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Highly Reliable Electrical Power for Information Systems

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Executive Summary

Highly reliable electrical power systems are required to serve critical Information Systems (IS) sites, designated as Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) facilities in the Department of Defense (DoD). This course provides an overview of power quality problems, with an emphasis on Information Technology (IT) equipment. Modern technology's sensitive components present new challenges for plant engineers who design, specify, install, or maintain plants and equipment. For example, SCR and diode rectifiers in computers, copiers, solid-state lighting ballasts, and power conversion sections of adjustable frequency drives increase the need to thoroughly address harmonic distortion and its role in overall power quality.

Introduction

The specific aspect of power quality addressed is the buildup of harmonic distortion in contemporary IT facilities. This is due to the hundreds of non-linear power supplies in UPS, PCs, motors, HVAC, routers, switches, and other IT equipment contained in typical IS sites. These equipment affect the overall facility power factor, produce resonance conditions, overload wiring and transformers, generate excessive heat, result in excessive power expenses, and in extreme cases, can present fire hazards.

Means of reducing these effects by the use of specially-designed harmonic eliminator transformers, use of "power factor corrected" power supplies, specifying equipment that meets IEC and IEEE specifications, oversizing neutral wiring, selection of K-rated transformers, etc., will be discussed. The main emphasis will be the measurement of power quality, elimination of problems, and designing telecommunications facilities to avoid power quality degradations in accordance with the NFPA 70 and IEEE 519.

The power industry and the power engineer are confronted with new problems because of the extensive use of a solid state power conversion technology, called Switched Mode Power Systems (SMPS). SMPS consists of various types of solid state switching elements. These switching elements are solid state devices such as: SCR's, DIAC's, transistors and capacitors. These switching devices are used in computers, copy machines, fax machines, telecommunications equipment, solid-state drives and controls, energy-efficient lighting ballasts, and numerous types of DC-Power Loads. These solid state elements degrade AC power by continuously switching on and off producing non-linear or non-sinusoidal wave shapes in the current supplied from the energy source.

A non-linear load (such as the SMPS) uses current in large pulses from the AC source which creates harmonic distortion. These non-linear current pulses can exceed the nameplate ampere rating of the power source and may cause transformers to run hotter than expected, even when these transformers are supplying less than 50% of their rated nameplate capacity.

With non-linear loads, overloaded neutrals are also showing up in three-phase panel boards serving single-phase loads. In some cases the neutral conductor carries 180 Hertz currents, rather than 60 Hertz currents. This phenomenon is called triplen harmonics. Triplens are multiples of three, which do not cancel but are additive in the neutral conductor.

Figure 1 is a recommended medium capacity (up to 2500 kVA) IS facility configured for maximum reliability and power quality.

The system uses one or two pad-mounted service transformers with primary selective feeders to the facility from the off-site power source. This system employs two low-voltage paralleled standby diesel generators, paralleling switchgear, and one or two large uninterruptible power supply (UPS) systems. The main computer or server room would have numerous power distribution centers that supply conditioned power to the load. The kilovolt ampere rating of the transformer shall be sufficient to supply the

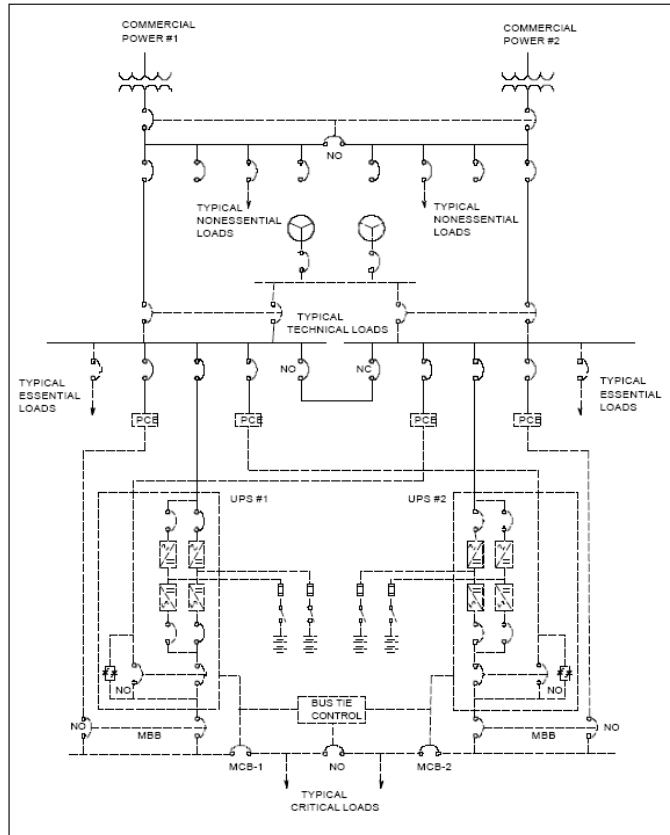


Fig. 1 Medium IS Facility

peak demands of the C4ISR site technical

facilities and any non-essential support facilities continuously without exceeding the 65°C (149°F) thermal rating in an ambient temperature typical for the site. The transformer shall have provisions for the future addition of fans. The kilovolt ampere rating may be reduced to 90 percent of the peak site demands if a double-ended substation is used, but the transformer shall be equipped with one stage of fans, with provisions for the future addition of a second stage.

System- or source-generated disturbances to IS facilities can include sags, surges, switching transients, frequency variations, high or low voltages, power outages, or harmonic distortion. Power degradations, with the exception of harmonic distortion, may result from faulty generation or regulation equipment, poor wiring techniques, improper grounding, or overloaded or unbalanced circuits. Harmonic distortion, on the other hand, is an inherent characteristic of power generation equipment and nonlinear switching power supplies. The performance of some electronic equipment will be affected by odd

harmonics (third, fifth, seventh, etc.) which are of sufficient amplitude to cause distortion. “Isolation from the power grid using transformers, motor generators, UPS etc., usually solves power quality problems (MIL-STD 419, paragraph 4.4.2).” But total harmonic distortion is a main operational problem even when on-site power systems are used, since it is generated internally.

Nonlinear loads cause harmonics to flow in the power lines. Harmonics are unwanted currents that are multiples of the fundamental line frequency (50 or 60 Hz). Fig. 2 shows how the 3rd harmonic of the power line frequency sums in a typical power system. These harmonic currents can overload wiring and transformers, creating heat and, in extreme cases, fire. In information technology power systems it is important to know how to identify and to eliminate these harmonics.

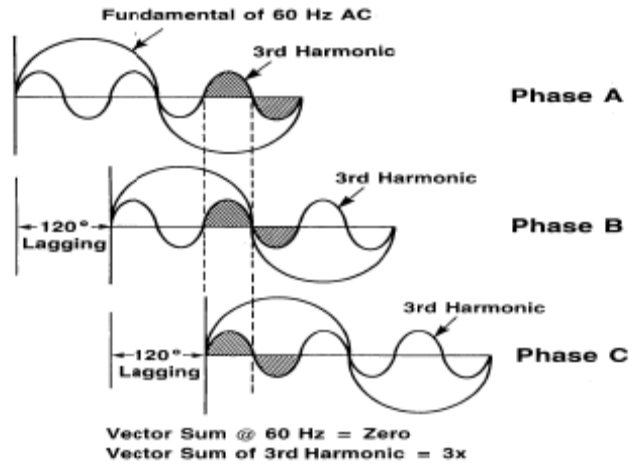


Fig. 2 Third Harmonic Addition

The load itself will draw a current wave made up of the 60 Hz fundamental frequency of the voltage source plus 3rd and higher order odd harmonic (multiples of the 60 Hz fundamental frequency), which are all generated by the non-linear load. It is not uncommon for portions of an industrial power system to have 15 to 25% of Total Harmonic Distortion (THD). THD is defined in the Institute of Electrical and Electronic Engineers (IEEE) Standard 519-1992 as:

$$V_{THD} \%_{\text{fundamental}} = \left(\frac{\sqrt{V_1^2 + V_2^2 + V_3^2 + \dots + V_n^2}}{V_{\text{fundamental}}} \right) \times 100$$

The amount of voltage distortion that can be tolerated on a power system is dependent upon the equipment connected to it and the equipment’s susceptibility to nonsinusoidal waveshapes.

Therefore, THD is the percent of odd harmonics (3rd, 5th, 7th, ..., 25th, ...) present in the load which can affect the transformer. This condition is called a "Non-Linear Load" or "Non-Sinusoidal Load".

In practice, it is far easier to use standard power quality monitoring equipment to determine the presence of harmonics, as shown in Fig. 3. The harmonic distortion for each phase is indicated, i.e. Phase A is black, Phase B is red, Phase C is blue. The magnitude of each harmonic is given in comparison with the fundamental power line

frequency. Most equipment also gives a table with the measured values of the individual harmonics.

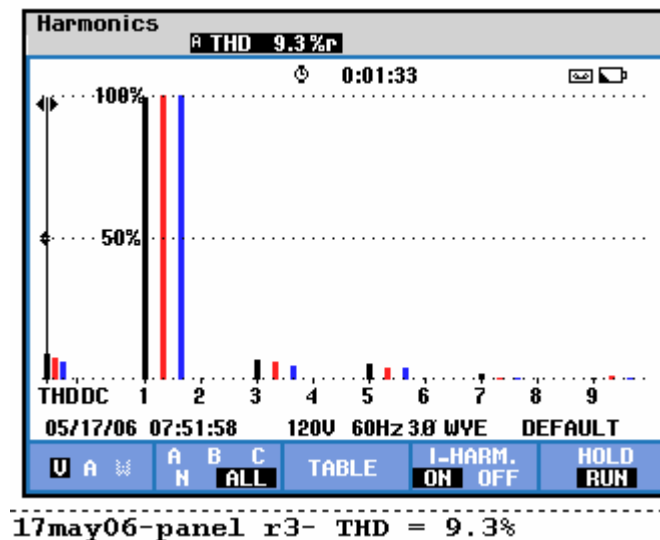


Fig. 3 Measured Harmonic Values

The IEEE-519-1992 standard lists a “Recommended Practice ...” specifically singles out electronic equipment (section 6.6) and highlights its sensitivity to distortion of the supply voltage waveform. It lists the consequences of excessive distortion - erratic equipment functioning and premature failures. Recommended limits are set at 5% Total Harmonic Distortion (THD) with no individual harmonic exceeding 3% of the fundamental. If it is determined from the electrical load analysis that the voltage THD will be greater than 5 %, or that any individual frequency voltage harmonic exceeds 3% of the fundamental, the power system shall be stiffened. Acceptable methods for stiffening the power system and reducing the effects of harmonics include:

- Increasing the transformer sizes
- Increasing the sizes of conductors and connectors
- Adding additional transformers and conductors
- De-rating transformers and motors and/or replacing them with larger ones
- Using only IT equipment complying with IEEE 519 or other relevant industry standards which limit the generation of harmonics
- Redistributing loads to balance three-phase load currents (as well as harmonics)

Balancing phase line currents will not necessarily reduce neutral current.

Balancing the phase load currents in a 208Y/120 volt three phase system (making load currents equal in each phase) will normally reduce neutral current to zero if load currents have an *undistorted* sinusoidal wave shape. However, **when load currents occur in short pulses, they are rich in harmonics. The 3rd harmonic and odd multiples of**

3rd (i.e. the 9th, 15th, etc.) will not cancel each other in the neutral. In fact, the neutral current consisting of these harmonics can be as high as 1.73 times the phase current. If the neutral conductor is the same size as the phase conductors, the heating in the neutral can be as much as three times the heating effects present in each phase conductor.

It is important to note that harmonic values will often change during the day, or the time of the year, as different loads are turned on and off within the facility, or in other facilities on the same electric utility distribution system. Use of a harmonic monitor or power quality monitor with harmonic qualities can record the harmonic values over a period of time for a more in-depth systems analysis. The phase voltages and currents, as well as the neutral-to-ground voltage and neutral current should be monitored. Monitoring the neutral will often show high 3rd harmonic values, indicating the presence of non-linear loads.

Nonlinear IS loads

Most personal computers present a nonlinear load to the AC supply. This is because they have a power supply design known as a "capacitor input switched mode power supply", or SMPS. Switch mode power supplies are notorious for creating radio frequency interference (RFI) and electromagnetic interference (EMI). Lowpass filters in the power mains leads are vital to reduce conducted interference. Faraday screens between the transformer windings and around sensitive components are required to reduce EMI and RFI. Many alternative SMPS circuit designs have been developed to smooth the sawtooth current output waveforms.

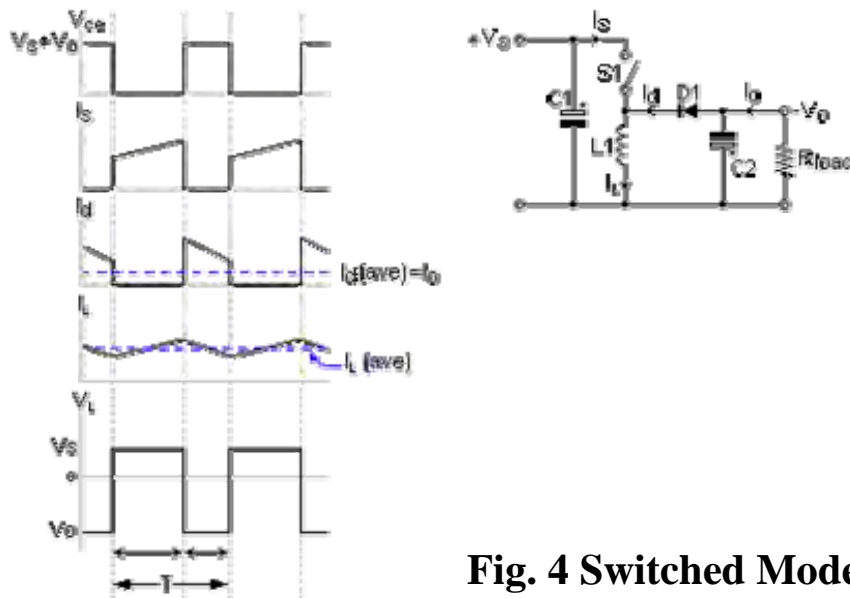


Fig. 4 Switched Mode Power Supply

Fig. 4 shows the smoothed load current, I_L , of a flyback regulator SMPS which approximates a DC voltage. Hundreds of SMPSs in a typical IS facility produce

significant harmonic currents. The series inductance and resistance of standard electrolytic capacitors has a large effect on residual ripple and noise voltages at the outputs.

Most electrical loads (with the exception of half-wave rectifiers) produce symmetrical current waveforms. The positive half of this waveform looks like a mirror image of the negative half. As a result of this only the odd harmonic values are present. The even harmonics will disrupt this half-wave symmetry. If even harmonics are detected with the power quality meter, there is probably a half-wave rectifier on the circuit. This could also result from a full wave rectifier when one side of the rectifier has blown or damaged components. Early detection of this condition in an UPS system can prevent a complete failure when the load is switched onto back-up power.

IT equipment, including servers, routers, hubs, and storage systems, often employs a different power supply design known as "Power Factor Corrected". These devices present a very linear load to the AC supply and do not generate harmonic currents. If these devices are used, they are one of the cleanest loads on the power grid and generate less harmonic current than many other devices, such as fluorescent lighting, or variable speed motors. AC induction motors run at a lagging power factor, but a synchronous motor can run at unity or even at a leading power factor. This is done by controlling the motor power factor by adjusting the excitation of the rotating DC field. Legacy IT devices present nonlinear loads like Personal Computers, but new devices today are commonly constructed using "Power Factor Corrected" designs.

Representative values of various information system loads with their corresponding K-Factors are given in Table 1. The K-Factor rating assigned to a transformer and marked on the transformer case in accordance with the listing of Underwriters Laboratories, is an index of the transformer's ability to supply harmonic content in its load current while remaining within its operating temperature limits. **A specific K-factor rating indicates that a transformer can supply its rated KVA load output to a load of specified amount of harmonic content.**

Type of IS Load	K-Factor	ILK
Telecommunications equipment (e.g. PBX)	K-13	57.74
UPS with input filter	K-4	25.82
UPS without input filter	K-13	57.74
Multiwire receptacle circuits	K-13	57.74
Mainframe Computer Loads	K-20	80.94
Solid State motor drives (variable speed drives)	K-20	80.94
Multiwire receptacle circuits in commercial offices	K-30	123.54
Small mainframes (mini and micro)	K-30	123.54

Table 1 Information System Load Currents

Regulations

- The European Community has developed susceptibility and emission limits for harmonics. For appliances of less than 16 amperes the 555-2 standard (“Harmonic injection into the AC Mains”) was created by the IEC in 1992 to limit the harmonic current injection of “non-professional” equipment. Today, a more encompassing set of standards under IEC 1000-4-7 is in effect. Other international and US standards for harmonic limits include the following:
 - EN61800-3 (IEC1800-3) Adjustable speed electrical power drive systems
 - IEC1000-2-2, Electromagnetic compatibility (EMC)
 - IEC1000-2-4, Electromagnetic compatibility (EMC)
 - IEC1000-3-2, Electromagnetic compatibility (EMC)
 - IEC1000-3-4, Electromagnetic compatibility (EMC)
 - IEEE519, IEEE Recommended practices and requirements for harmonic control in electrical power systems

Nonlinear loading reduces the distribution capacity of the power utility system, and it can degrade the quality of the power by distorting the AC power waveform. It can also increase the risk of fire on a customer's premises.

Because electrical power consumption was increasingly caused by electrical equipment using a capacitor input switched mode power supplies (SMPSs) , the International Electrotechnical Commission (IEC) issued the IEC 555-2 standard in the 1980s. This launched the development of Power Factor Corrected power supply technology.

In 1995, the IEC updated the IEC 555-2 standard, called IEC 1000-3-2 to cover all equipment drawing up to 16Amps per phase. The standard added additional limitations on both the absolute and percentage values of harmonics for products with nonlinear switched mode power supplies. The European Community (EC) adopted its own version of this standard later in 1995 as EN61000-3-2 and required equipment manufacturers to comply with the standard. This directive gave manufacturers until 1998 to comply for existing product designs. Later, the EC further extended this deadline to Jan 1, 2001.

The standard limits harmonic current injection as follows:

Harmonic	Maximum Permissible Harmonic Current per Watt (ma / W)
Third	3.4
Fifth	1.9
Seventh	1.0
Ninth	0.5
13 th	0.35
...	3.85 / n
39th	3.85 / n

Computer OEMs now specify IEC 1000-3-2 compliance for new OEM equipment intended for system integration. Most IT equipment other than small PCs complies with the standard, although non-compliant PCs are still sold in the US.

A system comprising equipment meeting the IEC 1000-3-2 standard has the following characteristics:

1. The harmonic current in the neutral circuit has less than 2% of the current contributed by harmonics greater than the third harmonic.
2. The "K" factor of the system has a theoretical maximum value of 9, provided that no loads are greater than 675W. The theoretical maximum "K" factor is reduced for greater loads (For example, with 2kW loads the maximum "K" factor is 3).

The theoretical maximum neutral current is 1.7 of the rated phase current value. This requires that all circuits are loaded to maximum rating, no loads exceed 675W, and all loads are generating a third harmonic at the compliance limit. If there are larger loads, then the theoretical maximum neutral current is reduced. Some loads are connected phase-to-phase (particularly in the USA), and therefore do not contribute to the neutral current.

Measurements of the harmonic currents in Table 2 were taken with a Fluke Power Line Analyzer. The K-factor was computed using IEEE Std 1100-1992. The neutral current ampacity sizing factor was computed for a 3 phase system loaded to maximum capacity.

System 1	System 2	System 3	
4 servers, table library, Network Attached Storage System	All PC loads	50-50 mix of PCs and networking equipment	
1.2	11.4	5.2	K-Factor
8	102	42	Neutral sizing as a % of phase conductor

Table 2 K-Factors for IS Loads

The data shows a tremendous difference between the K-Factors for PCs and networking equipment. When PCs and networking equipment are mixed, the K-Factor and neutral sizing requirements are reduced from the PC value. Where there is a large population of PCs, the K-factor was measured in other tests from 7.5 to 10.5. Neutral oversizing may be necessary in these environments.

Harmonics can overload the neutral wiring and create a potential fire hazard. Computers generate a substantial amount of 3rd harmonic currents which add out on the neutral wire.

The harmonic current alone in the neutral wire can, in theory, be up to 1.7 times larger than the full rated current of the power wiring. This is the most critical problem relating to harmonics and PCs. The neutral current can reach the phase current value in a PC environment. The neutrals should never be undersized in an office environment for this reason. In addition, fluorescent lighting ballasts also present nonlinear loads.

Harmonics can overload power transformers and shorten their useful life. Power transformers are rated in KVA and are designed to carry currents at the power line frequency (50 or 60 Hz). The factor that limits the power handling capacity of a transformer is the heat it generates. The heat in a transformer is caused by the internal resistance of the transformer and the current carried by it. When a power transformer carries harmonic currents, an effect known as the proximity effect causes the effective resistance of the transformer to increase with frequency.

The transformer rating must be decreased if the transformer carries significant harmonic currents, otherwise it will overheat and the insulation will degrade. Transformer failures are often catastrophic and emit noxious fumes or fire. Three facility conditions increase the probability of this type of failure:

1. The transformer must be loaded nearly to capacity ;
2. The transformer must have a poor "K" factor rating ; and
3. The load in the building must consist of mainly PCs.

Elimination and Reduction of Harmonic Problems

The objective is to reduce harmonic distortion at a minimum cost. Specific solutions include:

1. Specifying equipment that does not create harmonics in the first place
2. Correcting harmonics by proper selection of equipment
3. Oversizing neutral wiring based on measured harmonic distortion data
4. Specifying suitably K-rated transformers
5. Reduce voltage harmonic levels to the IEEE-519-1992 limits
6. Insure that the transformer and associated cables are not overloaded.
7. When possible, use passive solutions for maximum simplicity, greatest reliability, lowest maintenance and overall costs.
8. Do not use capacitors because of the risk of resonance
9. Use power factor correction UPS to power clusters of PCs and IT equipments
10. Use harmonic filters and harmonic eliminating transformers as required

If a UPS is used with the equipment, it can correct or eliminate the harmonics to some extent. Some single phase UPS eliminate neutral current entirely. If a power factor correcting UPS is used to power clusters of PCs, the harmonics problem cannot pass upstream to the building wiring or power transformers. This approach has the advantage that it can be retrofitted to an existing building, and used with existing loads.

Harmonic filters isolate harmonic current to protect electrical equipment from damage due to harmonic voltage distortion. They can also be used to improve the power factor. The detrimental effects of harmonic distortion can be manifested in many different ways, such as increased heating effect on electrical distribution equipment and cables, loss of synchronization (computers, routers, etc.), capacitor overloads, fluorescent light flickering, and others. For other types of loads, such as large industrial motor drives which are not covered by regulations governing harmonics, specialized products are available that can absorb harmonics near the source

Local electrical codes may permit undersizing the neutral wire, but the presence of harmonics in IS facilities preclude this. In modern facilities the neutral wiring should always be specified to be the same capacity as the power wiring (or larger). Particular attention should be paid to wiring in office cubicles, as the multiwire receptacle K-Factor data in Table 1.

Sizing transformers for harmonic non-linear loads

The K-Factor calculation is used instead of the THD formula, to determine the harmonic content for dry type transformers. The total amount of harmonics will determine the percentage of non-linear load, which can be specified with the following typical examples:

Transformers shall be sized to account for harmonic non-linear loads of 50% minimum (K-4), 100% (K-13), 125% (K-20), 150% (K-30).

The neutral connection shall be sized at 200% of the current rating of the phase connections.

The conductors of the transformer winding shall be sized to handle circulation of 3rd harmonic currents and not exceed the rated temperature rise.

Transformers shall be capable of operating within the specified temperature rise while supplying 100% of the 60 Hertz fundamental rated current values plus the following harmonics as calculated by ANSI/IEEE 57.110-1986.

50% Non-Linear Load (K-4 Rating)

16.7% of the rated current at the 3rd Harmonic

10.0% of the rated current at the 5th Harmonic

7.1% of the rated current at the 7th Harmonic

5.6% of the rated current at the 9th Harmonic

Beyond the 9th Harmonic the percentages of the fundamental current through the 25th Harmonic shall be equal to the reciprocal of the odd harmonic number involved times $\frac{1}{2}$. A FPT Type FHK4 series transformer, for example, is designed for 100% linear load plus 50% non-linear load which can operate at a total K-factor load value of 4.0.

100% Non-Linear Load (K-13 Rating)

33.3% of the rated current at the 3rd harmonic
20.0% of the rated current at the 5th harmonic
14.3% of the rated current at the 7th harmonic
11.1% of the rated current at the 9th harmonic

Beyond the 9th Harmonic the percentages of the fundamental current through the 25th Harmonic shall be equal to the reciprocal of the odd harmonic number involved times 1.0. A FPT Type FHK13 series transformer is designed for 100% linear load plus 100% non-linear load which can operate at a total K-factor load value of 13.0.

125% Non-Linear Load (K-20 Rating)

41.7% of the rated current at the 3rd harmonic
25.0% of the rated current at the 5th harmonic
17.9% of the rated current at the 7th harmonic
13.9% of the rated current at the 9th harmonic

Beyond the 9th Harmonic the percentages of the fundamental current through the 25th Harmonic shall be equal to the reciprocal of the odd harmonic number involved times 1.25. A FPT Type FHK20 series transformer is designed for 100% linear load plus 125% non-linear load which can operate at a total K-factor load value of 20.

THE UL APPROACH FOR SELECTION OF TRANSFORMERS

A transformer intended for use with loads drawing non-sinusoidal currents shall be marked "Suitable for non-sinusoidal current load with K-factor not to exceed x. (x= 4, 9, 13, 20, 30, 40 or 50)

The transformer load losses (PLL) calculated as a function of the eddy current losses (PEC) and the total I²R losses (PDC):

$$\text{PLL}=\text{PDC}(1+\text{K}(\text{PEC}))$$

where K= the K-factor rating at the transformer (4, 9, 13, 20, 30, 40 or 50)

The impedance losses and the I²R losses shall be determined in accordance with the Test Code for Dry Type Distribution and Power Transformers, ANSI/IEEE C57.12.91-1979.

The loss of a diode in a rectifier circuit can cause DC currents to accompany the harmonic load currents. A dc component of load current will increase the transformer core loss slightly, and may increase the magnetizing current and audible sound levels .

Relatively small dc components (up to the RMS magnitude of the transformer excitation

current at rated voltage) are expected to have no significant effect on the load carrying capability of a transformer determined by this recommended practice. Higher dc load current components may adversely affect transformer capability and must be corrected.

Harmonic currents flowing through transformer leakage impedance and through system impedance may also produce some small harmonic distortion in the voltage waveform at the transformer terminals. Such voltage harmonics may cause extra harmonic losses in the transformer core. Rising core temperatures are not usually the limiting factor for safe values of nonsinusoidal load currents.

Common mode noise can be suppressed using a grounded shield between the primary and secondary windings of a Noise Isolation Transformer. The grounded shield provides a low impedance capacitive coupling path to ground which prevents unwanted high frequency signals contained in the source voltage from reaching the transformer secondary.

This electrostatic shield does not perform any function with regard to harmonic current or voltage distortion wave forms. However the shield is extremely valuable in protecting sensitive equipment from common-mode electrical noise and transients generated on the line side of the transformer. The electrostatic shielded transformer attenuates higher frequency noise in the 10 K Hz - 100 K Hz range.

Isolation Transformers are designed to meet the requirements of SCR controlled, variable speed motor drives. They are specifically constructed to withstand the mechanical forces associated with SCR drive duty cycles and to isolate the source voltage circuit from low frequency noise generated from SCR voltage spikes and transient feedback.

Estimating K-Factor Loads for Transformers

Each transformer designer must make a decision regarding the K-Factor to assign to any load category. Table 1 is a conservative guide for representative IS equipment loads which produce harmonics.

Calculating K-Factor Load

1. List the KVA value for each load category to be supplied. Next, assign an ILK value that corresponds to the relative level of harmonics drawn by each type of load. Use the ILK values in Table 1 for representative IS equipment.
2. Multiply the KVA of each load times the ILK rating that corresponds to the assigned K-Factor rating. This result is an indexed KVA-ILK value.

$$\text{KVA} \times \text{ILK} = \text{KVA-ILK}$$

3. Tabulate the total connected load KVA for all IS load categories to be supplied.

4. Next, add-up the KVA-ILK values for all loads or load categories to be supplied by the transformer.

5. Divide the grand total KVA-ILK value by the total KVA load to be supplied. This will give an average ILK for that combination of loads.
 (Total KVA-ILK) ÷ (Total KVA) = average ILK

6. From Table 1, find the K-factor rating whose ILK is equal to or greater than the calculated ILK. Corresponding to this ILK is the K-factor of the transformer required.

Problem 1

Calculate the overall K-factor for a typical IS facility, containing the following equipment:

100 Workstation Volt/Amp Requirements (CPU + 17" monitor):

Startup: 120V x (1.35 + 3.5)A = 582VA

Continuous: 120V x (.9 + 1.5)A = 288VA

12 Servers Volt/Amp Requirements (CPU + 15" monitor):

Startup: 120V x (1.35 + 1.0)A = 282VA

Continuous: 120V x (.9 + 1.0)A = 228VA

Continuous CPU only: 120V x .9A = 108VA

20 ea. 40 watt fluorescent lights

30 ea. 20 amp receptacles

4 ea. HVAC 2 h.p. solid state motor drives

Telecommunications equipment (e.g. PBX)	K-13	57.74
UPS with input filter	K-4	25.82
Discharge lighting	K-4	25.82
UPS without input filter	K-13	57.74
Multiwire receptacle circuits	K-13	57.74
Mainframe Computer Loads	K-20	80.94
Solid State motor drives (variable speed drives)	K-20	80.94
Multiwire receptacle circuits in commercial offices	K-30	123.54
Small mainframes (mini and micro)	K-30	123.54

Load Category KVA Load x ILK = KVA-ILK Value

Discharge lighting 1.34

$$(20*40*1.4) / 1000 * 25.82 = 34.70$$

Receptacle circuits 72

$$(30*20*120) / 1000 * 123.54 = 8894.88$$

Servers 3.38

$$(12*2.35*120 / 1000) * 123.54 = 418.06$$

Workstations 58.2	$(100 \times 4.85 \times 120) / 1000 \times 123.54 = 7190.03$
Motor drives 6.26	$(4 \times 230 \times 6.8) / 1000 \times 80.94 = 506.36$

Totals 141.18 17044.03

Total KVA -ILK / Total KVA = average ILK

$17011.03 / 141.18 = 120.49 = \text{average ILK}$

From Table 1, the nearest K-factor greater than or equal to the average ILK of 120.49 is K-30 with an ILK of 123.54.

Problem 2

Substitute Dell notebook computers with an input power requirement of 19.5V / 4.62 A, for the 100 workstations in problem 1 above.

The KVA load for the notebooks becomes: $(100 \times 19.5 \times 4.62) / 1000 = 1112.97$, for a new KVA-ILK value of 10966.97. The total KVA load drops to $141.18 - 49.19 = 91.99$. This will then yield an average ILK of 119.22. We are now able to select a transformer with a K-Factor of 30, but we are moving in the direction of the K-20 transformer. If we select UPS equipment with input filtering and “power factor corrected” power supplies, we can continue to improve the situation. This problem does indicate how we can reduce the effects of harmonics in the facility by substituting notebook computers for workstations. Naturally, we must consider all the planned and programmed new IT equipment in the facility – requirements are continually changing in the IT environment and causing design engineers to reevaluate the facility.

Problem 3

Continuing with problem 2, we now examine the effects of shutting off equipment in the night and its effect on KVA-ILK. Suppose we reduce the receptacle use to ten instead of thirty. The associated KVA-ILK becomes 2964.96 which yields an average ILK of $2964.96 / 93.18 = 31.82$. A transformer with a K-Factor of 13 can now be selected. It can be seen from this problem that the harmonics vary with the load & the time of day,

Problem 4

Calculate the amount of additional K-30 load that can be handled by a 25KVA, K-13 transformer with 9 KVA of spare capacity.

1. Determine the available spare K-13 KVA-ILK, using the ILK that corresponds to the transformer's K-factor rating:

spare KVA x ILK = spare KVA-ILK
 $9 \times 57.74 = 519.66 \text{ spare KVA-ILK}$

2. Divide the spare KVA-ILK by the Index of Load K-rating for the load to be supplied. The ILK for a K-30 load of new IT equipment is 123.54

$$\text{spare KVA-ILK} / \text{new load ILK @ K-30} = \text{maximum additional KVA}$$

$$519.66 / 123.54 = 4.2 \text{ KVA maximum additional KVA}$$

3. Therefore, an additional 4.2 KVA of K-30 information systems load could be added to this transformer. This additional loading represents the absolute maximum non-linear loading for that transformer.

For a transformer already partially loaded, any additional KVA loading must take into consideration the K-factor of each of the new loads to be added.

Guide Specification for Ventilated Dry Type Transformer

1. Transformers shall be UL 1561 listed, type "FHK" and be a Federal Pacific type FHK approved or equal.

2. Transformer shall be designed to supply rated current at 100% linear load plus carry the percent of non-linear odd order load up to the 25th harmonic as listed in Table 3.

K-Factor	% Linear Load	Plus	% Non-Linear Load
4	100	+	50
13	100	+	100
20	100	+	125
30	100	+	150

Table 3 K-Factors Load Relationships

3. The transformer shall be three-phase with the fundamental frequency rating of 60 hertz.

4. Primary winding shall be delta connected and secondary winding shall be wye connected.

5. The transformer windings and terminals shall be aluminum. (Copper option is readily available).

6. The primary shall have two 2.5% full capacity taps above rated voltage and four 2.5% full capacity taps below rated voltage tap.

7. The temperature rise at the rated voltage and rated K-Factor load shall not exceed 150°C when measured by the resistance method as listed in ANSI/IEEE C57.12.91 with a

220°C UL Component Recognition Insulation System. (Optional: 115°C and 80°C temperature rise K-1 through K-20 transformers are also commercially available)

8. The primary and secondary conductor shall be sized; shaped and transposed where necessary, to keep eddy current losses to an absolute minimum. The primary winding conductor also shall be sized to carry the triplen harmonic circulating current effect in the delta winding without overheating.

9. The secondary neutral shall be 2x (twice) the ampacity of the secondary phase conductors for triplens and unbalanced single phase loads.

10. The Basic Impulse Level of all windings shall be 10 KV.

11. The enclosure shall be rated NEMA-1. (Optional: NEMA-3R units are commercially available.)

12. Optional: A full electrical width electrostatic shield shall be placed between the primary and secondary windings of each coil.

13. The average audible sound level shall comply with NEMA ST-20:

10 to 50 KVA - 45 dB
51 to 150 KVA - 50 dB
151 to 300 KVA - 55 dB
301 to 500 KVA - 60 dB
501 to 700 KVA - 62 dB
701 to 1000 KVA - 64 dB
1001 to 1500 KVA - 65 dB
1501 to 2000 KVA - 66 dB

Note: Lower sound levels may be desirable for critical areas such as hospitals, schools or critical mission essential office areas.

GENERIC FPT TYPE FHK/K FACTOR DRY TYPE TRANSFORMER

Type: AA Phase: Three Frequency: 60 Hz Insulation Class: 220°C Enclosure: NEMA-1
Primary Voltage: 480 V Delta (2.5%) 2-FCAN & 4-FCBN Secondary Voltage: 208Y/
120 V

Electrostatic Shield: Optional Windings and Bus: Aluminum (Copper Optional)

References:

ANSI/IEEE C57.110-1986, Recommended Practice to Establish Transformer Capability when Supplying Non-Sinusoidal Load Currents

ANSI/IEEE STD 519-1992, IEEE Guide to Harmonic Control and Reactive

Conclusion

International regulations have improved the specifications for information systems power requirements. Nevertheless, many sources of noise and distortion exist in IS facilities, and methods have been presented to eliminate and reduce the degrading effects by judicious use of “power factor corrected” power supplies, properly designed and selected K-Factor transformers, noise isolation transformers, and other techniques. Information system designs specifying double neutrals and transformers with K-Factor = 20 or above are expensive solutions, but may be necessary in legacy installations.