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INTRODUCTION

A key ingredient for reliable, predictable operation of computers and other electronic equipment is reliable, predictable power. The source of electric power that computers draw on is an electric utility power line. This line was originally designed to power electric motors and provide lighting. And in 90% of its applications, it performs its intended duty very well. In the last 23 years, computer loads have emerged; all with power requirements that arc much more stringent than for motors and light bulbs; requirements which existing power lines can meet on average, but not at any given moment As a result, protection from aberrations in the electric power supplied to the computer by the power line has become an absolute necessity.

INCOMPATIBILITY

Typically, computer hardware reliability exceeds that of the power delivered by an electric utility company many times over. Micro and minicomputer systems' mean time between failure (MTBF), is in the range of 3,000-10,000 hours, while MTBF of the voltage from the electric utility line is 10-100 times smaller, 24-700 hours. Due to this incompatibility, the MTBF of computer operations is much lower than it is possible to realize.

To improve system reliability, a power interface device (PID) is installed between the electric utility service and the computer hardware.

PARAMETERS OF POWER

PIDs function to improve the reliability of voltage delivered to computers. Quality PIDs accomplish this by providing voltage with parameters that are within the tolerance bands of the computer or other electronic equipment at any given moment, not only on average.

The electric utility companies deliver alternating (AC) voltage of sine waveform with set nominal amplitude and frequency. A well-known example is 120 V and 60 Hz. How-ever, there are many other nominal values of amplitude (e.g., 110, 127, 200, 208, 220, 240, 250, 380, 480, 600 V); and other frequencies (e.g., 50 Hz). In all cases, four major parameters of these voltages are necessary for reliable, predictable computer operations:

Amplitude must be within a band that is *±10% of nominal value for a load*
Frequency must be within a band that is ± 5% of nominal value
Waveform Distortions must not exceed 5% of main voltage harmonic
Continuity must be controlled manually by the operator or automatically by the PID, and not by a utility company

UTILITY POWER LINE DISTURBANCES

On average, electric utility companies deliver voltage within these parameters. Occasion-ally, however, this voltage is disrupted or disturbed, by normal operation of utilities' electrical distribution systems components and by the many users of the electricity. The specific types and regularity of power disturbances in the United States is well documented in studies by International Business Machines Corp. (IBM) [1] and Bell Laboratories [2]. They identified the following major disturbances of voltage waveform that randomly occurred at electric utility service outlets.

Sags (amplitude disturbance): cycle-to-cycle decreases in amplitude (10% or less of nominal value) lasting less than several seconds (Fig. 1)
Surges (amplitude disturbance): cycle-to-cycle increases in amplitude (10% or more

of nominal value) lasting less than several seconds (Fig. 2)

Failures (loss of continuity): zero voltage conditions lasting for more than one-half of one cycle (Fig. 3)

Oscillations (waveform distortion): a sine waveform decaying within one cycle, superimposed over line voltage waveform, with a frequency range of 400-5,000 Hz and a beginning amplitude of 15-100% nominal voltage (Fig. 4)

Spike (waveform distortion): overvoltage superimposed on the line voltage waveform that lasts 0.5-100 μs and has an amplitude of more than 100% of peak line voltage (extreme spikes, such as those caused by lightning, can be up to several thousand volts) (Fig. 5)

In addition to these random power disturbances, other disturbances are deliberately introduced by electric utility companies.

Brownouts: scheduled reductions of amplitude that serve to reduce power demands during extreme situations, usually associated with adverse weather conditions

Blackouts: sequential and scheduled turn-off of power in selected areas during times of excessive power demands by users and inadequate generating capacity of the electric utility company

Also, in smaller electric distribution systems, power line frequency can reach outside tolerance limit when electric power generators slow down under excessive power demands. Examples of this can be found in rural and remote areas or in special zones that use emergency power generators such as hospitals or facilities with uninterrputible processes.

Figure 6 summarizes IBM Corp. and Bell Laboratories' statistics about electric utility power MTBF in the United States. The table also compares computer MTBF with power MTBF. Clearly, there is significant incompatibility between electric power line reliability and computer reliability. Note that MTBF of electric utility power is significantly lower in other industrial countries. For example, in Germany the MTBF of power failure is 300 hours at the building service entrance-many times lower than in the United States.

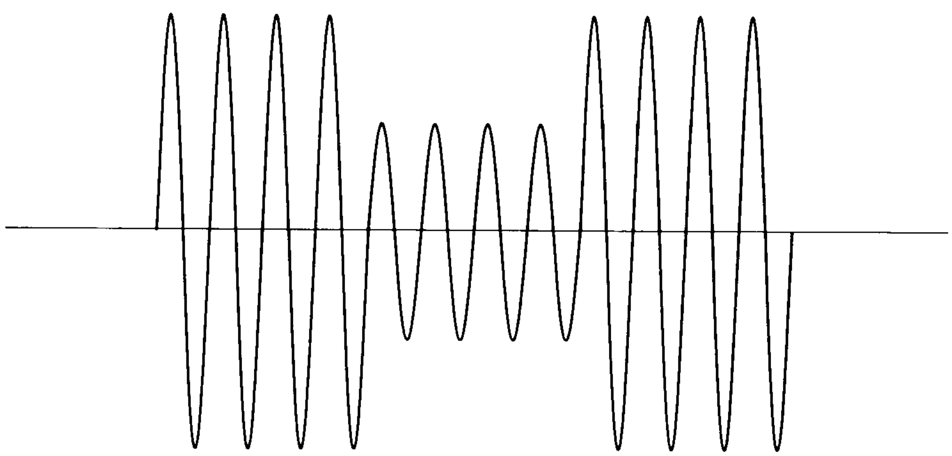

FIGURE 1. Sag.

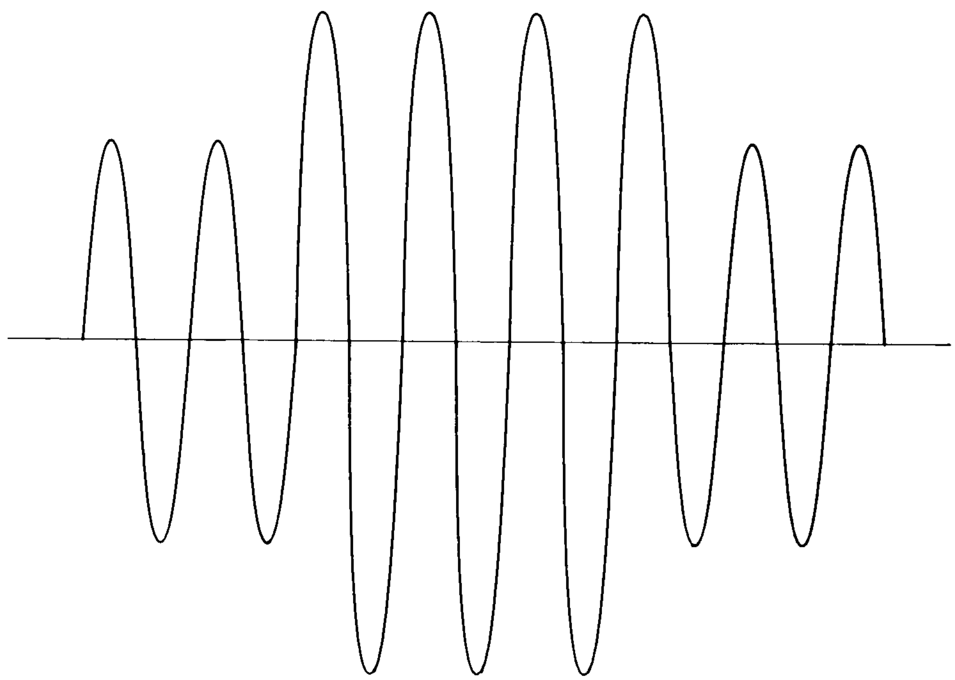

FIGURE 2. Surge.

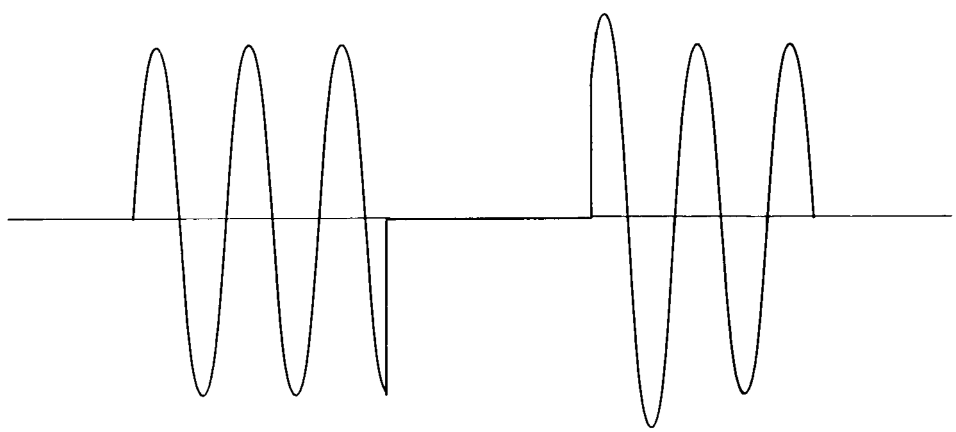

FIGURE 3. Power failure (outage).

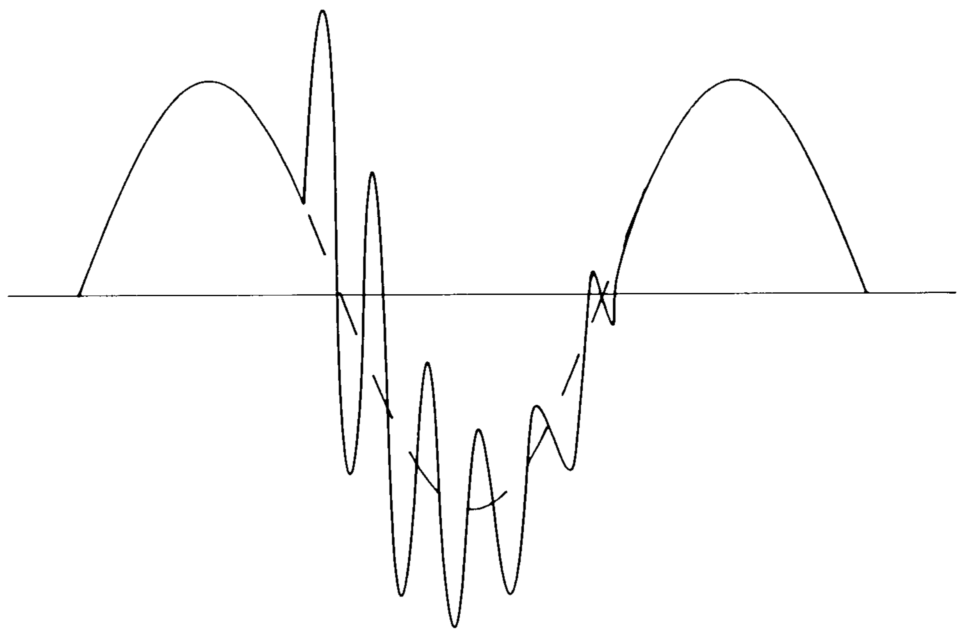

FIGURE 4. Oscillation: 400–5,000 Hz.

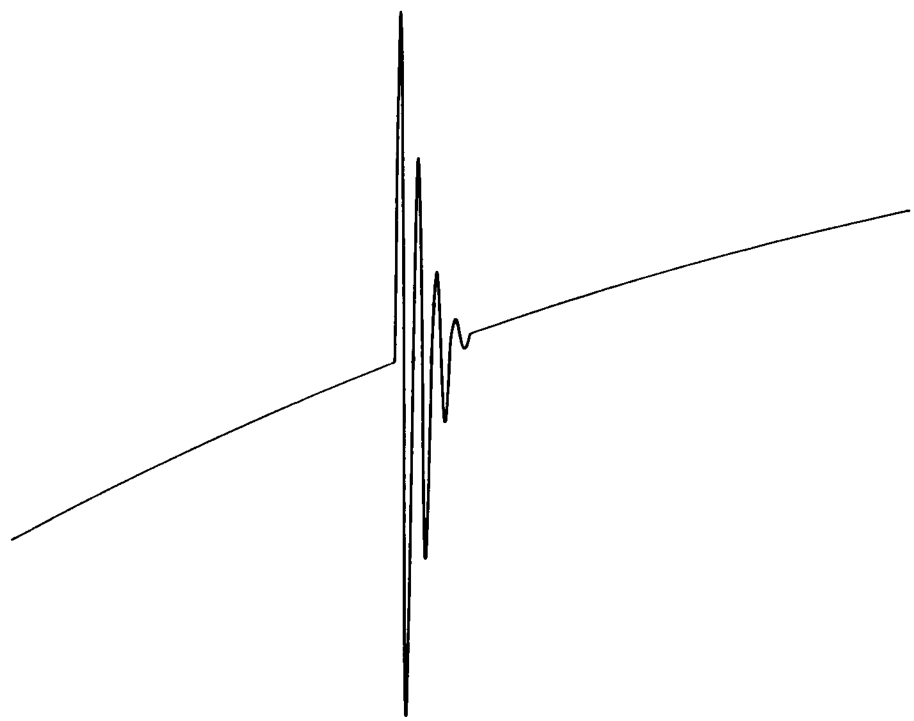

FIGURE 5. Spike: up to 6,000 V or 3,000A.

Power line disturbance	Quantity/Month	MTBF(h)
Oscillation	30	24
Sag	4	180
Surge	0.5	1,440
Spike	2	360
Power failure	0.6	1,200
Range of computer MTBF		
Microcomputer		10,000
Minicomputer		3,000

FIGURE 6. Utility power line MTBF.

EFFECTS OF POWER DISTURBANCES ON COMPUTERS

As expected, different disturbances and their relative severity have different effects on computer operations. But all power disturbances, the IBM study states, "can cause the malfunction of data processing equipment."

Oscillations

Oscillations, especially with high amplitudes of 50-100% cause either voltage or current stresses in computer equipment power supplies. These are manifested by inexplicable, premature degradation and eventual failure of the power supply, or by momentary failure. Oscillations with higher frequency, those in the range of several kHz, will propagate through the switch mode power supply when the regulation bandwidth is smaller than the oscillating frequency. The oscillation causes computer bus voltage to oscillate and to randomly change the status of 1’s and 0's in any part of the computer hardware. Keyboard lock is the most common manifestation. The higher voltage introduced to the magnetic heads of storage de-vices also causes permanent damage to magnetic media. Data loss and program "bugs" are common consequences of power line oscillations.

Surges

Surges cause failure of computers' power supplies.

Sags and Power Failures

Sags and power failures erase data in random access memory (RAM). They will also cause loss of files in permanent storage when they occur during disk write operations.

Spikes

Lightning spikes cause substantial loss of equipment.

Historic Technologies

During recent decades of computer usage, several technologies were developed to increase the MTBF of power fed into computers; all with the objective of raising it to levels that met or exceeded computer MTBF. Currently, there are four widely accepted technologies. Each has relative strengths and weaknesses.

Ferroresonant Power Conditioners

Ferroresonant power conditioners (ferros), also known as saturated magnetic voltage regulators, were invented by Joseph Sola early in the twentieth century. To date, ferros are the most widely used power conditioning devices in the world. Figure 7 depicts a functional diagram of ferros.

Ferros consist of parallel resonant circuits tuned to the power line frequency of either 60 or 50Hz and the series-connected magnetic reactor between input and output. The magnetic reactor in the resonant circuit is saturated. When the power line frequency is equal or vary close (within 1%) to the resonant frequency, this circuit does not shunt the output. The output voltage, then, is defined by the saturation curve of the resonant reactor. When input voltage amplitude varies, the output remains nearly constant because the saturation curve does not change. The device also acts as a voltage regulator If power line frequency vanes from resonant frequency, the output voltage changes significantly, both up and down. At frequencies much higher than resonant frequency, especially in the frequency range of oscillations (400-5,000 Hz), a ferro will attenuate from approximately 50 times at 400 Hz to approximately 100,000 times at 5,000 Hz.

In summary, the ferro eliminates the most frequent power disturbance-oscillation-and reduces the frequency of occurrence of sags and surges.

However, ferros, lacking auxiliary energy storage, do not eliminate power failures. By design, therefore, they improve power line MTBF from 24 hours (regularity of oscillation) to approximately 700 hours (regularity of power failure)-still inadequate in comparison with a computer MTBF of 3,000 hours or more.

A significant technical deficiency of ferros lies in the series magnetic reaction This component limits the amount of surge power on the output. Motors, light bulbs, computers, and other loads all require surge power of 700-1000% more than their nominal ratings. Ferros provide only 125-150%. Therefore ferros must he significantly oversized; three to four times, to comply with computer surge power needs.

Uninterruptible Power Supplies

Uninternuptible power supply (UPS) systems use internal energy sources to support loads during occasions when the primary energy source, namely the electric utility power line fails. In principle, UPS systems can provide loads with voltage that has MTBF which ex--

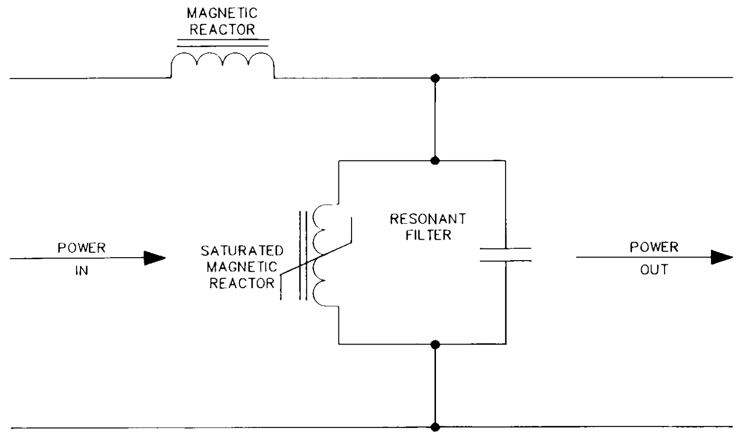

FIGURE 7. Ferroresonant power conditioner and voltage regulator.

ceeds computer MTBF. There are several types of UPS technology which accomplish this to varying degrees.

Standby UPS

Standby UPS is the oldest UPS technology, originating from emergency lighting. It is often referred to as SPS, or standby power supply. Figure 8 is a functional diagram of current SPS systems. when power line amplitude is within limits, output in an SPS system is connected to input via a switch, relay, or semiconductor. If amplitude falls below a specified limit, internal circuits disconnect output from the input and activate an internal alternating (AC) voltage generator The internal voltage generator replaces the failed electric utility power line. (The typical transfer time in quality SPS systems is about half of one cycle of power line voltage, O.008-0.O1O second.) This generator consists of an electronic solid-state de-vice (an inverter) and a storage battery. When the primary source of power is restored, the process is reversed. Simultaneously, the SPS initiates battery recharging through an internal battery charger.

The major technical deficiency of SPS systems is that they do not filter oscillations. Inasmuch as oscillations propagate unattenuated from the power line to the load, the MTBF of power supplied to the computer remains a low 24 hours.

However, SPS systems were not intended to improve power line MTBF to levels that exceed computer MTBF, but rather to provide auxiliary power. In this respect, it is critical that the computer's internal power supply has adequate energy storage to self-power during the time required for the SPS to transfer output to the internal generator. Small switch mode power supplies, especially underloaded ones, usually have enough of this energy stored in the rectifier filter capacitors. However, the linear power supplies used in modems and large switch mode power supplies do not.

In either type of load, the SPS must be able, at the moment of transfer, to power the load and to recharge the load's energy storage element. This requires that the SPS be over-rated by approximately 50 percent (e.g., a 500 VA load requires an SPS with a minimum nominal rating of 750 VA).

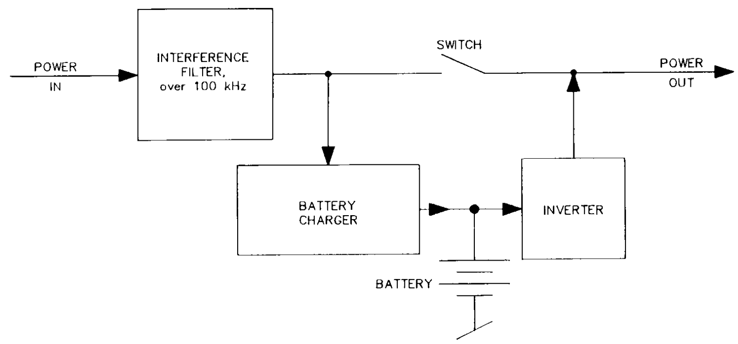

FIGURE 8. Stand-by UPS.

Another limitation of SPS systems is that they actually create new power line disturbances while in operation. For example, when any computer load is turned on, it demands surge power of ten times (1000 percent) greater than nominal power. This demand for excess power, required to start up computers and other loads, creates a brief input power line undervoltage. This undervoltage is misinterpreted by most SPS systems as a power line failure, causing the SPS to transfer the load from the power line with high power capacity to the SPS system's very limited power capacity inverter. Because of this power limitation, the output voltage dramatically sags some 50-70 percent, only slowly recovering over the course of several cycles. This process is shown in Figure 9, which captured on an oscilloscope, illustrates an SPS with a load requiring power equal to only 30 percent of the SPS system's nominal rating. The functional and operational reliability of SPS systems is also an issue. The operational life of semiconductors used in an SPS inverter is determined by the number of times it gets started, rather than by operating hours. This same reliability phenomenon is found in light bulbs and motors, where thermal stress determines usable life. The ramification of this poor reliability is that users have no indication of whether the SPS will work when power fails; therefore periodic checks must be performed to ensure that the SPS will be reasonably ready when needed.

Manufacturers produce a multitude of SPS systems. All vary in performance primarily by the type of voltage waveform they generate while in back-up mode, and in their transfer times. The most expensive models offer sinusoidal waveform and transfer time of less than 0.002 second. Less expensive and inferior models offer square waveform and transfer times of more than 0.02 second.

Ferroresonant Standby UPS

During the last decade, another PID was created, which combines features of ferroresonant power conditioners and standby UPSs. In function, it is an SPS with a ferro on its input (Fig. 10). A ferroresonant UPS eliminates virtually all power disturbances. The exception, how-

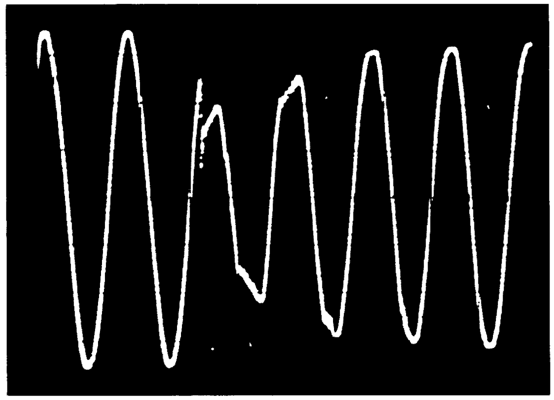

FIGURE 9. Stand-by UPS output sag under 30% computer load starting.

ever, is an important one; short duration voltage failure, or sag, on the output created by the SPS's transfer process. Nonetheless, if this particular disturbance is tolerable by any given load, then this device will increase power line MTBF to a range of 20,000-40,000 hours. The remaining shortfall of this system continues to be the reliability of the SPS portion of the ferroresonant UPS, specifically the inverter transistor's thermal stress during turn-on.

The major technical deficiency is the ferro portion's low overload rating. Figure 11a shows the output voltage of this device with an application of a computer load with a rating equal to 100 percent of the PID's rating. Figure 11b shows the output voltage of this device with an application of a computer load with a rating equal to 30 percent of PID's rating.

Even a 30 percent load generates a severe voltage sag. Typically this deficiency is overcome by greatly oversizing the ferroresonant UPS in comparison with the load's nominal power requirement by as much as three to four times the nominal load rating. For example, a load requiring 500 VA of operating power would be powered by a ferroresonant UPS with a 2,000 VA nominal rating an uneconomical solution.

Installation is also a significant problem with a ferroresonant UPS. Inherent in its operation is a saturated magnetic reactor which requires significant reactive current from the power line to maintain its saturated state, thereby keeping the output voltage regulated. The lower the operating voltage limit, the higher the current at nominal voltage must be. A lower voltage limit is required to allow a ferroresonant UPS to operate during brownout conditions. Then nominal input current is 25-50 percent higher than output current, a function of lower input voltage limit. This means that, in most cases, the electrical service used to provide power to the computer does not have enough current-carrying capacity to support the operation through a ferroresonant UPS. In most instances, this requires rewiring to obtain an electrical service with a higher current-carrying capacity.

An additional difficulty occurs at sites where power line frequency varies beyond a boundary of 1 percent. This variance is often present where diesel generators are used during emergency operations or in rural areas with small electrical generation plants. The resonant nature of ferroresonant UPS circuitry causes dramatic changes in output voltage in reaction to small frequency variations getting outside of the computer's voltage amplitude tolerance band. The usual response of the ferroresonant UPS during these instances is to switch to its internal generator, discharge its batteries, and shut down. This response is viewed as unacceptable performance, given that the computer equipment has a 5 percent tolerance band with respect to frequency.

On-Line UPS

The top technical performance in the UPS group belongs to the on-line UPS system. The functional diagram of this device is shown on Figure 12. The typical on-line UPS has an inverter which supplies ail power to the output, and hence to the computer, from an internal

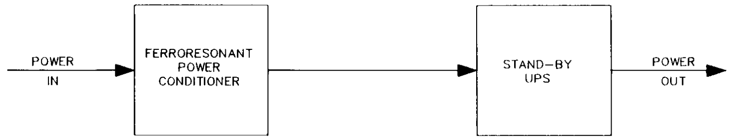

FIGURE 10. Ferroresonant UPS.

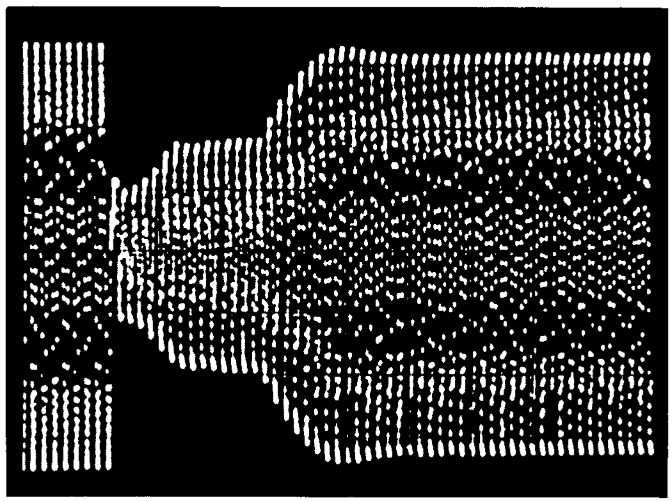

FIGURE 11A. Ferroresonant stand-by UPS output failure under 100% computer load starting.

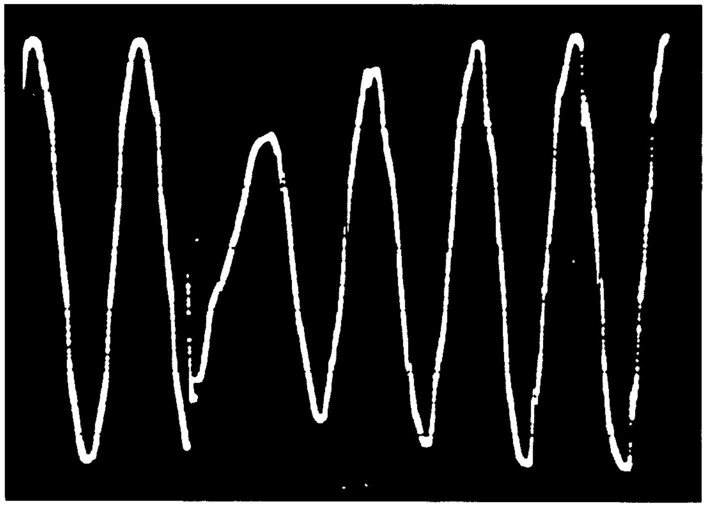

FIGURE 11B. Ferroresonant stand-by UPS output failure under 30% computer load starting.

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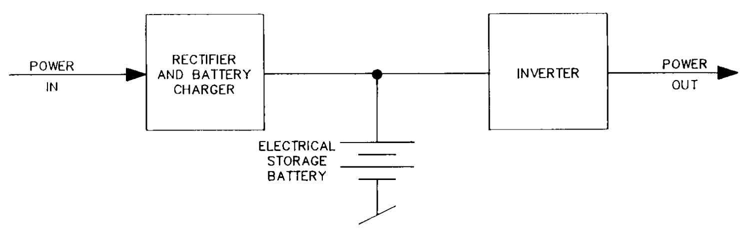

FIGURE 12. On-line UPS.

battery at all times. (The term on-line UPS is derived from this feature because the inverter is "on-line.") This is exactly opposite to the way an SPS functions. During operation, the battery is constantly recharged by an internal rectifier-charger which is powered from the electric power line. Any power disturbances associated with the power line are terminated at the battery, which serves as a large filter.

With a typical on-line UPS, the load derives power from the solid-state generator, not from the electric utility power line. Therefore, all the power disturbances associated with the electric utility power lines are eliminated. However, new power disturbances are created by on-line UPS systems.

The most common new disturbance is a voltage sag. Generated when different loads are turned on, the effect is the same in appearance as are observed on the output of ferroresonant UPSs. Figure 13a is diagram of the output voltage under application of computer loads having operating power demands equal to 100 percent of a given on-line UPS systems nominal rating. Figure 13b shows the output voltage diagram under application of computer loads having operating power demands equal to 40 percent of a given on-line UPS system's nominal rating.

Generally power sags can be overcome by oversizing the on-line UPS versus the load, similar to previously critiqued PIDs, causing greater expense (i.e., higher purchase price). Oversizing the typical on-line UPS is necessary because the solid-state inverter semiconductors, designed to be economical for any given power rating, are limited in current carrying capacity. The usual surge power rating for a typical on-line UPS is 150-200 percent. So the usual sizing tactic is to oversize the on-line UPS by two to three times larger than the load's power demand.

On-line UPS oversizing is not as dramatic as in ferroresonant UPS, and it can be reduced by using larger rating semiconductors or by using special bypass circuits to directly connect the output to the input temporarily. When using a bypass, the electric power line, with its large surge capacity, starts up the load. Once the load is started, the bypass switch transfers the load back to the inverter.

Another deficiency of a typical on-line UPS is that the output current is often about 50 percent lower than input current. It is caused by internal energy losses and by technically inferior but inexpensive rectifier-chargers. This usually requires that users bring in electrical service with higher current capacity (i.e., rewiring) to power the on-line UPS.

Deficiencies are also found within the battery electrical control. In typical on-line UPS systems, the storage battery is abused electrically by large pulsating currents that are fed to and from it by both the charger and the inverter. These pulsations cause premature, rapid exhaustion of the batteries, aging them five or more times faster than the batteries

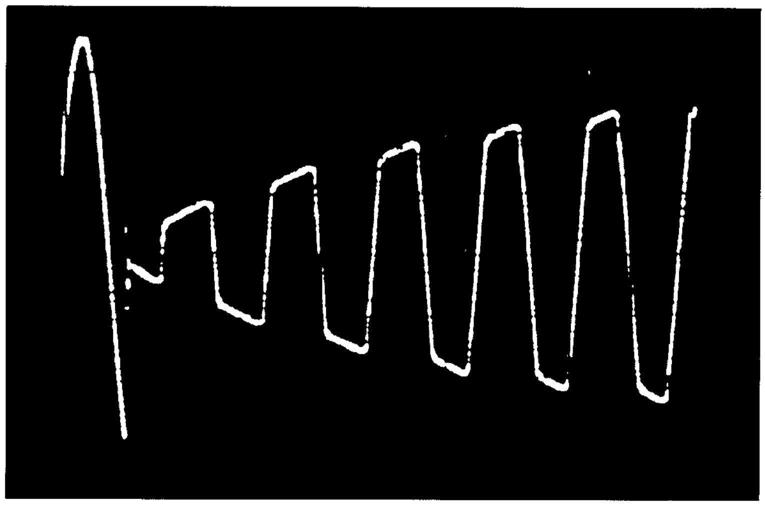

FIGURE 13A On-line UPS output failure/sag under 100% computer load starting.

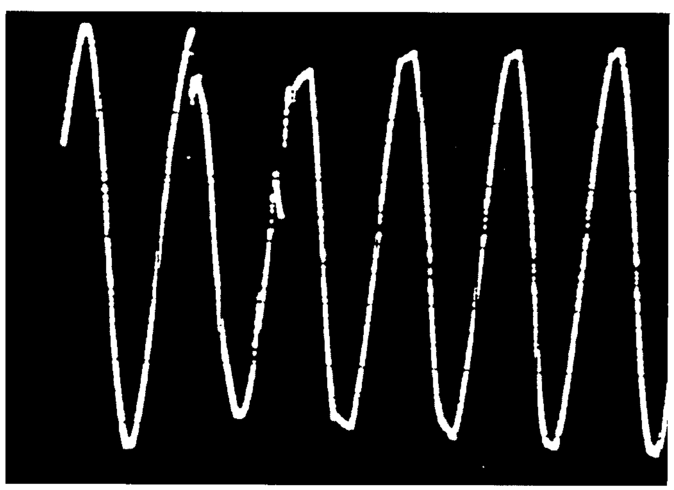

FIGURE 13B On-line UPS output sag under 40% computer load starting.

could otherwise last. However, properly designed on-line UPS systems are the most reliable of all UPS technologies. Even in cases of total failure of the on-line UPS, its static switch transfers the load to the power line, and the load continues to operate.

The on-line UPS is the most commonly used PIE). Its popularity is attributable to its effectiveness over the range of power line disturbances. There are two classes of on-line UPS systems: single phase, used to meet low and medium power range needs (400-1O,OOO VA); and three phase (10 kVA to several thousands kVA).

Power line disturbance	MTBF	Ferro-resonant power conditioner	Standby UPS	Ferroresonant Stand-by	On-line UPS
Oscillation	24	good	none	good	excellent
Sag	180	good	fair	good	excellent
Surge	1,440	good	poor	good	excellent
Spike	360	excellent	poor	excellent	excellent
Power failure	1,200	none	poor	fair	excellent
Frequency change		poor	good	poor	excellent
Brownout		good	none	good	excellent

FIGURE 14. Technologies effectiveness against power line disturbances.

Three-phase, large power on-line UPS systems usually are an element of complex installations and are linked with diesel generators to provide power during instances of extended power outages. There are numerous three-phase configurations in parallel and parallel redundant modes of operation.

Figure 14 summarizes the effectiveness of different power technologies in delivering reliable voltage to computer loads.

TECHNOLOGIES OF THE FUTURE

Trends

There are two apparent trends in power technology. The first is to integrate UPS systems into the loads that are in need of reliable power. This is economically feasible if the products are used alone and do not consume significant amounts of power, allowing lightweight batteries to be used. Common examples are battery-backed computer memory devices, alarm clocks, and telephones with memory devices. It is likely that in the near term the simple microcomputer workstation will utilize an integrated UPS.

For installations requiring numerous separately powered computers or other electronic peripheral devices, the most economical and sensible choice for power will continue to he an external, standalone alternating (AC) voltage UPS.

A second trend is developing in data interfaces. In more and more situations, an inter-face is provided to the host computer that allows the computer-through its program-to automatically control the operation of the UPS: start and stop it, recharge its batteries, and more. The use of the interface is limited by the availability of software operating system routines that monitor the UPS systems' status. Software operating systems that have this feature today are provided by IBM for their AS/400 minicomputers, and by several local area network (LAN) vendors, such as Novell, Microsoft, Banyan, 3Com, and others.

Load Independent

Less a trend than a sensible evolution, a new generation of UPSs is emerging that borrows heavily from the best features of existing on-line UPS systems. The rationale behind this evolution is that only on-line UPS technology totally eliminates all types of power disturbances from the electric power line. The new generation of on-line UPS systems will also eliminate all power disturbances. But, unlike a typical on-line UPS of today, the new generation will do so without creating new power disturbances and without prematurely exhausting batteries. In fact, the new generation will provide totally reliable voltage to the load regardless of either disturbances in the power line or the load changes or the load character.

Without exception, typical UPS products today are limited to powering only certain types of loads. This fact is reflected in the long list of performance specifications related to load transient power demands: lagging and leading power factor limits; crest factor limits; proportion of nonlinear load to the total load; waveform distortion limits; frequency ranges; phase changes; minimum operating load; and more.

The new generation of UPS systems meet one simple specification: disturbance-free power to any load.

Line Independent

The new generation of UPS systems will use current waveform control input circuits. These circuits will allow the use of the same electrical service to operate the load, despite the presence of the on-line UPS. The new generation of UPS systems will emulate ideal input power as measured by amplitude, frequency, continuity, and phase. By doing so, the new generation will eliminate the need for users to declare special configurations.

Distributed Power

The new generation of UPS systems will also be economical enough to allow for distributed power. Regardless of the size of the particular UPS, the cost per kVA of power will be linear, not exponential. This will allow cost-effective use of distributed UPS power versus today's centralized UPS.

Battery Control

The new generation of products will control the UPS system's battery in such a way that maximum battery life can be realized. The goal is to extend battery life to a point where it exceeds the useful life of the UPS itself. Ultimately, the ideal batteries would be those that never require replacement, outlasting semiconductors and other components.

Data Interfaces

The new generation of UPS products will be capable of providing data interfaces through RS232, the industry standard, or through other similar standard intefaces. This would eliminate user and manufacturer burdens of requesting and providing custom intefaces.

Summary

The new generation of UPS systems will do precisely what end users expect: provide totally reliable voltage for reliable computer operations; power any load from any electrical service; interchange data with its host; and be maintenance free.

PERFORMANCE CRITERIA FOR UPS SELECTION

Many types of PIDs are currently on the market, and selection of the proper PID for a given application requires evaluating any manufacturer's offer against basic criteria.

Fundamental Technology

First, it should be determined that the selected UPS system and its technology can provide (in principle and in practice) reliable voltage at the output. it can be deduced from the technology comparison table (Fig. 14), that only two technologies are ultimately suitable: on-line UPS or ferroresonant SPS. The selection can be further reduced to on-line UPSs only, since ferroresonant SPSs are limited to powering loads which tolerate transfer time and the resulting voltage sag, and are powered from lines with stable frequency.

Voltage Amplitude

Next, it must be determined that output voltage amplitude is within 10 percent of the load's nominal voltage, as documented on the load's nameplate. The often quoted performance parameter of voltage regulation being within 1-2 percent is not necessary. What is important, however, is that the voltage amplitude and peak value are within a 10 percent range during transient loads when surge power demands are 7-10 times (700-1000 percent) larger than the load's operating power
Power rating specifications consist of two reliability-related conditions:

1. Each half-cycle, within 10-20 seconds duration of a load 7-10 times larger than the operating load, the output voltage must have an amplitude within 10 percent of the load's nameplate voltage amplitude.
2. Continuous voltage at full operating power regardless of the load's character must also be within 10 percent of the load's nameplate voltage.

Phase Configuration

Phase relationship on the output of the UPS shall be identical to the phase relationship in the electric power line feeding the UPS. This allows retaining existing power distribution system to different computer loads and to easily bypass UPS when servicing is required. Several phase configurations are in use, namely:

Single phase 2-wire
Dual-phase 3-wire, including 2-phase conductors and neutral conductor, with
2 phases 120 degrees apart, lagging or loading
Three-phase 4-wire, including 3-phase conductors and neutral conductor (star configuration),
with all three phases 120 degrees apart from each other

Frequency Range

The output voltage frequency range must be within 5 percent of the load's nameplate frequency.

Waveform Distortion

Two major parameters of distortions impact the reliable operations of computers: First is the peak voltage during each half cycle of the output voltage. The peak voltage must he more than 0.9 x $\sqrt{2}$ of the equipment nameplate voltage under all conditions; this is especially necessary when operating loads that are 100 percent nonlinear, when starting loads [when surge power demands are 7-10 times (700-1000%) larger than operating power demands] or at the conclusion of battery discharge.

Second is the UPS system's performance against the next most commonly quoted parameter, total harmonic distortion (THD). This parameter is a ratio of the sum of all harmonics but the first one to the first harmonic of the output voltage at the power line frequency. This parameter is particularly important for linear loads line AC motors, as it deter-mines overheating. The accepted value is that THD must be less than 5 percent in cases where the UPS is operating a non
linear load, such as a commuter It is a given then that the UPS must limit THD) to less than 5 percent for any load of any character (linear or nonlinear), any power factor, and any crest factor.

Battery Control

As described earlier, the batteries must have a life expectancy that exceeds, ideally, the useful life of the UPS itself. And in the ideal UPS system, batteries should function exclusively as a backup-coming into play only during a power failure from the electric utility company. These two points form the basis for determining the three important parameters that must be realized with respect to electrical storage batteries.

First and most important is the maximum time the battery can be expected to operate the load in the event of actual utility power failure. When selecting a UPS with adequate backup duration, it should be noted that 70 percent of all power failures in the United States last less than two minutes. This suggests that during the first two minutes it is acceptable to continue operating the computer, in anticipation of power being restored. If after two minutes, power has not been restored, prudence requires than an orderly shutdown of the computer should be initiated.

The duration of this shutdown routine-and the amount of battery power backup time-depends on how the shutdown will be accomplished, manually by the operator or automatically by the host computer via the UPS data interface.

In single-phase UPS applications for micro-and minicomputers, 10 minutes of battery back up time is more than adequate for manual shutdown. If automatic shutdown is used, 5 minutes of battery backup time is adequate.

In three-phase UPS applications 15 minutes is often necessary, because the larger amount of data being saved requires additional time. In most instances, the emergency generator will be activated and brought on-line during this 15-minute period. Certain industries use emergency power generators to continue to supply power to their operations for hours or days that power failures sometimes last.

The second parameter to determine is battery recharge time. Simply put, the faster the UPS can recharge its battery, the faster it will be ready to provide battery backup power in a subsequent power failure.

In principle, UPS systems would signal computers to indicate that the resumption of operations is risky during occasions when there is inadequate battery backup time to execute an orderly shutdown of the computer. Current battery technology limits the speed of recharge to approximately eight times longer than the fastest discharge. If this limit is exceeded, the battery could begin gassing, creating a fire hazard.

An acceptable recharge time should be two to four hours.

The third parameter is the battery operating life. This life is limited by two major electrical conditions: pulsating currents and float voltage. The pulsating currents measured in RMS units must be less than 20 hours battery discharge current. Additionally, the float voltage must provide for the batteries to maintain 80 percent capacity after &-1O years.

Load Interaction

In keeping with users' demands and needs, UPS systems must not allow degradation of the voltage reliability under any load's influence. To be totally reliable, the voltage must be within computers' amplitude and waveform specifications when UPS powers:

- Loads with surge power requirements that are 7-10 times larger than the operating load power for 20 seconds
- Nonlinear (electronic) computer load with a crest factor of at least three
- Linear loads with any power factor, lagging or leading

Line Interaction

Line interaction criteria require that there must be no mutual harmful interaction between the electric power line and the UPS.

The UPS input current must not exceed the nonlinear computer load current; therefore no power line service with higher current would be required. This means that the UPS input power factor shall be almost at unity, and that the sinewave current being drawn from the electric utility power line would be like that drawn by a light bulb. Such current will not distort the electric utility voltage waveform.

The UPS system's continuous operation frequency range must be within 5 percent of nominal frequency; this is especially important where emergency generators are used.

The UPS must be able to operate continuously without utilizing battery backup during brownout conditions, such as when input voltage can be as much as 2(0-25 percent be-low nominal value.

The UPS must also be indifferent to the effects of lightning strikes (spikes) within the parameters defined by IEEE Standard C62.41-1980, Categories A and B. The UPS must prevent spikes from propagating through to the output and the load. For reference, lightning stresses are in 6,000 V and 3,000 A range.

Controls, Indicators, and Interface

Generally, users prefer UPS systems to be not obtrusive(i.e., to have few controls and indicators beyond those that are essential). To this end, the UPS must have a minimum of an on/off switch/circuit breaker, and visual and audible indicators of operation from the battery that will alert users of the power remaining in the batteries prior to exhaustion during power failures.

A data interface is required only when the computer software operating system is utilizing a UPS monitoring routine. Under these circumstances, the hardware and data parameters of the UPS interface are specified by the software.

Common Mode Noise Reaction

Another criterion for UPS selection is the system's response to common mode noise. The UPS system selected by the parameters given thus far will eliminate any power disturbance between the current carrying conductors of the computer system. But there is another disturbance, one not attributable to the power being delivered to the computer by the UPS, but rather one associated with the electrical safety of the computer operation.

All computer systems have a grounding conductor connected to the earth wound of any building. Usually the grounding conductor is part of the current carrying conductor plug.

The voltage induced on current carrying conductors in relations to a grounding conductor is called "common mode voltage." This voltage can cause computers to malfunction, not as a power disturbance but as an effect of electromagnetic interference (EMI). Figure 15 shows the path for the current from this common voltage source.

The common mode current found in the grounding loops will propagate through the coupling capacitance of the computer's internal power supply. The capacitive character of the coupling causes the loop current to be proportional to the frequency of the common voltage. Current state-of-the-art technology of minicomputers is such that this effect is observable at frequencies above 100 kHz, and not observable in microcomputers. At low frequencies and especially at power line frequency-there are no common voltage effects.

Two different approaches can be used to eliminate common mode noise effects. One is to install an isolation transformer (one that has significantly lower coupling capacitance than the computers internal power supply coupling capacitance) and thereby reduce the common mode noise current. The second is to use a filter which reduces common mode voltage approximately 1030 times at frequencies of 100kHz and higher. Filters are significantly less expensive than transformers and rapidly gaining popularity in the market.

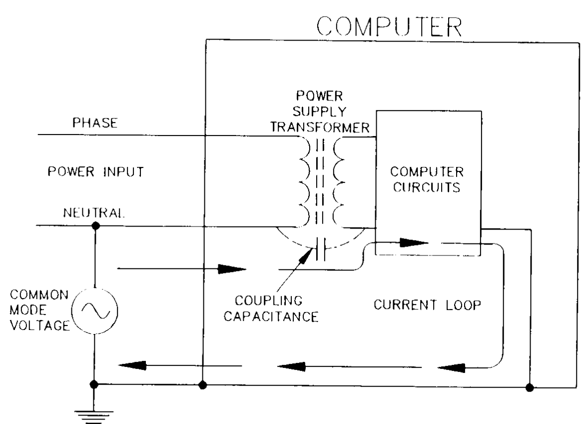

FIGURE 15. Common mode voltage effect.

It should be noted that having one current-carrying conductor on the output of the isolation transformer (usually called "neutral") connected or bonded to the grounding conductor does not guarantee the elimination of the effects of common mode noise. Only the use of a significantly smaller coupling capacitance transformer (one smaller than the computers internal power supply coupling capacitance) will have the desired effect.

The low frequency voltage between the neutral and grounding conductor can be of any value within the voltage rating of the electrical service without causing any common mode voltage effects. For example, in continental Europe, electrical plugs are not polarized. There, a user can connect the computer neutral to either power line neutral or power line phase without any common mode noise effects.

Sizing

It is absolutely essential that the computer's starting power demand be smaller than the UPS system's overload power rating. Likewise, the computer's operating power demand must be smaller than the nominal power rating of the UPS. The challenge is to find the UPS that can meet a given computer load's surge power requirement while not providing excessive operating power.

To select the correct UPS, there are three steps:

First: Select the computer equipment that the UPS will support.

Second: Determine the nameplate power requirements of the equipment.

a. Read the nameplate labels on each piece of equipment and add up the amperes (A) ratings that each requires.

An option is to actually measure the amperes ratings of each piece of equipment using a True RMS current meter. This usually will lead to a lower rating and a more economical model UPS.

b. Multiply the amperes sum by the load voltage (V) requirement.
Example: 6A x 120V = 720VA (volt-amperes)

Third: Determine the individual start up (surge) power requirements of the equipment.

a. Select the individual components which will be turned on while the others are already operating.
b. Add up the amperes ratings (by using the nameplate rating or a True RMS current meter readings that each of those individual pieces requires.
c. Multiply the amperes sum by 10.
Example: 4A x 10 = 40A
d. Add this number to the amperes ratings of the remaining pieces of equipment.
Example: 40A + 2A = 42A
e. Multiply this number by the voltage rating.
Example: 42A x 120V = 5,040VA

Use these final two numbers: the operating power requirement and the starting power requirement to select the UPS that will meet the needs of this system.

SUMMARY

Today's computers are the backbone of business. Clearly, for reliable computer operations, reliable power is an absolute necessity. UPS systems that keep up with computer technology progress and meet user expectations for reliable power do satisfy this critical need.

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