched equipment. As we all seek higher speed in our computers, laboratory automation and other digital processors, we are also making our business applications vulnerable to the nemesis of **induced harmonic distortion**. Harmonic distortion is fed back into the laboratory’s or business application’s power distribution network as reflected return on the electrical distribution system’s neutral wiring. This reflection back into the laboratory’s distribution system means that all instrumentation and systems now have the opportunity to share distorted voltage and current waveforms. **Engineered/Certified LPS systems correct for harmonics.**



**Figure 3: Harmonically distorted current wave form**

While the SMPS is a linear device in the sense that current and voltage are in phase, the resulting power factor (.6PF typically) for such a digital device is very low. This inefficiency is primarily due to the SMPS' high frequency switching which results in harmonic distortion of the current waveform.

Figure 3 illustrates a linear load (in phase with voltage), but a harmonically distorted current waveform with just the application of the fundamental (60 Hz), 3<sup>rd</sup> (180 Hz) and 5<sup>th</sup> (300 Hz) harmonics. All of these waves are superimposed to produce the resulting current harmonic waveform

In today's contemporary digital load environment, power factor is also a measure of the **Total Harmonic Distortion (THD)** in the current waveform. Refer to Figure 3 for an example of a simple harmonically distorted current waveform with only the superposition addition of the fundamental, 3<sup>rd</sup> and 5<sup>th</sup> harmonic. Switching at the high frequency levels (1 GHz) of today's digital processors requires very high current draws and results in high switching transients.

### How Do You Correct the Lab's Power Problem?

The laboratory's power problem can be corrected in a number of relatively simple ways. To do it effectively, however, the LM or PI must be aware of what his/her "power consultants" are advising to assure a fix. Otherwise, the resulting power "solution" can have a seriously aggravating effect, resulting in damage to the interface devices, instrumentation systems, as well providing a safety hazard to the laboratory and its staff. Correcting power delivery to an instrument and the laboratory is an "engineered application". This is one of those probable

situations where a little bit of "education", or lack of it, on the part of the specifier can provide a serious economic set back to the laboratory; and may even more so leave the lab without the power protection and correction that was originally desired/required. An engineered (laboratory) application requires an engineered solution. The LM and/or PI are recommended to seek the assistance of the system manufacturer and/or a known LPS manufacturer and power consultant, to provide an engineered and certified instrumentation grade solution.

The ubiquitous centrifuge that is required in all human and animal health, clinical and drug discovery labs is one of the largest generators of high reactance power (VAR) from its motors. In addition, the inrush current to bring the centrifuge up to speed is up to nine times the normal running current required for this non-linear load. The main drive for the centrifuge rotor is an induction motor. Coupled with vacuum pumps and refrigeration for the ultra high "G" loading systems operating at over 90,000 RPM and you have a classic case of low Power Factor due to high reactance power draws. Left unchecked, the out of phase current to voltage is reflected back into the lab disturbing the power to the rest of the lab's instrumentation. This problem can be corrected in a number of ways:

- Check with equipment manufacturer to assure that the power factor for motor applications (refrigeration, centrifuges, vacuum pumps, etc.) are specified with greater than .90 PF, to eliminate the need for these types of capacitor applications.
- Apply a LPS system to correct all of the reflected harmonics and non-linearity between voltage and current, that is affecting the lab's power distribution system.
- If necessary, Power Factor (DPF) correction capacitors, for this type of inductance load, are usually applied close to the source to bring the voltage and current phase angle back into phase synchronization.

Adding boosting capacitors to an inductance application is acceptable as long as harmonic distortion is not present (microprocessor controlled centrifuges, instrumentation, et al), otherwise serious capacitor damage will result due to internal resonance.

**Beware of applications where there are significant harmonics (variable frequency devices and other non-linear loads). The harmonics can cause resonances with the capacitors and damage them. If harmonics exist, consider harmonic filters, which also typically improve the load<sup>8</sup>**

While this solution has solved one problem, it has not really addressed the real TPF issue, which includes harmonics. All labs and their key respective instrumentation systems are filled with various power inefficient devices. These devices are

“harmonically polluting” by reflecting waves back into the laboratory’s AC power distribution system. Additionally the EPRI (Electric Power Research Institute) recommended in its recent address to the US Congress, that power interface devices (LPS) be installed in critical applications to bring the power quality to the necessary minimum levels specified by the instrumentation and equipment manufacturers<sup>9</sup>. Since laboratories also need to update their contingency management plans, particularly now with the bioterrorism initiatives being supported by the US Government, an uninterruptible and supplemental power solution, that also address power factor inefficiency and harmonics (TPF) is highly recommended. In particular, a **Laboratory Protection System (LPS)** specifically designed to correct reactive power and harmonics, with high TPF (>.9TPF); including VHF/UHF harmonic filtering for instrumentation, is the most preferable. Additionally, these interface devices operate with **true zero switch over time (true 100% online)** to provide required supplemental energy/power reserves and protection.

### Not All Uninterruptible and Supplemental Power Solutions are Suited for Instrumentation

Because of the unique loads required by instrumentation applications, **not all UPS devices**, especially those designed for the consumer PC computer market or marketed as lower cost “hybrid on-line”, are suitable to protect key **Category III systems**. Certified LPS products, however, are purpose built engineered power systems, configured and qualified/tested to assure 100% performance in the laboratory’s instrumentation environment. The IEEE and IEC have categorized LPS/UPS units according to their design functions and IEEE UPS Category 3 “Regenerative (True) Online, Sine wave – with precision line & load regulation”<sup>10</sup> designs are recommended for mission critical

instrumentation applications. These LPS instrumentation grade systems are identified as **Category III –3**<sup>11</sup>.

Selecting a suitable **Category III–3 LPS** for the laboratory’s particular instrumentation make & model, where continuity of load power - while providing output voltage and frequency independent of input voltage and frequency, is an economically wise step managing the lab’s bioterrorism contingencies. The additional benefit of specifying a LPS with **Power Factor corrected to .95 TPF** assists in maximizing the performance of the protected instrumentation system, availability and reliability of test results, while reducing the laboratory’s total cost of operation. The true benefit to the lab is that the investment in this type of power protection equipment is an economically smart decision. LPS systems protect the lab’s key investment in instrumentation and staff, correct power inefficiencies and effectively eliminate harmonic distortion (< 2% THD). Instrumentation availability and reliability substantially improves by providing very clean and highly regulated power to the equipment. Realizing a ROI in less than two or three months, by adding a safeguard, like a LPS that drops savings right to the lab’s bottom line, is truly the added bonus of smart lab management.



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<sup>1</sup> “Laboratory Management Contingency Planning – The New Paradigm”: MedPro Month Volume X1, Number 12, December 2001 – IHS Health Group

<sup>2</sup> “Laboratory Management Contingency Planning – Environmental Assessment”: JALA Volume 7 Number 1, February 2002 - The Association for Laboratory Automation

<sup>3</sup> “Reducing Power Factor Costs”, US DOE, Office of Industrial Technology, 1966

<sup>4</sup> “Energy Management Handbook”: Turner, Wayne C. - Fairmont Press Inc., 1993

<sup>5</sup> Danaher Corporation, Electrical Test and Measurement – Fluke Electrical Power, 2001

<sup>6</sup> “A New Approach to Load Balancing and Power Factor Correction in Power Distribution System”

A. Ghosh and A. Joshi, IEEE Transactions on Power Delivery, Volume 15, Number 04, October 2000

<sup>7</sup> “Power Factor and Harmonics” – Keith H. Sueker, Robicon Corporation, Bulletin 720-008, 1987

<sup>8</sup> “Reducing Power Factor Cost,” Technology Update – US DOE, Bonneville Power Administration, April 1991

<sup>9</sup> “Energy Realities: Rates of Consumption and Future Options” and “CEIDS – The Self Healing, Digital-Quality Super Highway” EPRI address to the US House of Representatives, Subcommittee on Science Hearing May 3, 2001

<sup>10</sup> IEEE/IEC Standard 62040-3 Categories for Uninterruptible Power Systems (UPS) – Category 3 Double Conversion “Rectifier /Charger (Dual Conversion On-line)”

<sup>11</sup> Source: Franek Technologies, Inc.