2

Operational Requirement

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2.1 Working Temperature Limit

2.1.1 Impact of Server Inlet Temperature

The rack/server supply air/water has an influence on the IT power consumption and also on the cooling system consumption. On one hand, the influence of temperature on the IT power consumption varies depending on the cooling system (air cooling or liquid cooling) and server architecture (i.e. AMD, Intel). There are several analyses available in literature characterizing this phenomenon. Figure 2.1 shows different correlations for liquid- and air-cooled systems [1]. As expected, the increment of supply air or water temperature increases the IT power consumption. Notice that the increments found in air cooling servers are higher than in the liquid, due to the fact that not only the current leakage is affecting the increase in the server consumption, but in the case of air cooled servers, the internal fans are responsible for this extra increase. The velocity of these fans normally is controlled internally by the server, and it is a function of the CPU temperature. Moreover, the life expectancy of computers goes down if the temperatures are too high, so the CPU manufacturers always specify maximum permitted temperatures for each CPU. On top of that, the server manufacturers specify maximum permitted temperatures for the entire server that is typically far lower than the permitted CPU temperatures.

On the other hand, working at high inlet, air/water temperatures reduces the energy consumption of the cooling system. For instance, if the inlet air temperature is 27ºC in a Data Centre which also has an air-free cooling, most of the year the Data Centre will operate using free cooling and therefore minimizing the hours of mechanical cooling. Similarly, if the heat generated

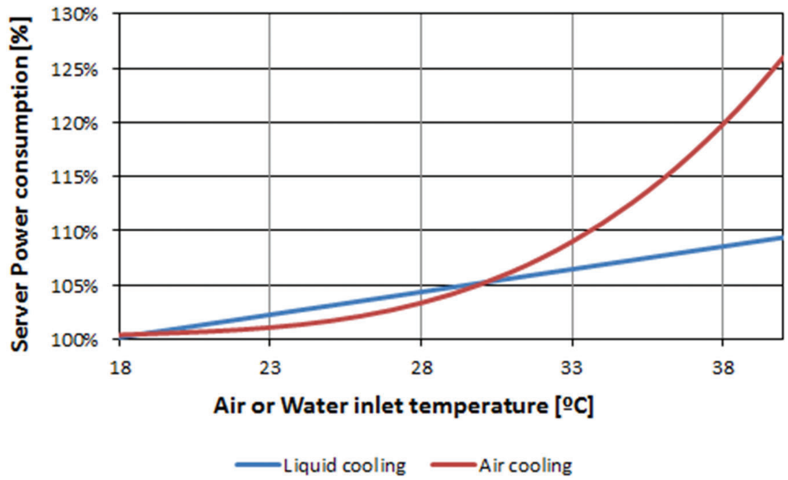


Figure 2.1 Variation of the IT power consumption for different cooling technologies [2].

by the IT equipment will be reused, the usefulness of the waste heat is much higher if the temperatures of the return water/air are higher.

Therefore, the goal is to find the optimal temperature range where the combined IT and cooling load is minimized. This temperature sweet spot varies by IT equipment, refrigeration technology, containment solution, the use of additional thermal energy efficiency strategies and other factors. It is important to note that not all Data Centres can immediately take advantage of the increase in operational temperatures. Historically, whitespace analysis results in a disparity in delivered temperatures due to inefficient air management systems, and therefore, an attempt to raise the temperature can put the systems located in hot spots at risk.

2.1.2 Permitted Temperatures of Individual Components

It is important to know that servers are built from many different systems such as memory RAM, CPU, HDD and main board. To gain a better understanding of the permitted temperatures of the individual components, Figure 2.2 shows the data found in the literature which can vary ±10ºC [2]. Notice that this data can change in the near future since the IT technology is improving faster but to have the numbers in mind it is a good approximation. But the permitted temperatures are only part of the thermal requirements. More important is the influence of higher temperatures on the life expectancy. Figure 2.3 contains a

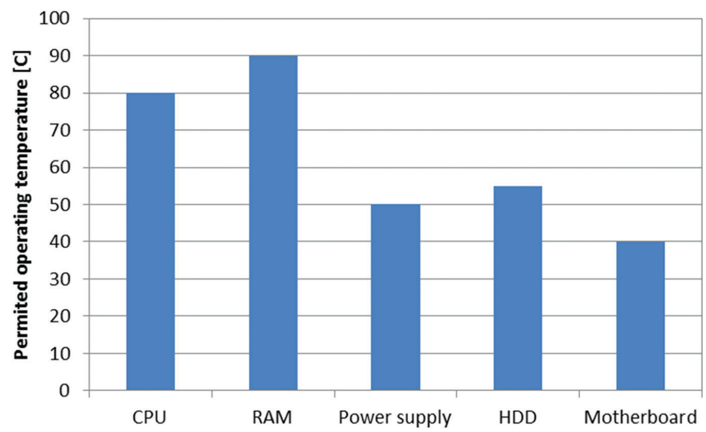


Figure 2.2 Permitted operating temperatures of different components.

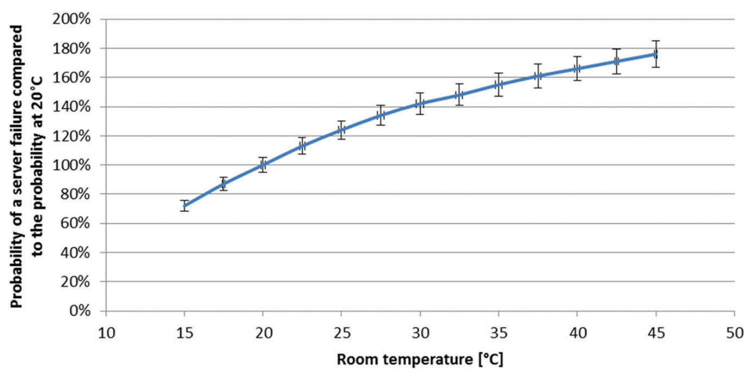


Figure 2.3 Probability of server failure versus room temperatures [3].

diagram based on data from [3] which shows the probability of a server failure compared to the probability at 20ºC in function of the room temperature.

2.1.3 CPU Power Management and Throttling

Since recently, it used to be that the CPU was running at a certain frequency, and as long as the maximum permitted CPU frequency was not reached, it will be continue running at maximum speed. However, in the last few years, this management changed completely. To study deeply this phenomenon, a power management block was introduced in a processor which measures the temperatures and the power consumption trying to overclock it as much as possible based on the following criteria [4]:

- Number of active cores
- Estimated current consumption
- Estimated power consumption
- Processor temperature

The experimentation was done using a thermal budget power management in which the CPU was used as much as possible while ensuring not overheat of itself. Thus, the lower the CPU surface temperature is, the better the chance of actually using the entire thermal budget and the better the chance of getting the maximum possible performance from the CPU. So basically if a processor is requested to do a calculation and is cool enough, it will be over clocked and therefore finish the calculation significantly faster than at regular clock speed.

In air-cooled systems, there is a rather steep temperature gradient due to the limits of heat transfer between the CPU die and the cooling air flow. The die temperature at hot spots on the CPU can easily be 30–50 K higher than the air exit temperature, depending on air volume flow, heat sink design and other parameters. From [4] and in particular for an Intel Xeon E5-2697 v2, if the air temperature before the CPU is at 30°C and after the die at 40°C, the die temperature might be 60–70°C and since the maximum permitted CPU temperatures is 86°C, there is enough thermal budget to overclock. On the other hand, if the room temperature is 35°C, the air temperature at the CPU might be 45°C before the die and 55°C after the die, and then, the CPU would not over clock and performance would be lower. Also, the motherboard life expectancy might be in danger because important parts are "cooled" with 55°C air or more [5]. This phenomenon will obviously depend on the internal server configuration, and if there is some other IT equipment after the CPU or not.

2.2 Environmental Conditions

2.2.1 Temperature and Humidity Requirements

The IT equipment is the main contributor to electricity consumption and heat production of a Data Centre. Thus, this incorporates the entire load associated with the IT equipment, including compute, storage and network equipment, along with supplemental equipment such as monitors, workstations/laptops used to monitor or otherwise control the Data Centre. Traditionally, these unique infrastructures have had very controlled environments due to its singularity. In its thermal guidelines for data processing environments, summarized in Table 2.1, the ASHRAE [3] provides suitable environmental conditions for electronic equipment. Moreover, Figure 2.4 shows the temperatures and relative humidity recommended by the ASHRAE for all equipment classes. These values refer to the air inlet conditions in the IT equipment and thus into the room or the cold aisles in cold/hot aisles configuration. A bad control of humidity ranges can put at risk the reliability of the computing equipment. Very high humidity can cause water vapour to condensate on the equipment, while very low humidity can cause electrostatic discharges. Thus, ASHRAE recommends a humidity envelope between 20 and 80%. Besides temperature and humidity, air pollution could also cause failures in IT equipment.

Table 2.1 Summary of 2011 ASHRAE thermal guidelines for Data Centres [3]

	Dry-Bulb Temperature	Humidity Range	Maximum Dew Point
	Recommended		
Class A1 and A4	18–27ºC	5.5ºC DP to 60% RH and 15ºC DP	–
	Allowable		
Class A1	15–32ºC	20% to 80%	17ºC
Class A2	10–35ºC	20% to 80%	21ºC
Class A3	5–40ºC	8% to 85%	24ºC
Class A4	5–45ºC	8% to 90%	24ºC

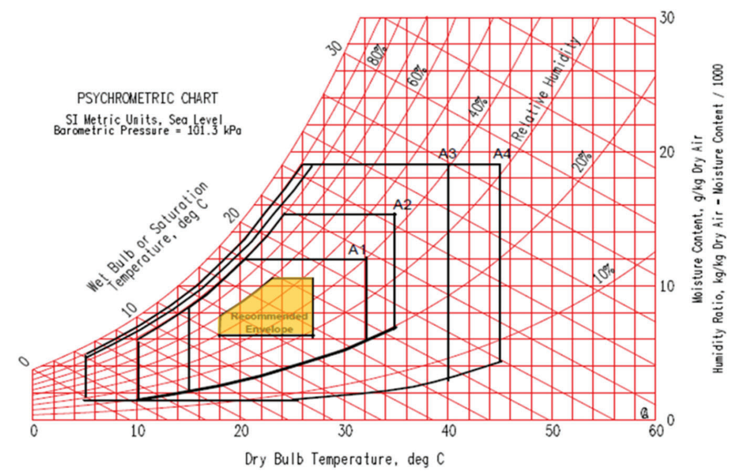


Figure 2.4 ASHRAE thermal guides for Data Centre operating environments [3].

2.2.2 Quality of the Room Air

Besides temperature and humidity, air pollution could also cause failures in Data Centres equipment. The effects of gaseous pollution and particles on different types of equipment failures are well documented. It is well known that moisture is necessary for metals to corrode but pollution aggravates it. Two common modes of IT equipment failures due to environmental contaminations are as follows [6]:

- Copper creep corrosion on printed circuit boards
- Corrosion of silver termination in miniature surface-mounted components.

Therefore, when operating in polluted geographies, Data Centre operators must also consider particulate and gaseous contamination that can influence the acceptable temperature and humidity limits within which Data Centres must operate to keep corrosion-related hardware failures rates at acceptable levels. Particulate (dust) contamination is characterized by its quantity and corrosiveness. The quantity of dust contamination can normally be identified by visual inspection of the IT equipment and by the filter replacement frequency. ISO 14644-1 has become the dominant, worldwide standard for classifying the cleanliness of air in terms of concentration of airborne particles. Table 2.2 provides maximum concentration levels for each ISO class. ASHRAE recommends that Data Centres be kept clean to ISO Class 8, which may be achieved simply by specifying the following means of filtrations:

- The room air may be continuously filtered with MERV 8 filters, as recommended by ASHRAE Standard 127 (ASHRAE 2007).
- Air entering a Data Centre may be filtered with MERV 11 or MERV 13 filters as recommended by ASHRAE (2009b).

For Data Centres utilizing free air cooling or air-side economizers, the choice of filters to achieve ISO class 8 level of cleanliness depends on the specific conditions presented at that Data Centre. In general, air entering a Data Centre may require use of MERV 11 or, preferably, MERV 13 filters.

Direct measurement of gaseous contamination levels is difficult and is not a useful indicator of the suitability of the environment for IT equipment. A low-cost, simple approach to monitoring the air quality in a Data Centre is to expose cooper and silver foil coupons for 30 days followed by coulometric reduction analysis in a laboratory to determine the thickness of the corrosion products on the metal coupons. ASHRAE recommends that Data Centre operators maintain an environment with corrosion rates within the following guidelines:

Table 2.2 ISO 14644-1 (ISO 1999) Air cleanliness classification vs maximum particle concentrations allowed [6]

	Maximum Number of Particles in Air (Particles in Each Cubic Meter Equal to or Greater Than the Specified Size)					
	Particle Size, μm					
ISO CLASS	>0.1	>0.2	>0.3	>0.5	>1	>5
Class 1	10	2				
Class 2	100	24	10	4		
Class 3	1000	237	102	35	8	
Class 4	10,000	2370	1020	352	83	
Class 5	100,000	23,700	10,200	3520	832	29
Class 6	1,000,000	237,000	102,000	35,200	8320	293
Class 7				352,000	83,200	2930
Class 8				3,520,000	832,000	29,300
Class 9					8,320,000	293,000

- Copper reactivity rate of less than 300 A/month
- Silver reactivity rate of less than 200 A/month

For Data Centres with higher gaseous contamination levels, gas-phase filtrations which are commercially available are highly recommended.

2.3 Power Quality

Power quality is a concern when IT equipment has to work properly. As defined by international standards, there are five basic requirements related to power supply to support IT equipment without malfunction or damage which are described below.

2.3.1 Input Voltage within Acceptable Limits

Most equipment manufacturers use universal PSUs that can support the various input voltages and frequencies found worldwide. That means the PSU in the IT equipment is likely to support the low 100 V AC, high 240 V AC, single-phase sources of 120 V and 240 V, and three-phase sources with voltages of 120 V, 208 V and 240 V. By standards set forth by the Server System Infrastructure Forum [7], a PSU rated for 120–127 V should operate normally at voltages ranging from 90 to 140 V. A PSU rated for 200–240 V should operate normally on input voltage from 180 to 264 V. Real design margins are even somewhat broader because of the need to handle input voltages from any country around the world. The power output from the PSU may even be automatically limited by input voltage to protect the PSU and internal circuitry from damage if connected to the lower voltage range.

2.3.2 Input Frequency within Allowable Ranges

Power supplies for IT equipment are typically designed for universal operations. That means a typical PSU can operate normally at frequencies from 47 to 63 Hz to accept utility power at both 50 Hz and 60 Hz. Moreover, the UPS should be able to regulate output frequency to meet the PSUs specification range of 47–63 Hz for all frequency variations in the AC power source.

2.3.3 Sufficient Input Power to Compensate for Power Factor

Power factor is the ratio of real power (W) to apparent power (VA), where real power is the capacity of the circuit to perform work, and apparent power is the product of the current and voltage of the circuit, which also includes current affected by reactive compounds. A power factor of 1 indicates that the voltage and current peak together, which means that the VA and watt values are the same. Poor power factor had been known to cause failed neutral conductors, overheated transformers and, in the worst cases, building fires. The power factor of a circuit is influenced by the type of equipment being powered:

- Circuits containing only resistive elements have a power factor of 1 (Figure 2.5).
- Circuits containing inductive elements have what is known as a "lagging" power factor because the current waveform lags the voltage waveform

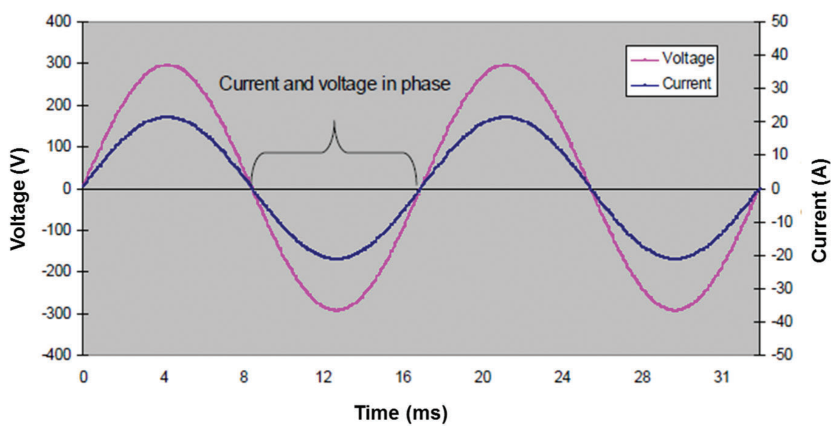


Figure 2.5 Resistive loads [7].

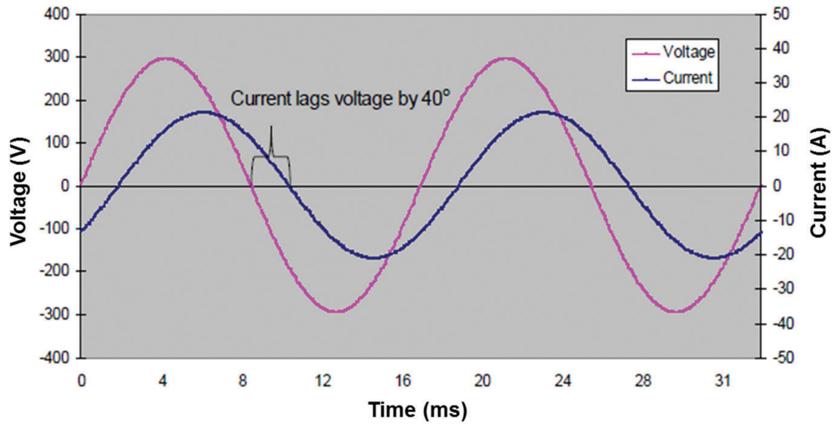


Figure 2.6 Lagging loads profile [7].

(Figure 2.6). Inductive elements consume reactive power. A consumption of reactive power by a load or generator can decrease, depending on the ratings of the load or generator, the voltage at its connection point with the network. If the voltage is reduced, the currents flowing through the generator/load have to be increased to maintain the same power generation/demand. High electrical currents imply high power losses.

- Circuits containing many capacitive elements have a "leading" power factor. The voltage waveform lags the current waveform. Capacitive elements generate reactive power. Generation of reactive power can increase the voltage at the connection point of an electrical load or generator. Conventionally, capacitive reactive power flows throughout the network is not permitted for voltage stability issues.
- Circuits containing a mixture of reactive components typically have what is known as a distortion power factor. The current drawn on the input is a mixture of the fundamental frequency, as well as several harmonic frequencies (Figure 2.7).

Power supplies used in IT equipment generally fit into this last category (harmonic load, Figure 2.7) due to the variety of power sources, load power profiles and power conversion systems based on electronic power devices. However, the current drawn from the source is much less distorted than that shown before. The harmonic distortion and the power factor are directly related. Thus, the higher the power factor of a device is, the lower the harmonic distortion.

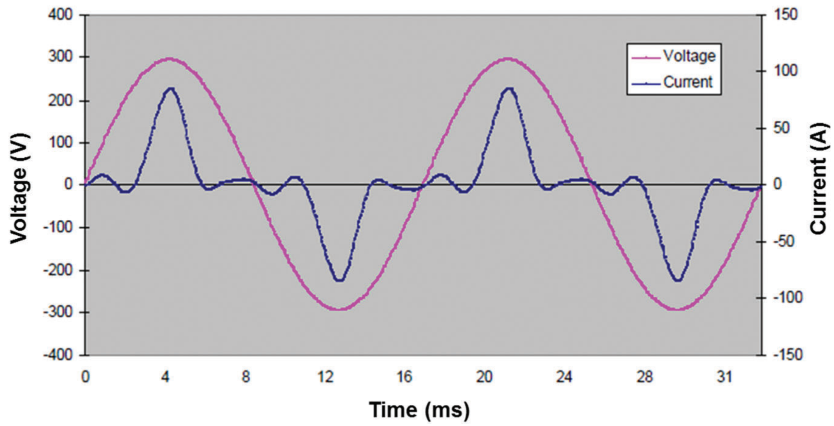


Figure 2.7 Harmonic load profile [7].

Nowadays, the PSUs used in IT equipment have a power factor trending towards unity, because of the need to minimize reactive currents for cost reduction in filters and cables, among others. The size of these components is directly related to the magnitude of the currents flowing through them, and therefore to the magnitude of reactive currents due to the presence of inductive or capacitive consumptions/generations, respectively, affecting the power factor of the installation. Moreover, and as previously noted, harmonic current content in the AC source feeding the IT loads is related to the power factor of the installation. Therefore, a power factor of 0.9 would be considered acceptable, 0.95 would be typical, and a value of 0.99 would be excellent. Since the power factor in a typical Data Centre is still less than unity, it is necessary to supply slightly more apparent power to get the real power needed.

2.3.4 Transfer to Backup Power Faster than PSU "Hold-up" Time

According to IT equipment standards, minimum hold-up time at fully rated output power is one cycle. At 50 Hz, this translates into 20 ms, while at 60 Hz, it would be 16.7 ms. Since most IT equipment is designed for the global market, the minimum hold-up time is 20 ms and may be longer at lighter loads. A related issue with respect to hold-up time is the peak inrush current (Table 2.3) required to charge up the capacitor that provides the ride-through capability. When first connected to an AC power source, the equipment temporarily draws a large inrush current that can last for 2–10 ms and be as much as 10–60 times the normal operating current.

Table 2.3 Example IT equipment nominal and peak inrush current

Equipment	Maximum Nominal Current	Peak Inrush Current
HP Proliant DL 360 G4 – IU server	2.4 A	61 A for 3 ms
HP Proliant e-class blade server	1.6 A	100 A for 2 ms
IBM BladeCenter, fully loaded	23.7 A	200 A for 4 ms
IBM x-series 260	4.9 A	120 A for 4 ms
Cisco 3825 Router	2.0 A	50 A for 10 ms

2.3.5 Protection from Damaging Power Conditions

PSUs are designed to handle voltage that sags 10% below nominal specification or surges 10% above, without loss of function or performance. If the nominal voltage range is 200–240 V, the PSU will operate normally when input voltage is as low as 180 V or as high as 264 V. The PSU is also required to handle surges of 30% from the midpoint of nominal for 0.5 cycles (8–10 ms). These tolerances are well defined by the Information Technology Industry Council curve shown in Figure 2.8 [8]. Voltage conditions within the upper and lower boundaries are safe. Below this zone is a low-voltage area where the

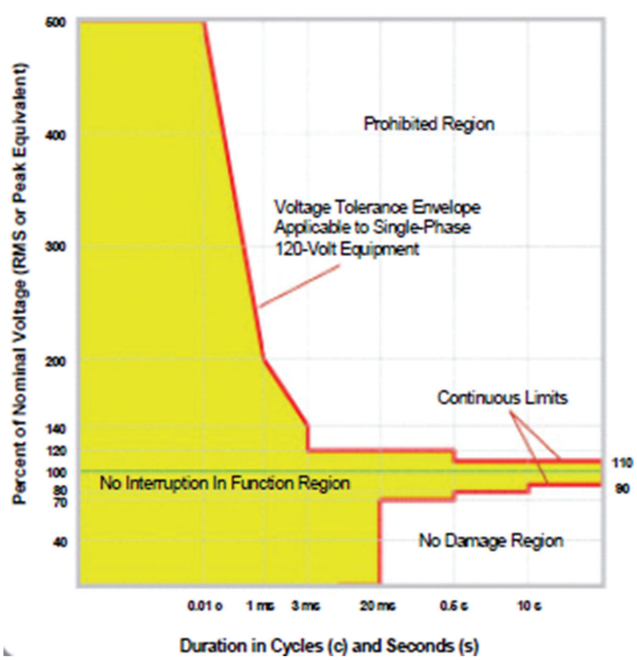
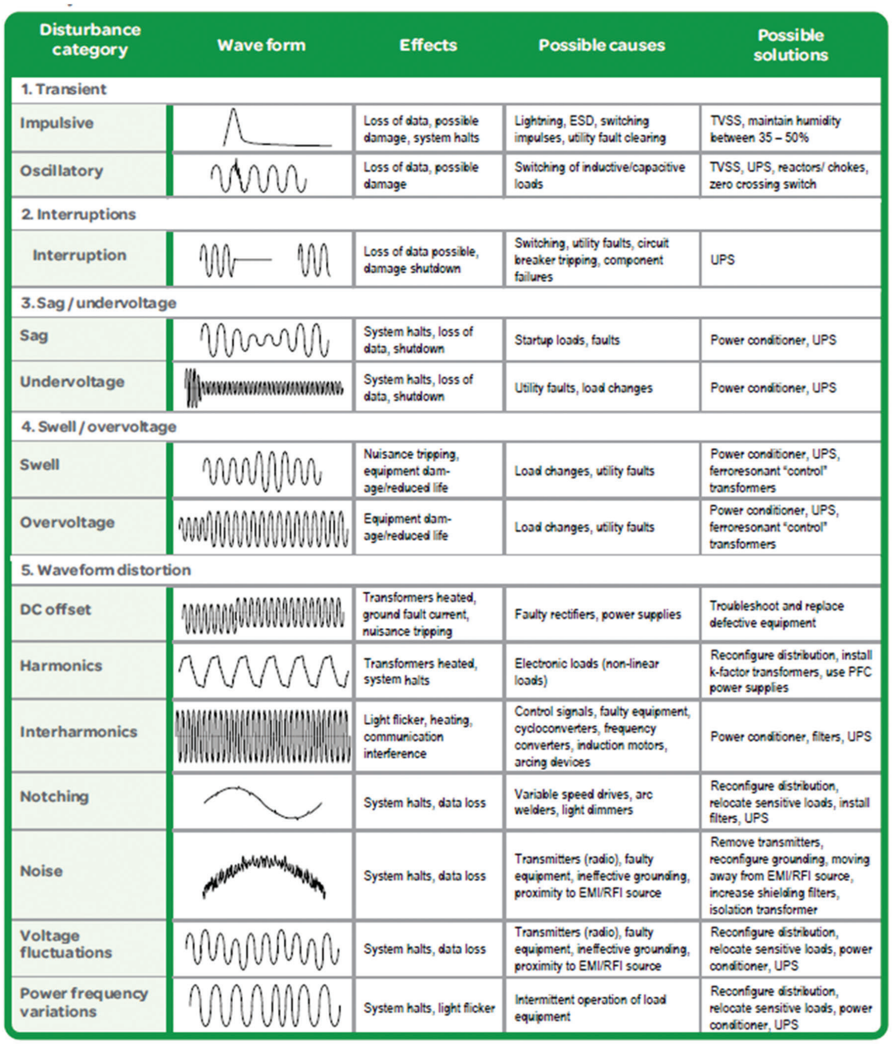


Figure 2.8 Range of power conditions that IT equipment can tolerate [8].

PSU would not be expected to operate normally, but it would not be harmed either. Above is the prohibited region, where voltage conditions could damage the equipment.

Moreover, IEEE Standards [9, 10] define and illustrate power quality disturbances and how to prevent them. Thus, Figure 2.9 summarizes the power disturbances and provides possible solutions to mitigate the effects that these problems can have on Data Centre operations.



Disturbance category	Wave form	Effects	Possible causes	Possible solutions
1. Transient				
Impulsive		Loss of data, possible damage, system halts	Lightning, ESD, switching impulses, utility fault clearing	TVSS, maintain humidity between 35 – 50%
Oscillatory		Loss of data, possible damage	Switching of inductive/capacitive loads	TVSS, UPS, reactors/ chokes, zero crossing switch
2. Interruptions				
Interruption		Loss of data possible, damage shutdown	Switching, utility faults, circuit breaker tripping, component failures	UPS
3. Sag / undervoltage				
Sag		System halts, loss of data, shutdown	Startup loads, faults	Power conditioner, UPS
Undervoltage		System halts, loss of data, shutdown	Utility faults, load changes	Power conditioner, UPS
4. Swell / overvoltage				
Swell		Nuisance tripping, equipment damage/reduced life	Load changes, utility faults	Power conditioner, UPS, ferroresonant "control" transformers
Overvoltage		Equipment damage/reduced life	Load changes, utility faults	Power conditioner, UPS, ferroresonant "control" transformers
5. Waveform distortion				
DC offset		Transformers heated, ground fault current, nuisance tripping	Faulty rectifiers, power supplies	Troubleshoot and replace defective equipment
Harmonics		Transformers heated, system halts	Electronic loads (non-linear loads)	Reconfigure distribution, install k-factor transformers, use PFC power supplies
Interharmonics		Light flicker, heating, communication interference	Control signals, faulty equipment, cycloconverters, frequency converters, induction motors, arcing devices	Power conditioner, filters, UPS
Notching		System halts, data loss	Variable speed drives, arc welders, light dimmers	Reconfigure distribution, relocate sensitive loads, install filters, UPS
Noise		System halts, data loss	Transmitters (radio), faulty equipment, ineffective grounding, proximity to EMI/RFI source	Remove transmitters, reconfigure grounding, moving away from EMI/RFI source, increase shielding filters, isolation transformer
Voltage fluctuations		System halts, data loss	Transmitters (radio), faulty equipment, ineffective grounding, proximity to EMI/RFI source	Reconfigure distribution, relocate sensitive loads, power conditioner, UPS
Power frequency variations		System halts, light flicker	Intermittent operation of load equipment	Reconfigure distribution, relocate sensitive loads, power conditioner, UPS

Figure 2.9 Summary of disturbances with solutions [11].

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