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To cite this article: Anna Romanska-Zapala *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **603** 052020

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Power Quality in Energy Efficient Buildings – a Case Study

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Abstract. Energy-efficient buildings are increasingly equipped with modern automation and control systems that enable significant energy savings by providing energy in the exact place and time of the demand. Moreover, high-performance LED light sources are used as interior lighting. Since the computers, automation system controllers and LED light sources require a lower voltage than the mains voltage, the buildings use a large number of power electronic converters adjusting the power supply conditions for the devices being serviced. Operation of this type of strongly non-linear receivers leads to an increase in transmission losses of electrical energy related to reactive power flow and generation of higher harmonics. Striving to reduce energy consumption in buildings leads to increasing use of these devices, which in consequence will aggravate the problem of insufficient quality of electricity. The paper discusses the provisions of standards for the quality of electricity. The paper presents the results of research on the quality of electricity in the Malopolska Laboratory of Energy Efficient Building – an experimental building equipped with a building automation and control system.

1. Introduction

The global trend to reduce carbon dioxide emissions is manifested, inter alia, by the desire to increase the energy efficiency of buildings. Legal regulations, such as Directive 2010/31 / EU [1] on the energy performance of buildings, oblige investors to meet standards and parameters related to energy consumption of buildings. Energy-efficient buildings are increasingly equipped with modern automation and control systems that enable significant energy savings by providing energy in the exact place and time of the demand. Moreover, high-performance LED light sources are used as interior lighting. Since the automation system controllers, LED light sources and computer components require a lower voltage than the grid voltage, the buildings use a large number of power electronic converters adjusting the power supply conditions for the devices being serviced. Operation of this type of strongly non-linear receivers leads to an increase in transmission losses of electrical energy related to reactive power flow and generation of higher harmonics. Striving to reduce energy consumption in buildings leads to increasing use of these devices, which in consequence will aggravate the problem of insufficient quality of electricity.



2. Power quality studies

Currently, it is estimated that 30–40% of total energy in the world and 60% of electricity is consumed in buildings. In the European Union buildings consume 40% of energy [2], 23–30% of which is used for lighting purposes [3, 4, 5]. By means of intelligent electrical installations – automatic control systems, it is possible to achieve considerable energy savings. The use of lighting control can reduce electricity consumption by up to 70–80% compared to a traditional installation. Even the simplest control system for heating, ventilation and air conditioning systems can reduce their energy consumption by more than 5%. However, the use of advanced control and monitoring can provide a 40% reduction in energy consumption [2]. Furthermore, to reduce energy expenditure related to lighting, light sources based on light emitting diodes (LED) are often used.

In [6] a power quality audit in an IT-intensive modern office building was carried out. The objectives of the audit were to detect major disturbances by means of power quality monitoring, identification of the power disturbances root causes, characterization of the electromagnetic compatibility level of equipment and installations, and provision of guidelines for implementing energy-efficiency solutions for the implementation of energy efficiency solutions. It has been found that the main problems for the building's devices were the emission of harmonics and energy losses during operation in the standby mode. In [7] the power quality parameters of LED lamps were analyzed. It was emphasized that their control and power supply systems equipped with switch mode power supplies (SMPS) generate higher current harmonics to the grid and draw capacitive reactive power from the grid. However, there are several other papers in the literature that are considering the impact of LED lamps on the power quality. In particular, they pay attention to high emissivity of current harmonics and low power factor [8, 9, 10, 11, 12]. In [13] it is shown that the current deformation of the LED lamps depends on the quality of the used power supply. Other paper [14] shows that the ambient temperature – which is particularly important in the case of street lighting – has a significant effect on the electrical performance of LED lamps, and can lead to an increase or decrease in the negative impact on the power grid.

Emission of harmonic disturbances in the power supply network signal, have a negative impact on the devices connected to it. Therefore, there is a need to conduct research on the quality of electricity leading to the determination of network parameters to eliminate undesirable phenomena.

3. Power quality in Poland

The basic – applicable in the countries of the European Union and in Poland – is the EN 50160 standard – Voltage Characteristics of Public Distribution [15]. This standard applies only to voltage, while currents in distribution networks are currently not standardized. The regulations in Polish legal acts have been adapted to the regulations contained in the standard. In Poland, the basic legal act determining the power quality is the Regulation of the Minister of Economy of 4th May 2007 on detailed conditions for the operation of the power system [16]. The ordinance specifies the required quality parameters of the power supplied from the grid for various groups of receptions, depending on the level of supply voltage, connection capacity and the nominal current of the pre-meter protection. For recipients included in the III-V connection groups (i.e. recipients whose devices, installations and networks are permanently connected directly to networks with nominal voltage lower than 110 kV), the following power quality parameters have been determined – in the case of a network operating without interference, expressed power supply parameters:

- frequency – the mean value of the fundamental frequency measured over 10 seconds should be between $50 \text{ Hz} \pm 1\%$ (49.5 – 50.5 Hz) for 99.5% of the week, while all values must be within $50 \text{ Hz} + 4 / - 6\%$ (47 – 52 Hz),
- magnitude of the supply voltage – each week 95% of the 10-minute root mean square values of the supply voltage should be within the range of deviations of $\pm 10\%$ of the nominal voltage,

- long-term flicker severity P_{lt} – for 95% of the time each week the long-term flicker severity P_{lt} caused by voltage fluctuation should not be greater than 1,
- unbalance – during each week 95% of the set of 10-minute root mean square values of the negative phase sequence component of the supply voltage should be in the range of 0% to 2% of the positive phase sequence component,
- higher harmonic content – 95% of the set of 10-minute root mean square values for each individual harmonic voltage should be less than or equal to the values specified in Table 1,
- the total harmonic distortion factor THD – the total harmonic distortion factor THD of the supply voltage, taking into account higher harmonics up to the order of 40, should be lower than or equal to 8%.

The above power quality criteria are valid under the condition that the recipients active power consumption is no higher than the contracted capacity, with the coefficient $\text{tg}\phi$, ratio of reactive power to active power, lower or equal to 0.4 [16]. It should also be noted that the energy company is obliged to meet certain power quality parameters at the place of its delivery, not at the internal network of the recipient. The place of delivery, which is the border of the energy company's liability, is defined by the terms of connecting the recipient to the network and the relevant contract.

Table 1. Values of individual harmonic voltages at the supply terminals for orders up to 25 given in percent of the fundamental voltage U_1 [15].

odd harmonics				even harmonics	
not multiples of 3		multiples of 3		order (h)	relative voltage (u_h) [%]
order (h)	relative voltage (u_h) [%]	order (h)	relative voltage (u_h) [%]		
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	0,5	>4	0,5
13	3	>15	0,5		
17	2				
19	1,5				
23	1,5				
25	1,5				

4. Research course

The aim of the study was to analyze the quality of the supply voltage and to assess the compliance of the Malopolska Laboratory of Energy Efficient Building (MLBE) building power conditions in accordance with the requirements of EN 50160 standard. The building of MLBE and its equipment were financed by the Project MRPO.05.01.00-12-089/12-00 created by DSc arch. Marcin Furtak and PhD Małgorzata Fedorczak-Cisak. The funds come from the Małopolska Regional Operational Program for the years 2007-2013. The MLBE is a 1:1 laboratory building that enables research in the field of energy-efficient construction in a broad sense [17, 18]. It is equipped with numerous LED light sources and building automation controllers, as well as computers and measuring devices requiring the use of power electronics systems adjusting the power supply conditions. Selected loads are also powered by an uninterruptible power supply (UPS) operating in double conversion mode.

The measurements were taken during the usual use of the building, in accordance with EN 50160 standard, during 1 week from 10th January, 2017, 7:00 a.m. The measurement was carried out using the

Sonel PQM-711 network analyzer, class A, which was connected to the power supply of the main switchboard of the building (figure 1).

5. Results and discussion

Based on the recorded data, it was found that during the period under consideration:

- the average magnitude of the supply voltage frequency measured for 10 s within the examined period of time is in the limits of 49.89 – 50.13 Hz,
- 10-minute average effective values of the supply voltage within the tested period of time are within the limits of 225.69 – 232.39 V, in all phases,
- long-term flicker severity P_{lt} was 0.22 in the L1 and L3 phases, and 0.23 in the L2 phase,
- unbalance of the supply voltage was 0.21%,
- the total harmonic distortion factor THD of supply voltage was 2.25%, 1.86%, 2.15% in the L1, L2 and L3 phases, respectively.

The recorded average content of higher harmonics in the supply voltage (relative values of voltage in percent of the basic component) is presented in figure 2.

Based on the results of the conducted tests, it was found that the quality parameters of the supply voltage meet the requirements specified in the ordinance [16]. In addition to the parameters specified in the ordinance, numerous transients (quick and short-term disturbances in the network) have been recorded that indicate switching operations in a normal operating power grid. In addition, increases, dips or interruptions in power supply were not recorded during the period considered.

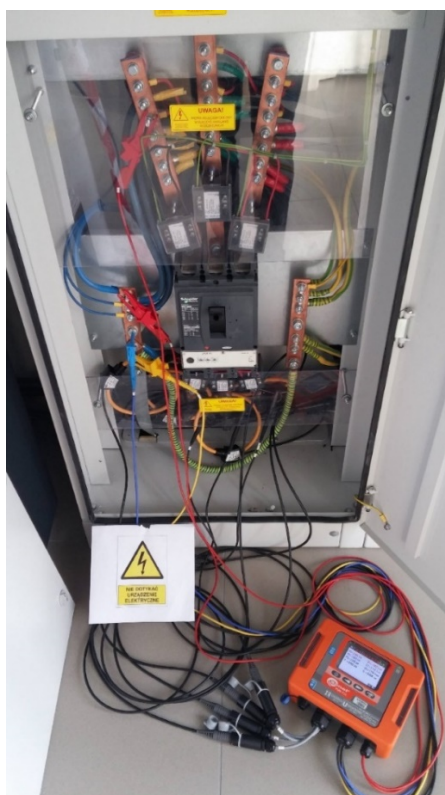


Figure 1. The Sonel PQM-711 analyzer during the measurement – the section I of the main switchboard RG of the MLBE.

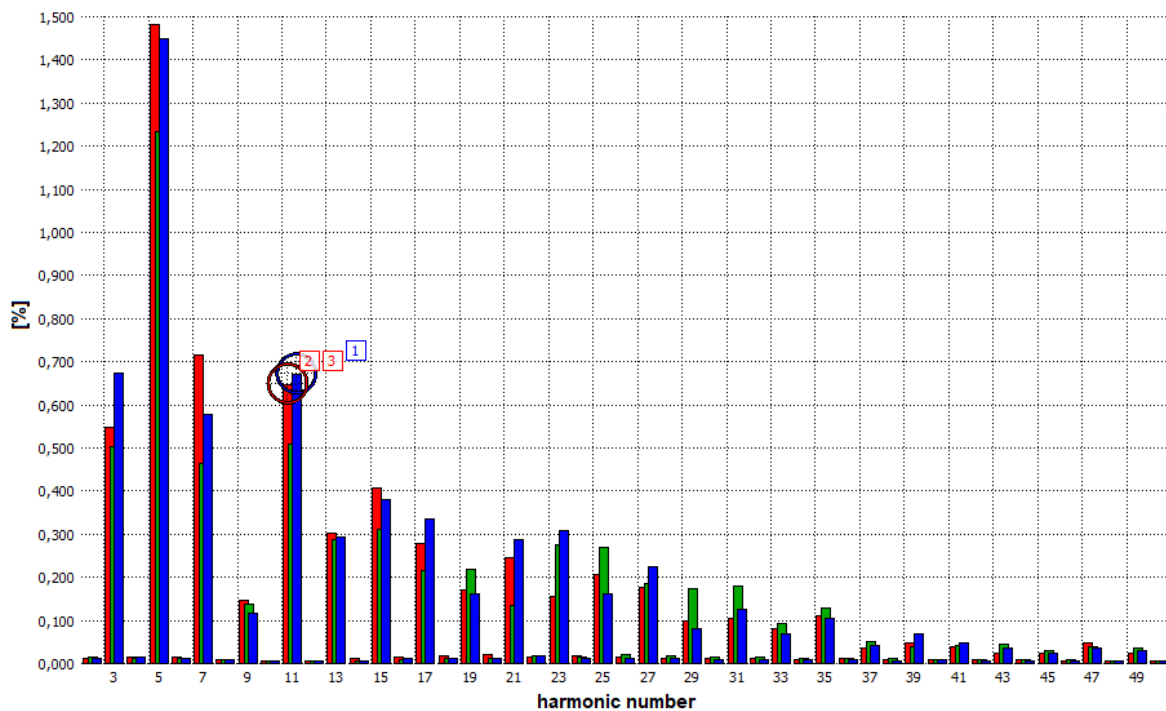


Figure 2. The recorded average content of higher harmonics of the supply voltage, in percent of the fundamental voltage U_1 (L1 phase – red, L2 – green, L3 – blue).

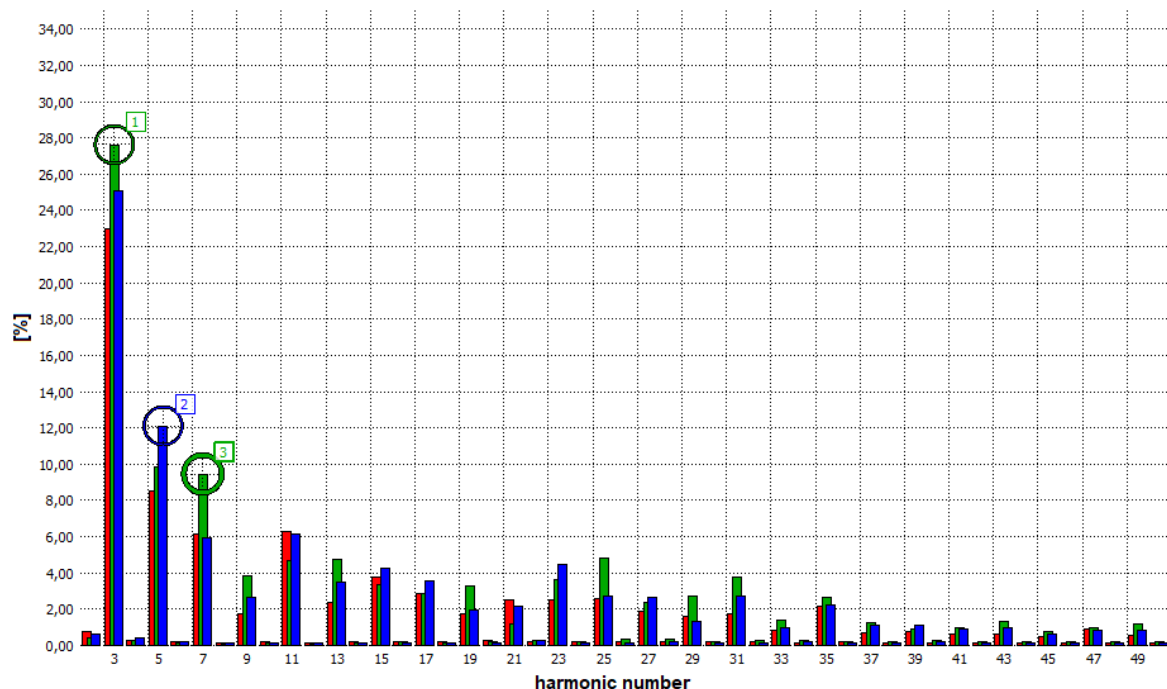


Figure 3. The recorded average content of higher harmonics of the current, in percent of the fundamental current I_1 (phase L1 – red, L2 – green, L3 – blue).

As shown in figure 3, harmonics dominating in the current are 3, 5, 7 and 11, which are characteristic for the many power electronic converters used in the MLBE building – switch mode power supplies (SMPS). The harmonic current content in the individual phases ranges from approximately 23% to

almost 28% of the value of the fundamental component. The current deformed in non-linear loads causes a voltage drop and strain in the impedance of the wires. As a result, the distorted voltage waveform applies to all other loads in the same circuit, causing the flow of the harmonics through the current – even if they are linear loads. Despite the fact that due to the low power of the power converters used, the absolute values of the harmonic currents generated by these devices are small, the total effect in the form of current and voltage distortion can be significant. In the case under consideration, both the building and the energy supplier are the source of harmonic distortion. In branched networks, with many different non-linear receivers, the active power flows of different receivers add up. It causes the flow of this power in different directions. Depending on the phase shift, there may be a reduction of individual harmonics or their amplification. In this case, based on a simple graph analysis, determining the location of sources of harmonic disturbances is difficult and it is not possible to clearly indicate the sources of the disturbances [19].

Figure 4 shows the course of the coefficient $\text{tg}\phi$ (10-minute mean values) over time, which is the ratio of reactive energy to active energy consumed by the user. The coefficient was negative at all times, which means that from the point of view of the power supply network, the building was a receiver that absorbed capacitive reactive power. It is also characteristic for the high saturation of the building's network with power converters.

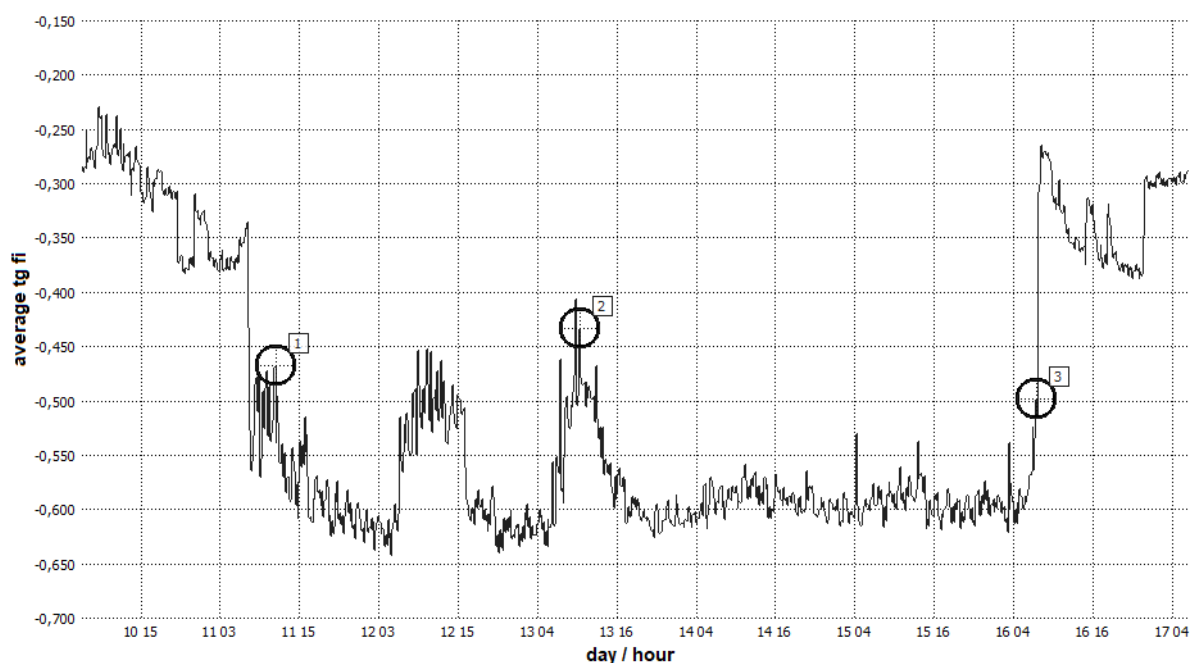


Figure 4. The recorded course of the coefficient $\text{tg}\phi$ over time.

6. Conclusions

The widespread use of technologies such as automation systems, variable speed drives, and LED lamps will be the key to achieving energy efficiency in buildings. These technologies are mainly based on power electronic supplies. Operation of this type of strongly non-linear receivers leads to an increase in transmission losses of electrical energy related to reactive power flow and generation of higher harmonics, which in consequence will aggravate the problem of insufficient quality of electricity. This case study evaluates the power quality of the Malopolska Laboratory of Energy Efficient Building. In particular, this study indicates a problem related to the impact of power electronic supplies, characteristic of energy efficient intelligent or smart buildings, on the power quality.

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