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EFFECTS OF A LARGE COMPUTER CENTRE OPERATION ON NEUTRAL CURRENT

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Abstract: *This paper deals with analysis of the neutral current values caused by simultaneous work of larger groups of non-linear loads. An analysis is performed on the basis of harmonic measurements carried out in the Computer centre of the Faculty of Technical Sciences (FTS) in Novi Sad. In a balanced three-phase system, sum of phase currents is zero, as well as the neutral current value. Beside phase load unbalance, harmonic producing equipment (non-linear loads) is the main cause of occurrence of high value of the neutral current. Computers, fluorescent lamps, and air-conditioning units are non-linear loads present in the Computer Centre. By processing and analyzing of measured data it is concluded that computers are the biggest causes of high value of neutral conductor current. In the case of supplying of 163 PC's the neutral current value is about 26% higher than the maximal phase current of considered feeder line, what may have a serious effects, like: overload of feeder line, overload of transformer, voltage distortion, etc. The impact of air-conditioning units and fluorescent lamps with magnetic ballast are significantly less.*

Key words: ***Neutral current, Harmonics, Computer Centre.***

1. INTRODUCTION

A three-phase building wiring consists of three phase conductors, a ground conductor, and a neutral conductor. Single phase loads are connected between the different phase conductors and the neutral conductor. Therefore, the neutral conductor serves as the "common" return for all of the single-phase load currents [1, 2].

In the star-connected three-phase system, the current in the neutral conductor is the vector sum of the three phase currents. With a balanced sinusoidal three-phase system of currents, this sum is zero at any point in time and the neutral current is therefore zero.

In reality, when a three-phase power system is feeding linear single-phase loads the current in the neutral conductor is rarely zero, because the load on each phase is different. Typically, the difference is small and in any case far lower than the phase currents.

By wide spread presence of small electronics and microelectronics devices, many changes in the system have occurred. These changes are result of increasing use of non-linear loads: computers, fluorescent lighting, air-conditioners, etc. These kinds of loads (especially PC's) generate a substantial amount of odd current harmonics, where the 3rd, the 5th and the 7th are the most significant current [3].

When non-linear loads operate, even in case of well balanced loads across the phases, there is likely to be substantial current in the neutral conductor. In fact, the 3rd harmonic component (and all other odd harmonics, whose order is a multiple of three, i.e. the 9th, the 15th, etc.) of the phase currents are all in phase with each other (i.e. they are homopolar components), so they are summing arithmetically rather than canceling by vector addition (Fig. 1). The result is occurrence of current in the neutral conductor that is often significantly higher (typically up to 170%) than the phase current [4]. This is one of the most critical problems related to operation of non-linear loads, which can grow depending on the supply characteristics, the size of the loads and how the load interacts with each other due to harmonics cancellation, attenuation and diversity [5].

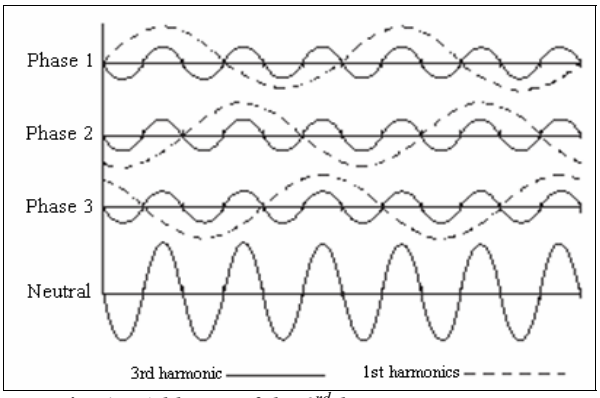

Fig. 1. *Addition of the 3rd harmonics currents components*

Impact of connected non-linear loads on the neutral current value is objective of numerous researches. Also, various relationships (mainly of empirical character) are developed for calculation of neutral current value [4, 6]. Negative effects of high value of the neutral currents are well known: overloading of power feeders and transformers, voltage distortion, increase of the neutral-ground voltage and a high level of common mode noise [4].

Due to possibility of overloading of power feeders, neutral conductor must be adequately dimensioned. Reference to sizing the neutral conductor in case of non-sinusoidal currents can be found in IEC 60364-5-524 [7], which recommend that the neutral conductor must have at least the same cross-section as the phase conductors.
Some of above mentioned negative effects of non-linear loads operation on neutral conductor current have been observed at the University of Novi Sad in the main building of the Faculty of Technical Sciences (FTS). The appearance of fuse blown and high heating of wire and cable ends in the main distribution panels of FTS have become very often. Such effects have been connected to the fast development and expansion of use of personal computers, lap-top computers, printers and other non-linear devices, especially at the feeder where the loads of Computer Centre have been connected. In regard to this, several extensive power quality measurements have been performed, since 2003 [8, 9].

Results of measurements showed a significant presence of high order harmonics in the phase currents and pronounced appearance of current in the neutral conductor of power feeder.

In this paper, focus will be on defining the major causes of high current value that is transmitted by neutral conductors of power feeders in the Computer Centre, where are numerous non-linear consumers (PC's, air-conditioners and fluorescent lamps) are located. The neutral current value analysis and the definition of consumer causes of this phenomenon will be developed on basis the latest measurements, performed at the end of 2008 [10].

2. MEASUREMENT RESULTS AND NEUTRAL CURRENT ANALYSIS

Seven-day measurements were conducted at the PCC (Point of Common Coupling) of Computer Centre where a larger group of consumers, as non-linear (the source of high order harmonics), and linear are connected. Measuring samples were taken at intervals of 10 minutes in reference to IEC 61000-4-7 Standard [11].

Values of phase voltages and currents, as well as neutral current were observed and saved. Measuring devices perform on-line calculation of the value of high order harmonics, active and reactive power. The value of important harmonics parameters (THD_U, THD_I, HD_U, HD_I) are calculated, also. By performing their comparison with the existing regulations (harmonic standards and recommendations) a level of current and voltage distortion can be obtained, i.e. quality of supply voltage in Computer Center.

Specifically, the measurements were realized at three measuring sites:

- Measuring position 1 (*MP1*) – distribution panel which powered a computers group (163 computers: 10 server computers and 153 PC's) and lighting of two laboratory of Computer Centre (total active power: 864+828=1692 W);
- Measuring position 2 (*MP2*) – distribution panel which powered an air-condition devices group of Computer Centre (14 air-condition units);
- Measuring position 3 (*MP3*) – distribution panel which supplied lighting (fluorescent lamps with magnetic ballasts) of the 3rd floor of Teaching Block Building (TBB) (some laboratories of Computer Centre that belongs to TBB and all classrooms and hall on the 3rd floor of TBB, the total active power 14.03 kW).

By analysis of the results of these measuring positions it can be gets the impacts of commonly used low-power ($I_n \leq 16A$) non-linear consumer: PC's, air conditioner devices and fluorescent lamps on power quality. Special emphasis in this paper will be given to their impact on the current generation in the neutral conductors of feeder lines.

2.1. The influence of PC's group on the neutral current generating

Computers are particularly important consumers in the category of non-linear loads. Their rapid development, large presence in the structure of consumption, as well as the specific structure of power supply unit – which generate pulse current (power) wave-form, makes them very interesting from the research point of view [8]. The PC current contains large amounts of odd harmonic components (especially the third harmonic).

Current harmonics spectrum of modern PC: Pentium IV, ATX Power Supply, TFT monitor (I_{1PC}), as well as harmonics spectrum of phase currents obtained by measuring at the *MP1* are presented in Table 1. The values of THD_I factors may also have been seen in Table 1. UPS of server computers, connected on phase 2 and 3, have influence on harmonics in mentioned phases.

Table 1. *Harmonics analysis for group of PC's*

Line		1	2	3
Number of PC's		57	48+2s	48+8s
Harmonics	I_{1PC} (%)	I_1 (%)	I_2 (%)	I_3 (%)
3	87.2	49.4	49.8	51.9
5	66.2	25.2	31.1	29.7
7	40.5	7.2	12.0	9.2
9	17.9	4.5	4.8	3.7
11	3.0	4.6	5.7	4.1
13	8.2	3.0	4.5	4.5
15	9.3	1.6	2.5	2.9
17	5.9	2.3	3.2	2.5
19	1.7	1.7	2.0	2.3
21	2.0	1.4	1.4	1.8
THD_I (%)	119.7	55.8	61.2	61.0

Current values of all three phases and neutral conductor of feeder line which supply a computers group in Computer Center (during measurement period) are shown in Fig. 2. On this Figure "deteriorating" of phase 3 current is marked. This is consequence of the problems that were existed with current clamps.

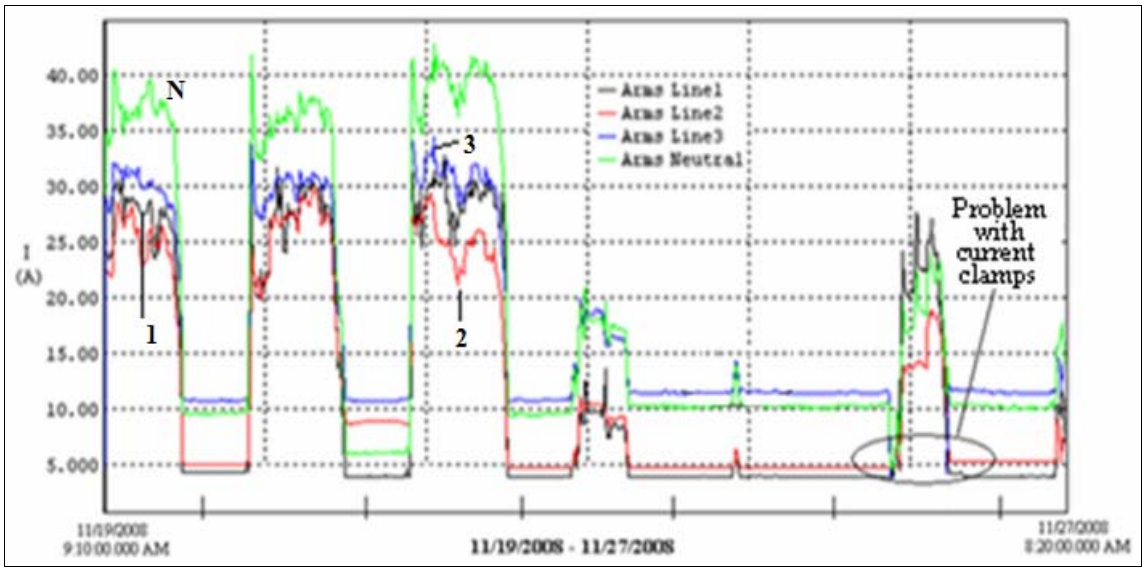

Fig. 2. *RMS values of phase currents (marked 1, 2 and 3) and neutral current (N) of feeder line.*

Maximal load of Computer Centre were in the days when the teaching process took place according to a defined timetable (19th, 20th and 21st Nov. 2008).

During these three days, maximal value of phase currents were in the range of 25 to 35 A (maximal measured values are: I_1 = 32.1 A, I_2 = 29.7 A and I_3 = 35.2 A). Also, the neutral current of feeder line was very intensive, and in period of maximum load, it was located in the interval between 35 and 44 A.

In the evening and weekend days, when the server computers and their belonging UPS devices are only supplied load, it's not observed a problem with high value of the neutral current. Therefore, simultaneously work of PC's group leads to the occurrence of high value of current that carries through neutral conductor. The RMS value of this current is about 26% higher then the maximal phase current (I_3). The similar results are presented in [12].

Confirmation of these observations can be seen on Fig. 3, which presents the time forms of phase currents and the neutral current of the feeder line – dominantly caused by superposition of 3rd harmonics of phase currents. Recorded forms are obtained in the case of load different from maximal, when the PC's were only supplied load.

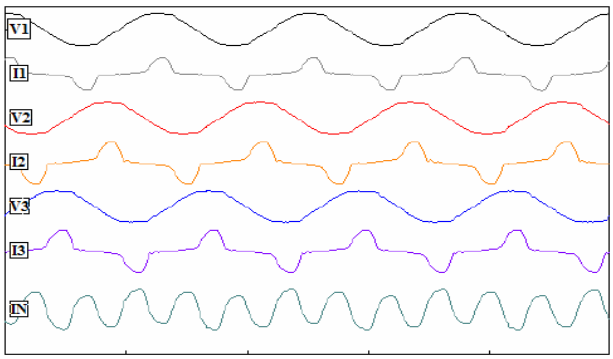

Fig. 3. *Phase currents and neutral current wave-forms.*

The changes of neutral current values in dependence on the number of connected non-linear consumers (PC's and fluorescent lamps), are presented on Fig. 4. With "C" is marked the number of connected PC's, and "W" mark represents active power of connected fluorescent lighting (for example: 163 C and 1692 W means that 163 PC's and 1692 W active power of fluorescent lighting are connected).

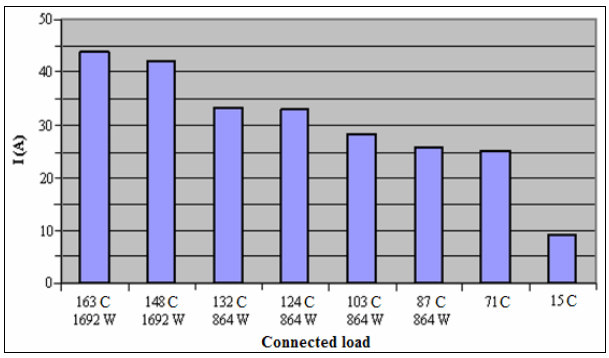

Fig. 4. *The neutral current values in function of connected load*

In the case of maximal load, when all PC's of Computer Centre are in use (163 PC's), and involving supplied lighting (1692 W), the neutral current was I_N= 44.1 A (25.2% higher than I_3 phase current). Only, for the small number of connected PC's (15), the neutral current value becomes less than I_3 phase current, which explicitly refers to PC's as the main cause of high value of the neutral current.

2.2 The influence of Air-conditioner devices group on the neutral current generating

Similarly to computers, air-conditioner devices also represent consumers in a great expansion, whose intensive use, especially during the summer months, causing significant changes in planning of the annual electrical consumption. Besides this aspect, the simultaneously work of air conditioner devices group are reflected on parameters of power quality. Eleven of fourteen air-conditioner devices located in the Computer Centre were in function during the measurement process. Four air-conditioner devices are connected on each phases 1 and 3, as well as three on phase 2.

The structure of current harmonic spectrum of air conditioner device is significantly different from the structure of the current harmonic spectrum of computer (Table 2).

Table 2. Current *harmonic spectrum of air-conditioner*

Harmonic	*2.*	*3.*	*4.*	*5.*	*6.*
(%)	15.0	4.5	1.9	18.5	1.2
Harmonic	*7.*	*8.*	*9.*	*10.*	*11.*
(%)	3.0	1.1	2.1	0.5	0.3

It is noticeable that the analysis of current harmonic spectrum of air conditioner device must take into account the participation of even harmonics, especially the 2nd harmonic, which is only a consequence of asymmetric torque of single-phase asynchronous motor that runs air-conditioner compressor [13]. The 5th harmonic is dominant among the odd harmonics, which is caused by the 5th harmonics of the supply voltage. THD_I of air-conditioner device is about 30%, while obtained values by the measurement for phase currents were: THD_{I1}= 14.9%, THD_{I2}= 16.8% and THD_{I3}= 19.5%. Therefore, the potential of air conditioner devices in terms of generating higher harmonics is much smaller than the computers.

During the simultaneous work of 11 air-conditioner devices, following phase currents were observed: I_1= 28.6 A, I_2= 11.9 A, I_3= 19.6 A. In this case, the neutral current was I_N=15.7 A, which is about 45% less than the maximal phase current (I_1). This phenomenon is a direct consequence of the fact that air conditioner devices don't have high level of current harmonic (particularly low is the value of the 3rd harmonic).

Considering the values of phase currents, it's obviously a noticeable unbalance of load across the phases, which contributes appearance of the neutral current. Also, if more air-conditioner devices are connected to different phases, serious problems may occur in the common neutral conductor as consequence of pulsating currents arising due to different slip of induction motors. This neutral current can creates additional losses in distribution network and can cause a voltage flickers.

2.3 The influence of fluorescent lighting on the neutral current generating

The fluorescent lamps with magnetic ballast (standard fluorescent lamps) and the fluorescent lamps with electronic ballast (compact fluorescent lamps) are in use.

The Computer Centre laboratory lighting, as well as lighting on the 3rd floor of TBB is realized by fluorescent lamps with magnetic ballast. For the analysis of power quality effects of simultaneous operation of group of fluorescent lamps, it is very important to emphasis the type of ballast.

Generally, the ballast represents regulator of energy flow through the lamp tube, or a sort of transformer that provides the required voltage value (greater or less than the supply voltage) for the properly functioning of the components inside the tube. Magnetic ballast is an inductance which doesn't change the frequency (retains the nominal frequency of the system).

From the aspect of effects on power quality, fluorescent lamps with magnetic ballast are almost identical with the incandescent lamps. However, this should be verified, so investigation of effects on power quality was the main task of performed measurement on *MP3*.

Total active power for group of fluorescent lamps supplied from *MP3* is 14.03 kW. In the structure of the used fluorescent lamps in Computer Centre (TBB) lamps with total active power: 80 W (41%), 60 W (8%), 36 W (49%) and 18 W (2%) are present.
The current harmonic spectrum of fluorescent lamp with magnetic ballast is shown in Table 3.

Table 3. *Current harmonic spectrum of fluorescent lamp*

Harmonic	*3.*	*5.*	*7.*	*9.*	*11.*
(%)	8.3	3.1	2.5	1.4	1.2
Harmonic	*13.*	*15.*	*17.*	*19.*	*21*
(%)	0.8	0.4	0.3	0.1	0.1

It's obvious a low level of the 3rd harmonic presence in current harmonic spectrum, as other odd harmonics. THD_I factor of fluorescent lamp with magnetic ballast is about 13%, while the measurement obtained values of this factor for phase currents are: THD_{I1}= 12.2%, THD_{I2}= 9.7% and THD_{I3}= 17.5%.

The maximal recorded phase current values were: I_1= 36.3 A, I_2= 26.6 A and I_3= 26.8 A. The neutral current was I_N= 14.5 A. It was significantly smaller (about 250%) than the maximal phase current (I_1). Presence unbalance of load across the phases also has negative impact on the neutral current value. Therefore, the problem with the neutral current value is the least expressed in the case when the feeder line powered the group of fluorescent lamps with magnetic ballast.

3. DISCUSSION

The neutral current r.m.s. value of feeder line (PP-Y 5x4 mm^2) that supply PC's of Computer Centre FTS is I_N= 44.1 and this current value is about 26% higher then the maximal phase current (I_3). The maximum current value which can be transmitted by mentioned feeder line is I_{max}= 47 A. In regard to this it can be concluded that the current capacity of neutral conductor is on the upper limit.

Opportunities for further expansion of Computer Center taking into account power quality issues were investigated. The level of harmonic content which would be generated by Computer Center was used as a criterion for this assessment. It was concluded that installation of additional 100 PC's is possible without surpassing the EN50160 limits for total harmonic distortion of grid voltage (THD_U = 8%) [10].

However, further increase of the capacity of Computer Center, in terms of increasing the number of connected PC's, will result in even greater neutral current value, i.e. overloaded neutral conductor of feeder line. From the aspect of the maximal current value that can be transmitted by existing feeder line (PP-Y 5x4 mm^2, I_{max}= 47 A) it evident that this increase will require estimation of expected value of neutral current.
It is calculated that the above increase of 100 new PC's (33 per phase) will brought an additional 20 A of neutral current, what will result in the total neutral current value

of 64.1 A. This means that the feeder line PP-Y 5x4 mm^2 wouldn't be adequat with the assumption that the sizing of neutral conductors is carried out according to standard [7]. In this case it will be necessary to substitute the existing cable with line of larger cross-section, i.e. with the following one: PP-Y 5x10 mm^2, I_{max}= 80 A.

However, there are other possibilities to solve the above problem. According to [14], there are three on different options:

1. Replacement of feeder line with line that has larger cross-section – This solution is considered above and present adequate option. However, one drawback must be taken into account. During cable replacement, the Computer Centre needs to be without the power for a longer period, which is not suitable as it operate 24h.
2. Use of filters – Effects of filters installation will be manifested in reduction of the harmonics levels (especially the 3rd). The positive aspect of this solution is relatively short non-supply state of Computer Center, but the financial factor is often a limiting factor in its implementation.
3. Connection of insulated protective earth conductor in parallel with the neutral conductor.

The authors believe that the 3rd option is the most acceptable one for the Computer Center. Namely, the feeder line of Computer Center has its own protective earth conductor (same capacity as a neutral) that is isolated and can be used for this purpose. In this manner, parallel connection will increase the capacity of a neutral conductor by double.

4. CONCLUSION

With wide-spread presence of non-linear consumers in the structure of consumption, problem with the neutral current is significantly increased. Non-linear loads generate a substantial amount of higher current harmonics, especially the 3rd harmonic, which can cause high value of the neutral current, even when the load is well balanced. This phenomenon is a consequence of the summation of the 3rd harmonic components of the phase currents (which are all in phase with each other). Analyses of the effects of simultaneous operation of group of non-linear loads located in the Computer Centre of FTS Novi Sad on the neutral current values were conducted on the basis of the performed measurements. It was found that the most of the problems occur in feeder line, which supplies the Computer Centre. Results showed that the neutral current value is about 26% higher than the maximal phase current. Some of the negative effects have been already observed, like: overheating of the grid connections, aging of insulation, and overloaded of the feeder line. These problems can be further expressed in the case of increase in the number of connected PC's in Computer Centre. The measurement also showed that air-conditioner devices and fluorescent lamp with magnetic ballast are not important causes of high level of the neutral current value.

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