APPLICATION NOTE
NEUTRAL SIZING IN HARMONIC-RICH INSTALLATIONS

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SUMMARY

Both national and international standards for the conductor sizing of cables do not adequately take into account the additional heat load arising from harmonic currents. Some standards prescribe the maximum current values for four-conductor and five-conductor cables under the assumption that only two or three conductors are loaded. However, today's harmonic situations may give rise to the fourth conductor (neutral) being fully loaded or even overloaded simultaneously with a balanced load on the three phase conductors. Other standards provide a general instruction that under a particular harmonic impact on the phase conductors, a certain additional load has to be taken into account for sizing the neutral conductor. However, the practitioner will usually not know how much harmonic impact arises from a particular load or group of loads.

In the following application note, an approach will be given to estimate the additional thermal impact due to harmonic currents in the LV power supply system of a building. Based on this estimation, it provides a methodology on how to dimension and select three-phase cables that are supposed to feed single-phase final circuits containing distorting loads.

INTRODUCTION

If three A.C. circuits are formed from a three-phase system at the end-user to feed single-phase loads, as is normally the case in any household or office, an effort is made to distribute these loads evenly across the three phases.

However, it has long been known that currents, the curve shapes of which are not sinusoidal, at most only partly cancel each other out in the return, and there has been much discussion of consequences and measures. There have been sporadic reports of neutral conductors burning out. Nevertheless, how relevant are these unquestionably existing effects in the average usage scenario, and how should the planner handle them?

NORMATIVE SITUATION

When the newly revised standard VDE 0298-4 was published in August 2003, these circumstances had again not been taken into consideration, even though they were known at the time. The standard gives a variety of values for the current-carrying capacity of cables and wiring of various cross-sections for different layouts and grouping factors. And yet, just like in the previous version, limit values are only given for cables and wiring with either two or three loaded wires. Once again no account was taken of the fact that today four wires can also be loaded simultaneously in a five-core cable. Indeed, despite the balanced distribution of the single-phase loads, the neutral can conduct additional current – and in extreme cases too much current.
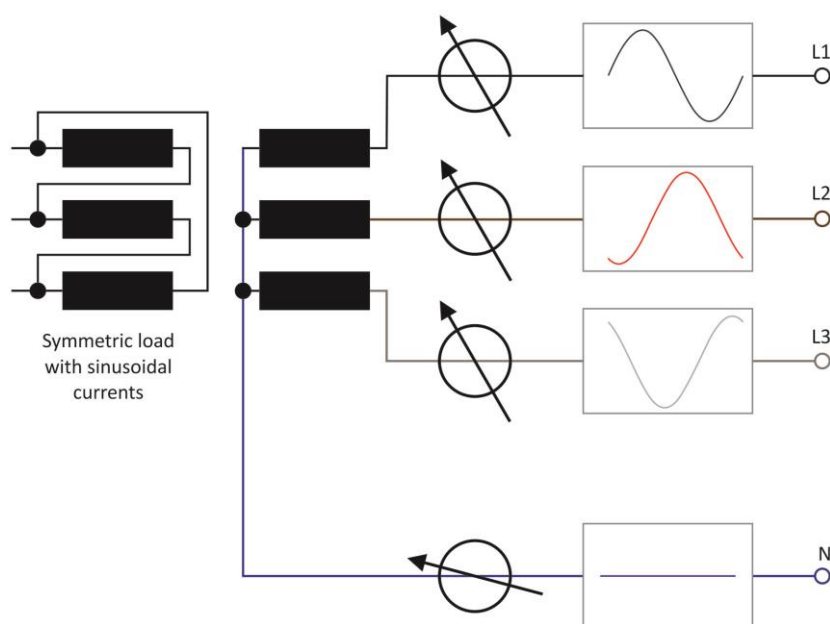

Figure 1 – With a balanced three-phased load the neutral current is zero – provided the loads are linear and with sinusoidal currents.

This shortcoming is shortly covered by Annex E of IEC 60364-5-52 and now stands to be put right in a somewhat more detailed way with the publication of supplementary sheet 3 to VDE 0100-520, which shows the planner how the cables and wiring should be selected and measured if a neutral load is to be expected. Above all, the planner should be put in a position to assess whether such a risk exists at all, and if so, to what extent. The approach adopted there corresponds approximately to the observations below.

THEORETICAL BACKGROUND

In a star-connected three-phase system, the current in the neutral conductor is the vector sum of the three line currents. With a balanced three-phase system, this sum is zero at any point in time and the neutral current is therefore zero, provided the loads are linear (figure 1). These involve a sinusoidal voltage that always results in a sinusoidal (or cosinusoidal) current curve, in other words ohmic, inductive, capacitive and their hybrid forms. Now, a vector sum can only be formed from sine and cosine curves, since simply put, vectors have something to do with angles, and sine and cosine are angle functions. However, other curve shapes can be divided into an infinite sum of sine curves, the so-called harmonics, the frequencies of which are integral multiples of the "fundamental frequency" to be depicted. Vector analysis must therefore be carried out for each of these sine oscillations individually, including the fundamental.
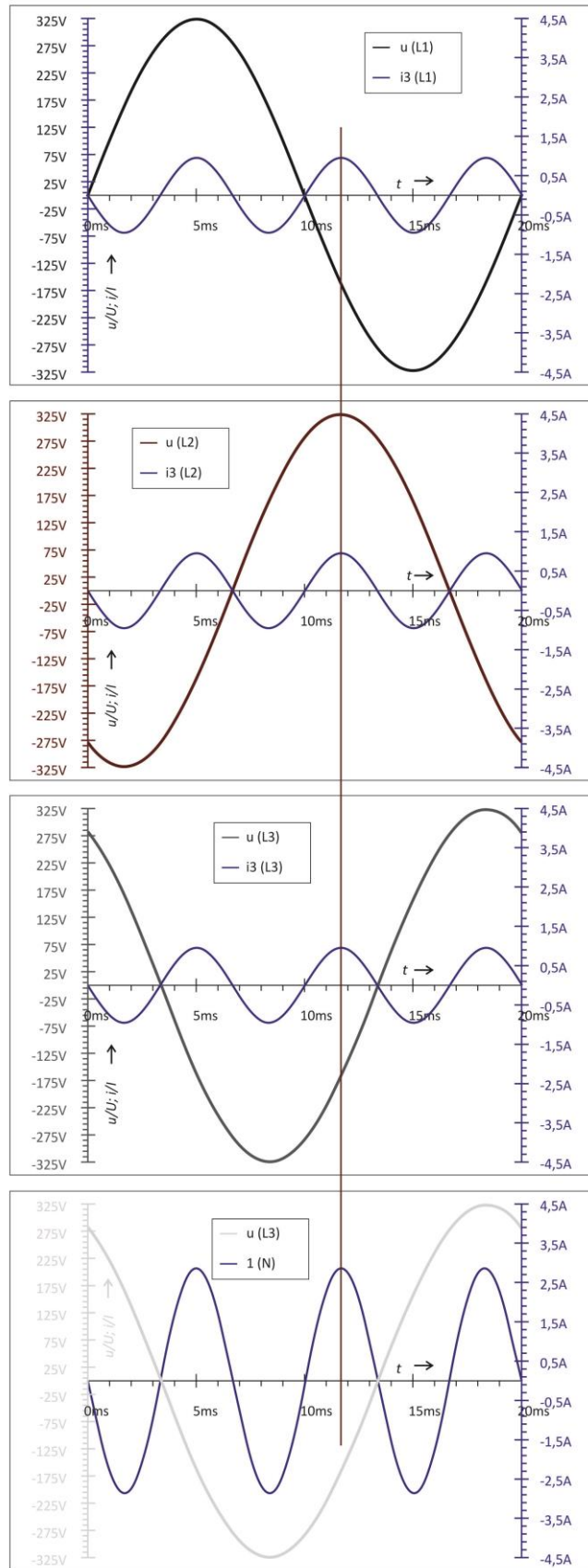
Figure 2 – Voltages (fundamental) and third-harmonic currents in the three phases and in the neutral conductor.
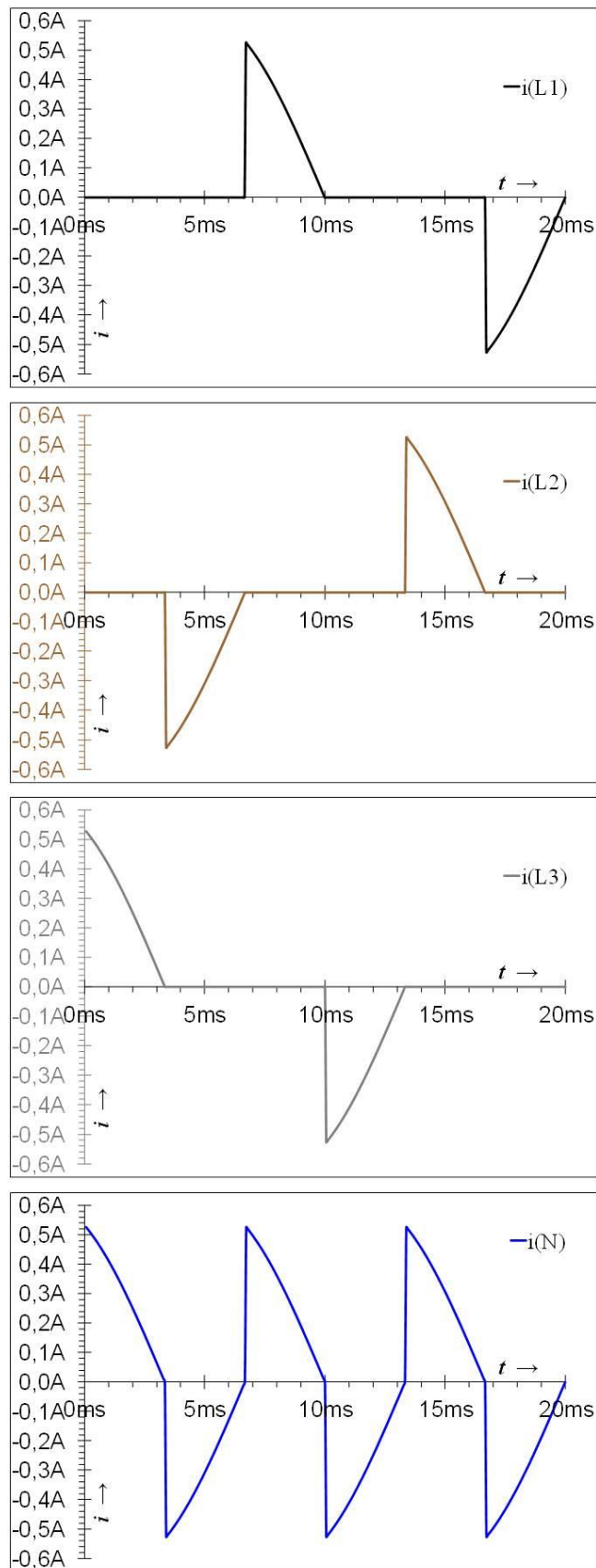
Figure 3 – Phase-angle dimmer with ohmic load (100 W lamp), truncated by 120° (60° conductive angle only): balanced 0.19 A in each phase, but almost 0.33 A in the neutral.

No, this does not require interminable effort, since the amplitudes of these partial oscillations become smaller and smaller towards higher frequencies and therefore lose their practical significance relatively quickly. It is then possible to stop adding together. That's the good news.

The bad news is that the phase sequence and phase angle of these harmonics do not necessarily correspond to those of the (line-frequency) fundamental. In part they have the opposite direction of rotation, and those harmonic numbers that are multiples of three, i.e. primarily the third (150 Hz) and ninth (450 Hz), have no direction of rotation at all, but are in phase in all three phase conductors (figure 2). The even-order harmonics (100 Hz, 200 Hz, 300 Hz, etc.) only occur with unbalanced curve shapes such as one-way rectification, and therefore rarely occur in practical techniques.
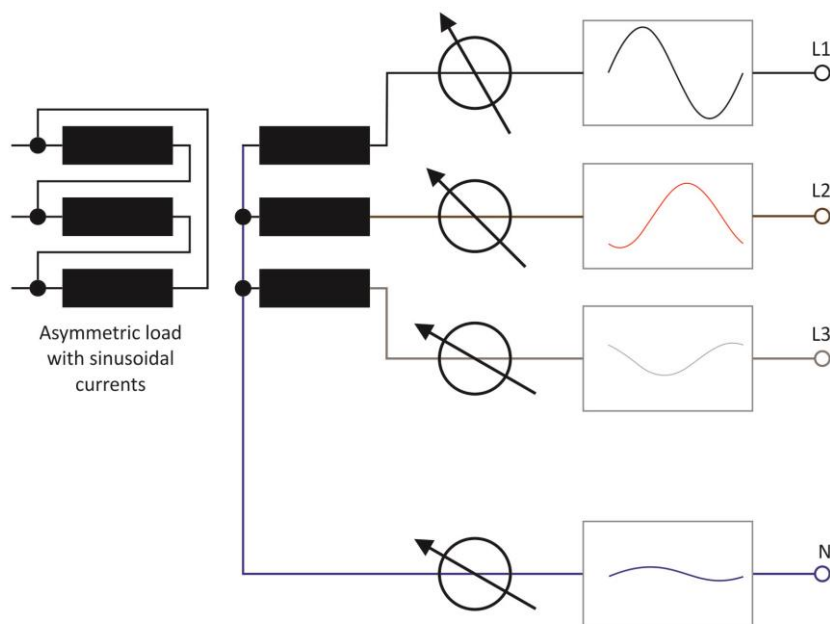

Figure 4 – With an unbalanced three-phase load the neutral current is not zero, but it is smaller than the biggest phase current.

Figure 5 – With a non-linear, albeit balanced, three-phase load the neutral current is not zero and can even be larger than the phase current because of the zero phase-sequence system.

In a three-phase system feeding single-phase loads, the neutral current is rarely zero because the load on each phase is more or less different. Typically, however, the difference is small, and in any case far lower than the biggest phase currents (figure 4). Where non-linear loads are being supplied, however, even when the load is well balanced across the 3 phases, even with the same RMS values and phase angles of the phase currents, there is likely to be substantial current in the neutral conductor (figure 5). For example, three currents with equal RMS values and square shape will result in a significant neutral current, proportionally to the phase current. And the smaller the conductive angle, the more acute the triangle.

Procedure in situations not previously covered by the standards

Under the conditions of current distortion described, heat loss in the conductors is greater than under the linear conditions assumed in the standards, and the line capacity is correspondingly lower. Neutral conductors, often previously undersized, as can often still be found in buildings, can be overloaded without the neutral current reaching the phase current at all.

It is impossible to determine the neutral current unless the real or theoretical wave form of the load currents is known. However, as an approximation the neutral current can be assumed to be around 1.6 times the phase current (figure 6) in the case of rectifier loads such as smaller compact fluorescent discharge lamps, including LED lamps in the range up to a rated power of 25 W, but can also reach its theoretical maximum value of 1.73 times the phase current in the worst situations, e.g. with phase controls set to small delay angles ($\alpha \geq 120°$, see figure 3).

Note on the RMS value

The arithmetic mean value of the neutral current in figure 3 is even 3 times each phase current, as can be seen by simply adding the current/time areas. Since these processes do not reveal any temporal overlaps of the three phase currents, quantitative addition takes place. Only if phase currents partially or entirely overlap in time, in other words if the incoming current of a phase simultaneously forms the reverse current of another phase, can there be a full or partial extinction of the phase currents in the neutral occur. However, the RMS value of the neutral current, which appears without overlaps, is determined by the factor $\sqrt{3}$ (= 1.73), by which the phase current must be multiplied; whereas the arithmetic mean value is determined by the factor 3. However, the measure for the thermal load of a line is the RMS value.
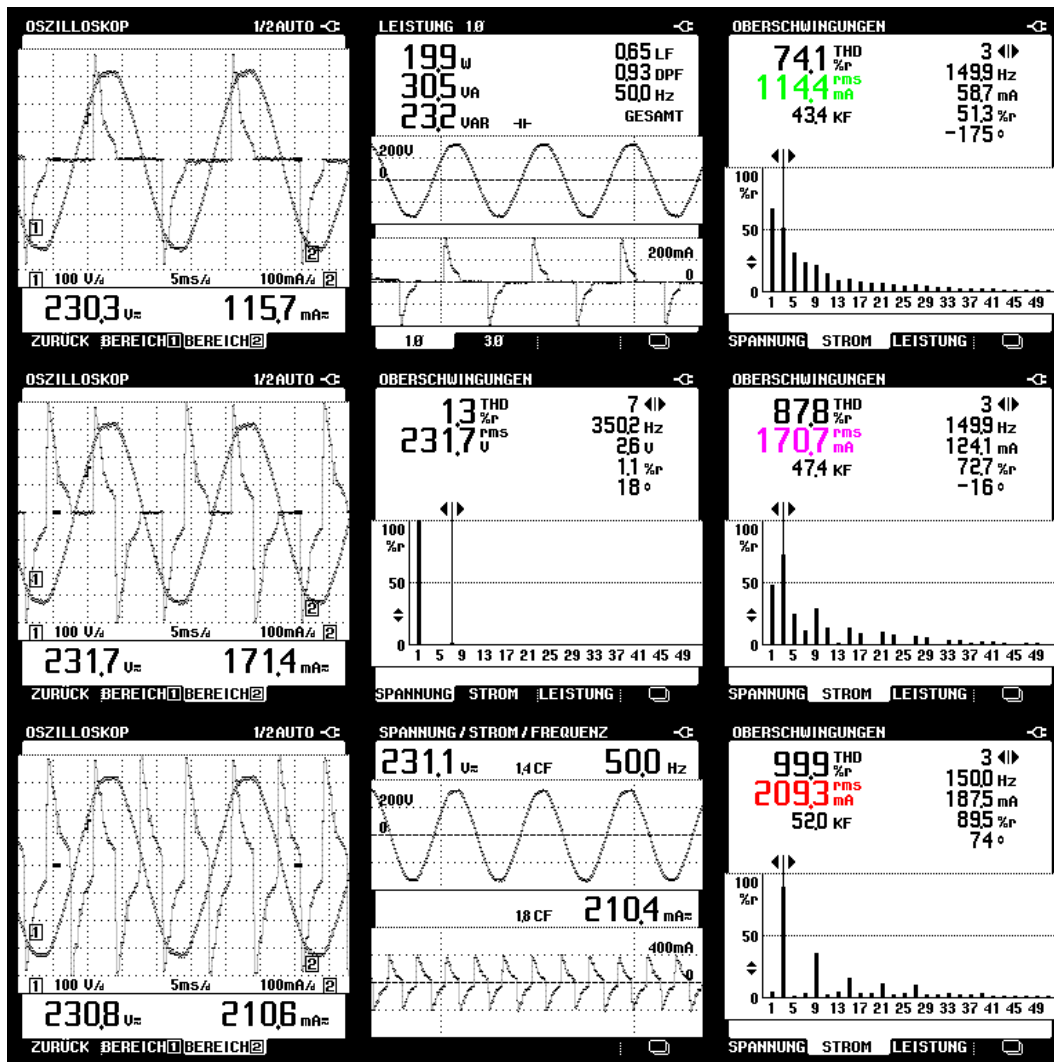
Figure 6 – Operation of 21 W compact fluorescent discharge lamps ("energy-saving lamps") – at the top one lamp connected in single-phase, in the middle two lamps connected in two-phase, at the bottom three lamps connected in three-phase; voltage L1 against N and current in neutral recorded.

In principle, with compact fluorescent discharge lamps with a rated power greater than 25 W, only a small harmonic load on the network need be taken into account (figure 7), since according to EN 61000-3-2:2010-03 significantly lower limits apply here, so that an appreciable additional load of the neutral beyond the single-phase loads caused by unbalanced distribution no longer need be taken into account. In practice, it should be noted that in particular new components such as LED lamps often do not satisfy this requirement, or the requirement is bypassed "quite legally", for example by using two 24 W lamps instead of one 48 W lamp. The type and number of lamps operated is therefore decisive. It is less helpful, for example, to fit the popular quadruple lamps in a commercial building with 4 fluorescent discharge lamps each of 18 W with 4 individual EBs (electronic ballasts) instead of using 2 double EBs or one quadruple EB, to keep the individual power of the appliances < 25 W per EB and bypass the stricter normative limits. Besides, it is better to use IMBs (improved inductive / magnetic ballasts), a combination of tandem and lead-lag wiring and electronic starters, despite these being frequently but incorrectly deemed to be inefficient. Such a system, with some 2400 lights, i.e. 9600 lamps, 9600 starters, 4800 IEBs and 2400 capacitors, has now been running for 5 years without a single outage – no lamp, no IEB, no starter and no capacitor [1] has yet failed.
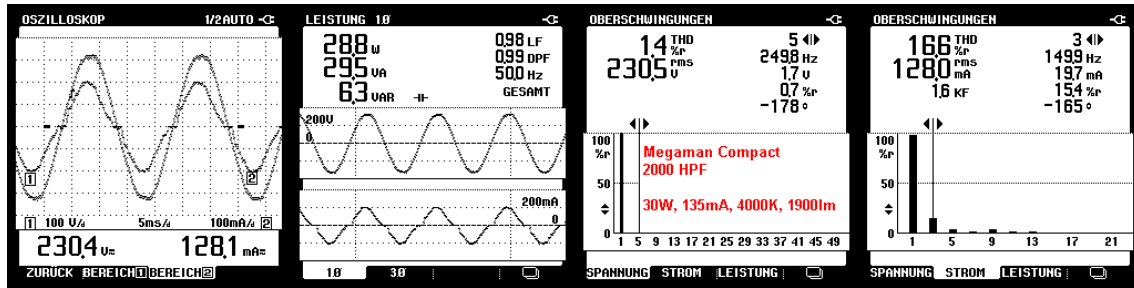
Figure 7 – 30 W compact fluorescent discharge lamp – modern, compliance replacement for an incandescent lamp of around 150 W.

PROCEDURE FOR CALCULATING CAPACITY

To calculate the capacity of a 4- or 5-conductor cable with a neutral loaded by harmonic currents, the THDI (total harmonic distortion) of the current must first be determined. This is the ratio of the total RMS value of all harmonics contained in the load current to the fundamental, in other words to the line-frequency sinusoidal part of the total load current. The load current from VDE 0295 should then be multiplied by the following correction factors (Table 1):

- For phase currents containing up to 15% THDI, no corrective measures are required. Under these circumstances, a neutral current of 45% compared to the phase current can be expected, as well as an increase of about 6% in heat loss across the entire cable compared to the normal cable rating. This excess is normally tolerable.
- For phase currents containing 15 to 33% THDI, the neutral current may be expected to be similar to the phase current, and the cable must be de-rated by a factor 0.86. In other words, for a current of 20 A, a cable capable of carrying 23.25 A has to be selected.

Harmonic content THDI in the phase conductor current	Value selected according to	
	Phase conductor current	**Neutral conductor current**
0% … 15%	1	-
15% … 33%	0,86	-
33% … 45%	-	0,86
>45%	-	1

Table 1 – Reduction factors for cables carrying harmonic currents.

- As soon as the THDI exceeds 33%, the cable must be selected based on the neutral current. For phase currents containing 33% to 45% THDI, the cable size is determined by the neutral current, and the load is to be reduced by a factor of 0.86.
- For even higher harmonic components, the cable size is determined solely by the neutral current. There is no need for a correction factor because the phase conductors are now over-sized, and therefore generate correspondingly less heat, which balances out the overload on the neutral. However, such high harmonic components will rarely ever occur in practice.

Care must be taken to ensure that the correct current is assigned to the correct voltage. In figure 6 bottom right, for example, this is not the case, since there the focus was on the neutral current. However, the

measuring device is still triggered by the mains voltage of 50 Hz. The measuring device interprets this as the fundamental, but with a balanced distribution of the loads in the N-current no longer finds any 50 Hz component. The 50 Hz components still cancel each other out; only for the harmonic components does this not apply. The instrument therefore thinks that the current can only be a distortion current, as there is no longer a fundamental current, and displays a THDI of almost 100%. Obviously that cannot be true. Rather, the N-current only has a fundamental of 150 Hz, and its harmonics of 450 Hz, 1350 Hz, etc. in turn make up the THDI *of this* fundamental. Had the measuring device's voltage circuit been disconnected, the device would automatically have switched to current triggering, not found any further oscillation of 50 Hz and deemed 150 Hz to be the fundamental. That, however, was not the object under consideration (figure 6).

FURTHER INFLUENCING FACTORS

Strictly speaking, any calculation of the effects of current harmonics would also have to include the skin effect that influences capacity depending on the cross-section, but as an initial approach this can be ignored. Finally, two simplification factors were built into the – simplified – method described above, both of which are on the safe side:

- The load placed on the phase by harmonics generally consists of all uneven harmonics, of which, however, only those that are multiples of 3 add up fully in the neutral – and even then only with the same phase angle. The others, conversely, add up only partially or not at all. Nevertheless, it was assumed here that all harmonics add up fully in the neutral conductor. This is justified because as a rule the third constitutes by far the largest component of the total RMS value of all harmonics.
- In addition, harmonics with identical order numbers but of different origin or cause can also have different phase angles and therefore only add up partially instead of fully. For example, the third current harmonic from a PC power supply has a different zero crossing (shortly before the mains voltage peak) from that from a compact fluorescent discharge lamp (well before the mains voltage peak), since the PC power supply is generously equipped with smoothing capacitance, but the "energy-saving" lamp is designed "economically" also with respect to smoothing capacitance. However, it was assumed for calculation purposes that all harmonics of the same order were in phase with each other.

Particular attention has to be given to armoured or metal-screened cables. The contribution of current to eddy current losses in the armour or screen rises by the square of the frequency and may therefore assume to be considerable if harmonics occur.

The voltage drop of all current harmonics causes harmonic voltage distortions in all phases as well as the neutral. This may require a further increase in neutral cross-section, if not the entire cable cross-section, for long cable runs, to keep the total harmonic distortion of the voltage (THDU) within limits. However, this may also require an increase in phase cross-sections beyond the requirements of thermal loadability – even before this is the case for the "normal" voltage drop of the fundamental.

Finally, it should be borne in mind that in commercial facilities with a high workload and long operating times it is in no way economical if a conductor reaches its maximum permissible temperature. Rather, calculations show [2] that a conductor e.g. in installation method C to VDE 0298-4 [3] with a rated cross-section of 16 mm², a load profile close to the maximum permissible current and 2-shift operation after 10 years, is more expensive in the overall operating costs than a conductor with a 50 mm² cross-section. It is therefore more economical to always assume the largest conceivable THDI. The other performance characteristics of the installation, such as voltage drop, are also improved as a result.

ALTERNATIVES

The most direct way to proceed is independent sizing of the neutral conductor. When using single-core cables, the choice of the neutral and phase conductor cross-sections becomes independent. On the other hand, the mutual thermal interaction is more difficult to model analytically because of the varying relative positions. Duplicate logistics also become necessary, for instance for clamp and plug connections of two different sizes. As a rule it is better to use the aforementioned benefits of over-sized phase conductors and therefore to always select these conductors to be as strong as the neutral has to be.

One Swiss manufacturer now offers a cable that has 4 wires of equal cross-section, but 3 phase conductors made from aluminium and a neutral conductor made from copper (figure 8). The shield is also made of copper and is constructed such that it can and may be used as a PE conductor. Unfortunately, this design has thus far only been available as an underground cable and not as installation wiring. But it suggests that in Switzerland, work has now begun on installing in accordance with the TN-S system in new constructions, repairs and extensions, even outside buildings.
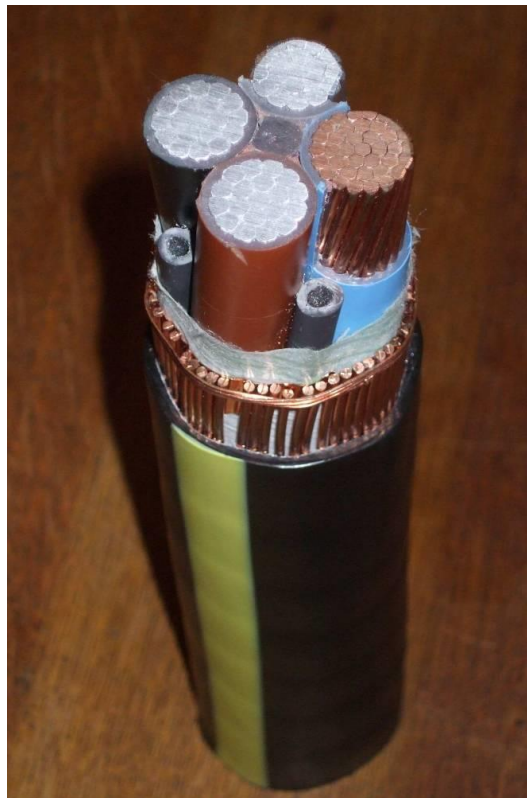

Figure 8 – Compromise cable from Switzerland between high copper prices and high neutral currents.

PRACTICAL GUIDELINES

The weak point of everything described up to this point as a possible way of proceeding lies in the fact that the load on the phase conductors with current distortions, from which the neutral load could be deduced, is not known. In this respect, this way of proceeding is not possible simply because many low-voltage distribution systems have to be planned for buildings for which no users have been found, not to mention the fact that the type of load then has to be guessed. However, equipping a modern office with electrical appliances is very similar to any other modern office. Here, a glance at the characteristics of the consumables normally used in such cases, together with an estimate of numbers, depending, for instance, on the available area or the number of workstations, can help obtain a usable ballpark value. But where to get the data from without stealing them? Manufacturers do not specify the THDI of their appliances. Even current or apparent power are often missing. Therefore, several measurements were carried out on common office equipment by way of example.

EXAMPLE VALUES

Table 2 gives guidelines for the expected neutral load for a selection of typical harmonic-generating single-phase loads as used extensively in residential and office buildings. Since the actual power consumption can sometimes differ considerably from the given power P_{Nom} of the appliances and sometimes no rated power is given at all, typical measured values for the active power P_{Meas} and the apparent power S_{Meas} were also given in each case. It is particularly noticeable that PC power supplies are commonly oversized by several magnitudes, so that a calculation based on rated values would give false results in any event. With part-loads, the THDI, while being smaller in absolute terms (measured in amperes), is higher in relative values (percentages) [4]. The values in actual operation are therefore somewhere in between. The question is where exactly. To be able to estimate this, Table 2 also shows the values for phase currents I_{L1}, I_{L2}, I_{L3} and neutral current I_{N} measured on selected example appliances that are produced if three appliances are operated on the network and spread evenly across the three phases.

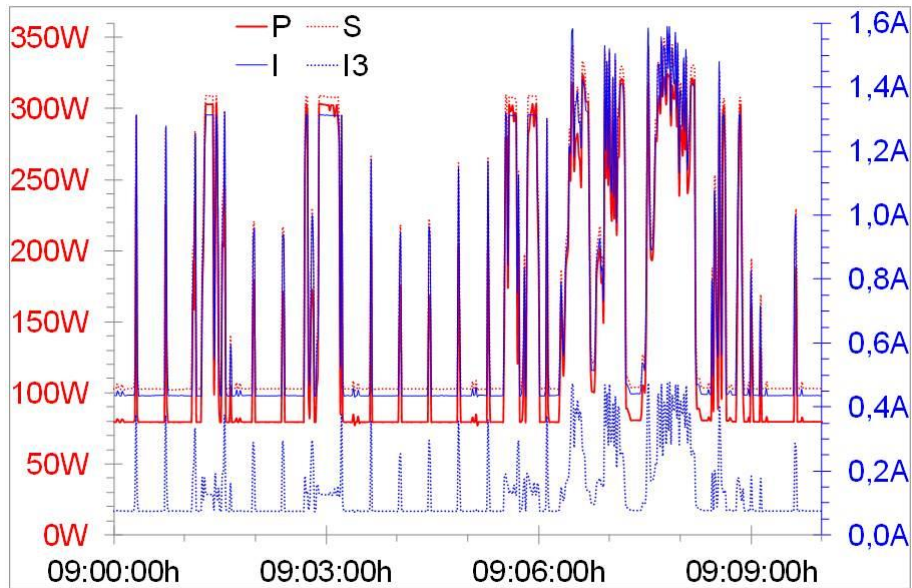*Figure 9 – Long-term measurements on a photocopier.*

Figure 10 – 10-minute snapshot from the 24-hr measurement on a photocopier: "Idling" to approximately 9:03; then something is copied.

IMPLEMENTATION IN PRACTICE

To now find the total load produced by varying numbers of different types of appliances and similar appliances of different powers, proceed as follows:

- For example, three compact fluorescent lamps of 23 W each, one connected to each phase conductor, will load the neutral with around 240 mA. This value can be read straight from the penultimate column of Table 2.
- For three identical compact fluorescent lamps of different power, but not exceeding 25 W, which according to Table 2 are therefore to be assigned to the same type of distortion load, this value can be converted linearly. This can be done using the value in the last column, which, multiplied by the power of the individual lamp, leads directly to the neutral current.
- For a large number of identical consumers, e.g. compact fluorescent lamps of the same power, the value in the last column is multiplied by the number of lamps per phase and the power per lamp.

The neutral loads thus chosen for the different groups of similar appliances can then simply be added up. This again gives somewhat too high a value and is therefore once more on the safe side.

Device under test and its operating / measurement conditions	Remarks and explanations	Mains loaded with 1 device per phase							Con-version
		Example measurements							
		Power intake			Current				
		P_{Nom}	P_{Meas}	S_{Meas}	I_{L1}	I_{L2}	I_{L3}	I_N	I_N/P_{device}
Compact fluorescent lamps up to 25 W	Compact fluorescent lamps	23W	23W	35VA	0,15A	0,15A	0,15A	0,24A	10,43mA/W
Fluorescent lamps above 25 W with internal or external electronic gear		30W	29W	30VA	0,13A	0,13A	0,13A	0,06A	2,00mA/W
	Linear lamp with external ballast	58W	55W	59VA	0,25A	0,25A	0,25A	0,13A	2,24mA/W
Fluorescent lamps above 25 W with internal or external magnetic gear	without compensation (inductive)	58W	62W	140VA	0,60A	0,60A	0,60A	0,20A	3,45mA/W
	with parallel compensation	58W	62W	67VA	0,30A	0,30A	0,30A	0,20A	3,45mA/W
	with serial compensation (capacitive)	58W	75W	170VA	0,73A	0,73A	0,73A	0,30A	5,17mA/W
Incandescent lamps with phase angle control dimmers	undimmed (min. angle ≈5°)	200W	200W	200VA	0,87A	0,87A	0,87A	0,02A	0,10mA/W
	dimmed 60° (120° conductive angle)		161W	179VA	0,78A	0,78A	0,78A	0,67A	3,36mA/W
	dimmed 120° (60° conductive angle)		38W	87VA	0,38A	0,38A	0,38A	0,66A	3,29mA/W
LED lighting tubes (perceived re-placement for fluorescent lamp 58 W)	without ballast	25W	26W	27VA	0,12A	0,12A	0,12A	0,05A	1,87mA/W
	with magnetic ballast		27W	27VA	0,12A	0,12A	0,12A	0,06A	2,38mA/W
Office PC without active power factor correction (PFC)	inactive (idling)	400W	80W	105VA	0,46A	0,46A	0,46A	0,76A	1,89mA/W
	Mean office workday		85W	112VA	0,48A	0,48A	0,48A	0,81A	2,02mA/W
	Peak (max. processor demand)		145W	190VA	0,83A	0,83A	0,83A	1,34A	3,36mA/W
Office PC with active power factor correction (PFC)	inactive (idling)		77W	83VA	0,36A	0,36A	0,36A	0,16A	0,40mA/W
	Mean office workday		82W	87VA	0,38A	0,38A	0,38A	0,17A	0,43mA/W
	Peak (max. processor demand)		136W	139VA	0,60A	0,60A	0,60A	0,24A	0,60mA/W
CRT monitor	Obsolete technology, dropping stocks	60W	60W	90VA	0,38A	0,38A	0,38A	0,60A	10,00mA/W
Flat screen	100% brightness	35W	32W	54VA	0,24A	0,24A	0,24A	0,41A	11,71mA/W
	20% brightness		22W	38VA	0,17A	0,17A	0,17A	0,29A	8,33mA/W
Laptop-PC up to 75 W (limit according to EN 61000-3-2:2010-03)	PC operating & charging battery	65W	65W	118VA	0,53A	0,53A	0,53A	0,91A	13,99mA/W
	PC operating, heavy CPU load		24W	50VA	0,20A	0,20A	0,20A	0,35A	5,33mA/W
	PC operating, weak CPU load		16W	38VA	0,17A	0,17A	0,17A	0,29A	4,40mA/W
Laptop-PC above 75 W (limit according to EN 61000-3-2:2010-03)	PC operating & charging battery	90W	67W	84VA	0,36A	0,36A	0,36A	0,60A	6,67mA/W
	PC operating, heavy CPU load		56W	69VA	0,30A	0,30A	0,30A	0,54A	6,00mA/W
	PC operating, weak CPU load		17W	23VA	0,10A	0,10A	0,10A	0,18A	2,00mA/W
Fax machine	Stand-by	3A	20W	40VA	0,16A	0,16A	0,16A	0,21A	10,68mA/W
	Active		325W	330VA	1,40A	1,40A	1,40A	0,57A	1,76mA/W
Photo copier	Daily minimum	–	62W	101VA	0,43A	0,43A	0,43A	0,22A	3,47mA/W
	Daily mean		103W	142VA	0,61A	0,61A	0,61A	0,43A	4,21mA/W
	Daily maximum		324W	352VA	1,59A	1,59A	1,59A	1,93A	5,96mA/W

Table 2 – Typical values of non-linear single-phase loads, divided evenly between 3 phases.

NOTES

1. Because the harmonics produced by different loads generally have identical order numbers but slightly different phase angles, the harmonic currents can sometimes be made to cancel each other out instead of adding up. Through arithmetic addition, therefore, the necessary safety framework is created for the simplified procedure, and the reserve is established. As a result, the appliances given here by way of example do not necessarily have to be the worst distorters under the sun. Also, the values thus calculated are on the safe side of reality simply because the cables and above all the feeding distribution transformer have certain filtering effects on the harmonic currents. Thus, when the total connected distorting loads are multiplied, the harmonic currents do not multiply to precisely the same degree. For example, in practice, 100 flat screens will not cause 100 times as large harmonic currents as one flat screen, but roughly speaking, depending on the characteristics of the network, perhaps 70 times.

2. If the network load is unbalanced, e.g. with only 2 compact fluorescent lamps on 2 phases, it can be assumed that the loading of the neutral by harmonics drops about as far as its load increases due to imbalance. The unbalance current is therefore simply added to the harmonic current in the N-conductor. The resultant error is again on the safe side.

NUMERICAL EXAMPLE

Twelve PC workstations are to be created on one floor of an office. To this can be added a total of 30 compact fluorescent lamps, each of 20 W, and 1 photocopier. The probable load of the neutral as a result of supplying this floor is to be calculated.

Procedure:

It is assumed that the computers – desktops with separate monitors – are distributed evenly, i.e. 4 per phase conductor. The same applies to the lamps: 10 per phase conductor. It is not known whether the computers' power supplies will be fitted with active electronic power factor correction (PFC) or not. For safety's sake it must therefore be assumed that none of the computers will be. It may, however, be assumed that "shoot-'em-up" games will not constantly be running on these computers, but that they will be used for ordinary office work. Therefore, the peak load does not need to be taken into consideration, and the mean load value can be used. The power take-up of the appliances is not known. An economical computer with the latest processing technology and a fanless power supply uses 45 W, but who pays attention to power take-up when buying computers? The empirical value of 85 W from Table 2 is therefore assumed. The neutral current of 810 mA from Table 2 can then be multiplied directly by 4.

It is safe to assume that CRT monitors are no longer used. The value for flat screens at full brightness, again multiplied by 4, provides sufficient accuracy.

There is no 20 W compact fluorescent lamp in Table 2. The relative neutral current in the last column helps here. The total power can easily be determined – 10 lamps each of 20 W per phase makes 200 W. This figure should then be multiplied by the typical value for this category of loads, namely 10.43 mA/W, to calculate the neutral current.

Note: This gives a quite different result from, for instance, 5 lamps of 40 W each. According to Table 2, such lamps would be in a different category and cause far less harmonic current.

The only photocopier present (figure 9) cannot be "evenly distributed". It represents a single-phase unbalanced, load – and a relatively big one. The relative distortion remains within limits, but is a highly erratic load with extreme peaks (figure 10 shows actual power, apparent power, total current and current of the third harmonic in operation and "at rest"). For the sake of simplicity, the neutral current of the copier, which is therefore necessarily identical to its phase current, is added to the neutral current of the evenly distributed but distorting loads. The mean is sufficient, the regularly occurring pulse-like peaks typical of devices with laser printing, are short, and contained within the mean. The unevenness of this load increases the heating of the conductor. However, it is counterbalanced by the fact that the linear addition of the fundamental of the copier current to the harmonic current of the other users in the N-conductor leads to the assumption of an excessively high neutral current. The total neutral load is therefore calculated as follows:

Devices	Neutral current	
3 * 4 PCs	4 * 0.81 A =	3.24 A
3 * 4 flat screens	4 * 0.41 A =	1.64 A
3 * 10 compact fluorescent lamps of 20 W	10 * 20 W * 10.43 mA/W =	2.09 A
1 photocopier		0.43 A
Total		**7.40 A**

Table 3 –Totalized neutral current from the example calculation.

Adding the phase currents of these users together gives 4.76 A for that phase on which the photocopier is operated in addition to the evenly distributed loads. Accordingly, the conductor cross-section must be chosen on the basis of the neutral current in this case. A reduction factor is then no longer required. Although 4 conductors are loaded simultaneously, the full current is not or cannot be reached in all 3 phase conductors, not even in the one feeding the single-phase load, since the neutral current will always be bigger still. The selection of the installation wiring must therefore be based on the neutral current.

SPECIAL INFORMATION

The following are two other points that should be borne in mind in this context.

IN CABLES AND WIRING: SHORT-CIRCUIT CURRENT CALCULATION

It should be noted that harmonics can be ignored when calculating short-circuit currents [5]. By their nature, harmonic currents only occur in specific consumables and spread out from there into the network, instead of from the supply side. Therefore, when the equipment is cut off from the power supply by a short-circuit, they disapppear. The short-circuit currents are then determined by the impedances of the various network resources – cables, lines, busbars, transformers – which all represent linear elements.

IN TRANSFORMERS

It is important to note that transformers can become overloaded (overheated) by harmonic currents even if the rated load current (true root mean square current) is not exceeded, since the additional losses that occur in the transformer rise not only by the square of the load current, but also by the square of its frequency/ies. See HD 428 for further details.

CONCLUSION

Several common pieces of office equipment have been measured to ascertain their impact on the harmonic content of the input current. The resulting typical values are compiled in Table 2. They estimate the impact upon the neutral conductor current of a given number of devices evenly distributed across the three phases. Table 2 also provides a calculation factor for each type of device. This enables to directly deduce the neutral conductor current caused by three such devices operated on the three phase conductors, based on the intake power ratings.

The observation is made that the harmonic impact can be substantial. Therefore, cables have to be over-dimensioned accordingly, i.e. their current carrying capacity has to be down-rated. However, many devices only draw a high current during a short period of usage or at periodic intervals. The stand-by current (no-load current) can also have a high harmonic content in relative terms, but its absolute magnitude will be only a fraction of the harmonics currents caused by loads. Therefore, for the correct selection of the neutral conductor cross section, the mean currents given in Table 2 are to be recommended, and not the corresponding peak currents.

This simplified approach assumes that all harmonics accumulate in the neutral, which is not actually the case. Consequently, this approach falls on the safe side. This safety margin is nevertheless required to offset the uncertainty that arises from the limited number of loads that have been tested and from the fact that similar loads can have a significantly different harmonic behaviour, e.g. PCs with or without power factor correction. It also provides some reserve for imbalance coming on top of the harmonics. Moreover, selecting a cable cross section that is greater than strictly required will also provide many operational advantages such as a reduced voltage drop, reduced energy losses, and a reduced impact of harmonics currents on the voltage.

REFERENCES

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3	DIN VDE 0298-4 (VDE 0298 Part 4):2003-08
4	Pratical problem "Leistungsbilanz an Schaltnetzteilen", "de" 20/2008, p. 44
5	Stefan Fassbinder: "Verhalten von Schutzwandlern bei Kurzschluss". "de" 23-24/2004, p. 18