UNIVERSITATEA TEHNICĂ DIN CLUJ-NAPOCA
DEPARTMENT OF BUILDING SERVICES

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PhD THESIS
summary

POWER QUALITY IN THE OFFICE BUILDINGS’ ELECTRICAL INSTALLATIONS

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The power quality issue concerns, on the one hand, the compatibility between the parameters of the electrical energy supplied to the users and their operating characteristics (determined by the susceptibility to disturbances of their receivers). Office buildings represent users of electricity in which the electronic office equipments (computers, faxes, printers) use the same power network as the light sources. On the other hand, the power quality refers to the analysis of the power quality disturbances due to the presence, in the power system, of current harmonics generated by the electronic equipments.

The PhD thesis analyzes the subject of the power quality in the office buildings electrical installations, based on the current state of research. In the conducted studies the characteristics of the nonlinear receivers predominantly used in the office buildings were analyzed, as well as the characteristics of the office buildings, as users of electricity.

The arguments that led to the development of the thesis are: the continuous and rapid increase of the number of nonlinear receivers connected to the office buildings electrical installations, the increasing concerns regarding the energy efficiency and the sensitivity of modern equipment to the decrease of the power quality. Different topics were considered: measurements of the characteristics of the nonlinear receivers used in office buildings, measurements of the electrical characteristics at the point of common coupling of the office buildings electrical installations, studies and analysis of the effects of connecting nonlinear receivers at the office buildings electrical installations (using DIALux programs, OrCAD PSpice and MATLAB).

The author has received research traineeship sessions both in Romania and abroad:

- Research traineeship session at the Electrical Engineering Faculty, University of Craiova, under the guidance of Prof. Ion Mircea, between September 23rd and 25th, 2009. The author attended the National Colloquium “Metode, Instalații și Echipamente pentru măsurarea, conservarea, și gestiunea energiei”, held between September 24th and 25th, 2009.

- Research traineeship session, through the PRODOC doctoral studies program, at the Aalto University School of Electrical Engineering, Department of Electronics - Lighting Unit, Aalto, Finland, under the guidance of Prof. Liisa Halonen and Dr. Eino Tetri, between February 1st and June 30th, 2010. Measurements of the electrical and luminous characteristics of the light sources were conducted.

- Research traineeship session, through the PRODOC doctoral studies program, at the “Utilizări ale Energiei Electrice“ Laboratory, Power Engineering Faculty, Politehnica University of Bucharest, under the guidance of Prof. Cornel Toader, Nicolae Golovanov and Mihaela Albu, between November 29th and December 10th, 2010. Different measurements of the electrical characteristics of electronic office equipments were achieved. The author participated at two Round Tables: „Calitatea energiei electrice”, held on 30 November 2010, and „Tineri cercetători
in domeniul energiei”, held on 7 December 2010.

- Research traineeship session, through the PRODOC doctoral studies program, at Politechnico di Torino, Dipartamento di Ingegneria Elettrica, Turin, Italy, under the guidance of Prof. Gianfranco Chicco, between February 21st and March 6th, 2011. Simulations and analysis were conducted to determine the power quality effects of connecting nonlinear receivers in the office buildings electrical installations.

The thesis is developed in six chapters, references and appendixes.

**Chapter 1 Power quality at the user** analyzes the power quality problem by presenting the definitions of the power quality concept, the standard recommendations and the main used power quality indicators. The operation of all the user electric receivers at the nominal parameters is conditioned by the power quality of the network, deviations outside the standard limits leading to errors or equipment damage. At the same time, the development of new electronic equipments and technologies and their proliferation generate disturbances – the increase of harmonic distortion and the occurrence of voltage unbalance. Taking into account the power quality aspects from the supplier and user perspectives, the power quality indicators have been synthesized in two categories: primary indicators, that relate to the quality of the product “electric energy” and the electric power supply service, and secondary indicators, that relate in particular to the disturbances caused by nonlinear receivers. The implementation of these indicators allows the delimitation between the attributions of the supplier and the users for maintaining the disturbances in the established limits. The indicators are classified in: frequency deviations, slow variations of the supplied voltage, voltage surges, voltage dips, short and long term power supply interruptions, voltage fluctuations, harmonic distortion, and voltage unbalance.

The office buildings are also analyzed, as electric energy users. The office buildings nonlinear receivers are classified in two categories: light sources and electronic office equipments. For each category the ratio of the receivers found in the office buildings, the receiver operations aspects and the available methods of reducing the electricity demand are described. This last aspect is particularly important due to the increased attention provided to the economical issues and environmental impacts, methods and initiatives to reduce the electric energy demand.

**Chapter 2 Operating conditions in the user power systems** presents aspects regarding the conducted electromagnetic disturbances that exist in the user power supply system (harmonic distortion and voltage unbalance): methods of analysis, effects and different mitigation solutions. The importance of the harmonic distortion problem is justified based on the effects caused in the
supplier and user power networks. Because the majority of the nonlinear receivers that exist in office buildings is connected to single-phase power network, the voltage unbalance phenomenon is also analysed.

Section 2.3 describes the disturbances determined by the electronic office equipments and the light sources, and the effects of their simultaneous use in the low voltage electric power distribution networks. The presented data represents an overview of different literature research studies. Sections 2.4 and 2.5 analyze the methods of modelling the low voltage electric power distribution networks in real time and the current and voltage harmonic propagation in the power network. These aspects allow the estimation of the harmonic distortion levels at different points in the power network and caused by the connection of various nonlinear receivers.

Chapter 3 Experimental analysis of equipments used in office buildings analyzes several topics: the characteristics measurements of the nonlinear receivers predominantly used in the office buildings, the analysis of two case studies and the measurements of the electrical characteristics at the point of common coupling for two office building electrical installations.

Section 3.1 presents the measurements of the electrical and luminous characteristics of the light sources used in office buildings. The luminous efficacy under dimming is analyzed also for several light sources. If the light sources are not dimmed, the luminous efficacy of the LED light sources is superior to the luminous efficacy of the light sources equipped with tubular fluorescent lamps or halogen lamp. In the case of the light sources equipped with tubular fluorescent lamps, the luminous efficacy of the one equipped with T5 fluorescent lamps is better than the luminous efficacy of the light source equipped with T8 fluorescent lamps. The measurements also show that the luminous efficacy of the light source equipped with T5 fluorescent lamps has lower values for lower dimming levels than the light source equipped with T8 fluorescent lamps. If the luminous flux is decreased, for the LED light sources dimmed using PWM technology and Dali interface, the luminous efficacy has greater values throughout the dimming process. In the case of 12 W LED light source dimmed using a triac dimmer, the luminous efficacy drops linearly; similar trend can be seen in the case of the halogen light source, with the use of the same triac dimmer. The power factor impact of dimming the light sources is also analyzed. The light sources equipped with fluorescent lamps and LEDs have similar descending trend for the power factor values. The 12 W LED light source dimmed with triac dimmer has low power factor values as the voltage level is decreased; the halogen light source presents no variation in the power factor value. The results show that LED light sources have a greater luminous efficacy than other types of light sources equipped with fluorescent lamps.

Section 3.2 presents the electrical characteristics measurements for the electronic office equipments used in office buildings. The measurements have captured the nonlinear electrical
parameters of the electronic office equipments during various operating modes. The voltage and the electrical current variations during switching from one operation to another were also recorded. An attenuation of the current harmonic distortion was observed for the computer systems, compared to individual devices, due to the phase compensation between the current harmonics generated by the computer system’s equipments.

In section 3.3 a case study is presented that analyzes the harmonic distortion impact of dimming the light sources. Four cases are considered, corresponding to the use of four different light sources in an office room: light sources equipped with 2 x 36 W T8 fluorescent lamps and electronic ballast, light sources equipped with 2 x 49 W T5 fluorescent lamps and electronic ballast, 62 W LED light source and 37 W LED light source. For each case, the light sources are positioned in a 60 m² office room. Using the program DIALux the required number of the light sources in the office room and the light characteristics of the office room are determined. For all the four cases analyzed, the light sources are placed in parallel rows with the windows. It was assumed that the office room is located in Cluj-Napoca, and the simulations were performed for January 21st, 2010, at 17:00. The maintained level of light at the work plane, due to natural light, varies linearly, as the distance increases from the windows, between 506 W (near windows) and 37 W (the plane farthest from the windows). To ensure a maintained level of light of 500 lx on the work plane (according to the recommendations of SR EN 12464-1) the luminous flux of the light sources is set at different levels for each row. The case study shows that the current harmonic distortion level for all the light sources is attenuated due to phase compensation between the current harmonics generated by each of the light sources.

In section 3.4 the supply voltage harmonic distortion due to the use of light sources was estimated, based on the previous measurements and using different simulation programs. Four cases were analyzed, corresponding to four different types of light sources positioned in an office building. For the first case, six scenarios are studied. The parallel resonance phenomenon was highlighted when connecting the capacitors used for the correction of the cosine of the phase angle between the voltage and the electrical current, at the fundamental frequency. The effects of connecting anti-resonance coils to the network were also studied. For all the analyzed cases, the harmonic voltage distortion is below the recommended limits by the EN 61000-2-2 standard. The impact of the current harmonics generated by the light sources on the neutral conductor is also analyzed. The neutral conductor section recommended by the NP 07/2002 norm is sufficient even in the presence of current harmonics, of rank three or multiple of three, generated by the light sources.

Section 3.5 presents measurements performed at the power distribution network of two office buildings in Cluj-Napoca. The power quality is analyzed from the supplier and the user
perspectives. The use of light sources and electronic office equipments cause increase of the harmonic distortion, decrease in the power factor and increase in the current harmonic distortion of the neutral conductor. Their predominant use in office buildings can lead to serious power quality problems if no measures are taken. It can be concluded that, when designing the electrical installations for an office building, the existence and the positioning of the nonlinear receivers need to be taken into account.

**Chapter 4 Analysis of the harmonic distortion in office buildings due to light sources and electronic office equipments** assesses the harmonic distortion of the office building power distribution networks. Different configurations of the power distribution networks are analyzed, starting from the lighting and power circuits. The nonlinear receivers used in the simulations are previously analyzed in Chapter 3. For the lighting circuit, two cases are studied, corresponding to the use of two light sources: 36 W T8 fluorescent lamp and 18 W CFL. The attenuation effect due to the interactions between the changes of current harmonics injected by the non-linear loads and the resulting variations of the load voltage is analyzed, using the MATLAB program.

In section 4.2 the power networks of three office buildings are analyzed. The theoretical study aims at evaluating the harmonic voltage distortion at various points of the distribution networks due to the presence of nonlinear receivers, the harmonic distortion effect on the current effective values and the possibility that these values exceed the phase conductor calculated values. The receivers used are light sources and computer systems. The power networks are designed in compliance with the recommendations of NP 07/2002 norm. The study shows that the harmonic voltage distortion is within the standard limits.

The effects of reducing the harmonic distortion by implementing passive harmonic filters were analyzed also. Using OrCAD PSpice program, the power network for an office building was simulated. The passive harmonic filters were positioned at different levels of the power network. It is showed that the greatest mitigation effect takes place when the passive filters are located closer to the nonlinear receivers.

In section 4.3 a virtual tool, entitled RNHARM, is presented. The program allows the estimation, at various points, of the voltage harmonic distortion level for a fixed radial power network. The nonlinear receivers used in the network are light sources and electronic office equipments. Their electric characteristics were previously measured (Chapter 3).

**Chapter 5 Sensitivity of equipments to the supply voltage disturbances** presents different aspects regarding the effects of the low power quality on different nonlinear receivers used in office buildings. The analyzed power quality disturbances are: slow variations of the supplied voltage, voltage surges, voltage dips, short and long term power supply interruptions, voltage fluctuations. The considered equipments are the light sources and the electronic office
equipments. In the case of electronic office equipments the sensitivity curves at voltage dips and short term power supply interruptions are emphasized.

**Chapter 6 Conclusions and contributions** presents the final conclusions and the contributions brought by this thesis. There are proposed, also, possible directions for further research on the addressed topics.

The author personal contributions consist of:

1) Synthesis of the power quality problem in the office buildings electrical installations;

2) Summary of the characteristics of the nonlinear receivers that are used in the office buildings electrical installations;

3) Measurements of the characteristics of various light sources and electronic office equipments predominantly used in office buildings;

4) Analysis of the power quality effects if the light sources are dimmed;

5) Analysis of the voltage harmonic distortion due to different types of light sources;

6) Analysis of the power quality effects of connecting nonlinear receivers in the office building power network;

7) Development of the RNHARM virtual instrument that allows the estimation of the harmonic distortion levels for a fixed network configuration;

8) Comparative analysis of reducing the power losses in the electric networks by installing passive filters in various nodes;

The possible directions for further research are:

1) Analysis of the harmonic distortion for different configuration of power networks;

2) Development of the RNHARM virtual instrument for other network configurations.

**Appendixes** include the scientific papers written by the author during the PhD program and different recordings performed during measurements.
Selected References

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