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Energy balance and quality in electric network powering IT objects

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The paper deals with elements of issues regarding the impact of electromagnetic disturbances and electric energy management. The energy balance and tests of distortions of voltage and current waveforms in the power supply system of an IT facility such as a computer laboratory were carried out. The measurements covered current and voltage values, active power, reactive power and apparent power, power factor and THD (Total Harmonics Distortion) factor for voltage and current, waveforms and content of current and voltage harmonics in the facility under consideration. On top of this, effects of the UPS EVER POWERLINE power supply, provided with the reactive power compensation function (without connecting reactive compensation components) were tested in reference to the reactive power consumption by devices connected in parallel with the UPS to the electric network in the object. The analyses were carried out in terms of introducing rationalization of energy management and eliminating the impact of disturbances in systems covering power supply and energy receivers, that is, achieving technical (reliability of devices) and economic benefits (reduction in operational costs resulting from occurring power losses and in charges collected for consumption of electricity) in using large powered objects.

KEYWORDS: quality of energy, disturbance waveforms, higher harmonics, energy balance, reactive power compensation

1. Introduction

Different forms of energy have been an object of interest for people since ancient times. Man, as an intelligent being inclined to abstract thinking tried to bring energy under control and use it for his own purposes. These first forms of energy which man tried to take advantage of in various ways included thermal energy, light energy and mechanical energy. In the history of mankind, there were milestones related to the civilisational development of man; the most spectacular ones were: striking the fire, invention of wheel, or in the epoch of industrial revolution, invention of steam machine and use of electricity. At present, the most convenient form of energy, because of easiness of its generation, transmission (even to long distances), storage and processing is the electric energy. In all the areas of man's existence, both in economic activity and in private life, various electric, electronic and IT equipment is used commonly. The demand for electric energy has been increasing steadily, and at the same time, sophisticated technical appliances become sensitive to more and more frequently appearing power supply irregularities, and also emit more and more disturbances into the surrounding environment.

Operating conditions of electrical devices, to a particular extent, depend on the quality of energy supplied to them, though they are also related to environmental parameters, operational conditions etc. Each element (system) integrated into an electric circuit has an effect on it. If it is non-linear, then it introduces non-linearity into the circuit with which it is integrated. As a result, it is evident that electric energy receivers and power supply systems have reciprocal effect on each other. They should cooperate with each other in such a way as to not disturb their proper operation reciprocally whereby their operation should not cause unjustified energy losses [1-15].

The paper deals with power balance and energy quality related to the power supply of a specific facility such as a computer laboratory. Attention has been paid mainly to reactive power consumption as well as distortions of voltage and current waveforms (harmonics). Considerations related to the quality of power supply selected for laboratory analyses depict the conditions of functioning of other facilities, in which the main energy receivers include computers, servers, uninterruptible power supply systems and lighting systems.

2. Occurrence of disturbances in electric circuits

Electromagnetic fields are generated both in power supply electric circuits and in receiving circuits under the influence of flowing currents and voltages occurring in them. The fields interact with the elements present in the surrounding environment and as a result of this, disturbing signals may be transmitted. After reaching sensitive elements such signals may disturb their proper functioning. Similar effects can be noticed in the case of occurrence of connecting, transient states during dynamic changes in load, etc. The spreading disturbances which are generated in such circumstances may lead to the defective operation of equipment or occurrence of emergency states [1-9].

Electric systems are exposed to hazards related to uncontrolled and sudden voltage decays. Such decays may result from emergency states of power supply circuits or deliberate power cuts with regards to specific recipients, resulting from problems related to covering the electricity demand. The consequence of frequent starts and stops of high loads are voltage dips and increases. Also, in switching states, particularly in circuits containing reactive elements (coils, capacitors), there are transients states which, in turn, result in the occurrence of overvoltages and disturbances particularly dangerous for electronic subassemblies. In view of the dynamic development of the electronic systems and automation, where non-linear elements and systems are used more and more commonly, currents and voltages with significant distortions appear often in electric circuits. Thus, the effects of higher harmonics are present [2-7, 9].

It follows from the above considerations, that the most typical disturbances that spread in power supply circuits are fluctuations in the value of voltage (voltage increases and dips), its decays (long-lasting or short-lasting), overvoltages, frequency variations and distortions of voltage or current waveforms. The proper identification and elimination of these adverse effects is necessary in order to ensure the correctness of performance of the operated electric equipment and to ensure man's safety.

In the case of operation of IT equipment, the biggest problem is the occurrence of current and voltage waveform distortions, i.e. the effect of higher harmonics. For this reason, the following sections of this paper include test results regarding these disturbances as well as related remarks.

3. Effects of impacts of electromagnetic disturbances

Electromagnetic disturbances which affect elements, systems or equipment cause specific adverse effects.

Overvoltages (or voltage increases) often cause the puncture of semi-conductor connectors (and as a consequence of this, permanent damage to these elements and occurrence of emergency conditions), degradation of insulation or deterioration of the conductive pathways or electric connections, may cause unplanned changes in the operation of logic gates, errors in the transmission of data or its deletion, irregularities in the software operations. They also affect the premature aging (destroy) of electronic components, which ultimately leads to damage to operated facilities.

During voltage dips or unexpected interruptions of power supply (short-lasting or long-lasting), the receivers are not powered sufficiently, which causes irregularities in their performance or interruptions in their operation. Such uncontrolled voltage variations or decays may lead to irreversible loss of processed information in IT facilities. In microprocessor systems which control complex technological processes, because of the lack of transmission of signals or errors in their transmission, they can affect CPU's, I/O cards or logic states of PLC's, and as a result of this, cause the interruption of the currently completed tasks, technological processes, or shut-down of the production lines etc. With regards to the operation of electric machines, they can be the cause of occurrence of unstable states or shut-downs of engines and the necessity to carry out the complex process of their restart. As industrial processes often require precise control of many parameters (such as pressure, temperature, flow) dependent on the proper operation of electric engines, the moment and the speed of the engine may have the direct impact on the process variables, deregulating them in such situations. In the situations when the discharge lighting is used (e.g. sodium vapour lamps), during voltage decays or dips, it can turn off, and the lack of the lighting may last for the time required by the lamp to cool down and to carry out its ignition again.

Supply voltage distortions (effects of higher harmonics) may cause the occurrence of additional power losses resulting from the existence of components with higher frequencies than the usable frequency, turned into heat, and as a result of this, overheating and damaging of the electrical elements, systems or equipment. Opposite sequence harmonic currents generate the torque with the opposite direction to the driving direction, increasing the anti-torque, which, as a consequence, leads to overloading and overheating of electric (induction) engines. Higher harmonics of the neutral sequence do not rotate and in three-phase four-wire system, they sum up in neutral wires, finally overheating and damaging them. In three-phase transformers operating with the delta connection, the added zero sequence currents flow through windings causing similar effects. Higher harmonics may also be the cause of unexpected activation of protection devices (automatic switches), improper operation of devices that control the technological processes, overload of capacitor banks for power factor correction, intensification of results of occurrence of the skin effect, acceleration of processes of aging and degradation of insulation elements, occurrence of resonances including their effects etc.

To sum up – the most frequently occurring effects of electromagnetic disturbances may include the occurrence of additional power losses and excessive increases in the temperature of elements and subassemblies, the occurrence of emergency states in devices and systems, the loss of processed data or information or even the presence of risks for human life and health. (operation of the medical equipment and occupational health and safety conditions at electric devices), deterioration of service life, reliability of facilities and also change in technical parameters of the used hardware [4].

Protection of the operated electric equipment against the occurrence of the described hazards is a priority both for technical as well as economic and organizational reasons.

4. Proper energy management

Energy receivers consume active (usable) power from the power network. This is related to the fulfillment of complex functions by them, for instance, processing to a different energy type. However, they also consume reactive power, which is not used, though is necessary to create specific physical conditions in the system, e.g. creation of electric or magnetic fields, collection of energy in these fields, etc. The proper energy management consists in the limitation of the occurring power losses and reduction of the consumption of reactive power [1-3, 5, 8, 11].

Elimination of unreasonable energy consumption, that is, the improvement of the energy efficiency in the facilities consists in the implementation of specific natural measures (mainly turning off the equipment running at idling speed), use of proper materials and subassemblies (low-loss elements increasing the efficiency of equipment), exclusion of effects of higher harmonics and application of reactive power compensation.

Among technical measurements aimed at limitation of reactive power consumption, it is possible to distinguish:

- activation of reactive elements with opposite nature in relation to the reactive power consumed in the facility,
- use of electromechanical compensators,
- use of electronic phase shifters.

The facility, which consumes great amounts of energy, is often considered to be resistive-inductive nature. Indeed, in the majority of manufacturing plants, as well as the output power also the inductive reactive power is consumed in view of using, for the most part, devices and machine tools containing engines, transformers and other electromechanical converters. However it must be taken into account that many of the presently operated facilities are of resistive-capacitive nature. These will mainly include units, where computers, uninterruptible power supply systems or modern energy-saving lighting systems are in use. These include IT data centers, office buildings, banks, shopping galleries and other similar buildings [2, 3, 5].

Reactive power consumption, irrespective of its nature, is related to unreasonable consumption of electric energy (not being the usable energy), additional power losses occurring in power transmission and distribution equipment as well as blockage of transmission capacities of the existing technical infrastructure. In order to achieve the rational electric energy management, it is necessary to identify and then eliminate reactive power consumption as well as effects of higher harmonics (as causes of energy losses).

5. Characteristics of the considered object

The university computer laboratory has been selected as the object of tests of reactive power consumption and current and voltage distortions. The nature of the utilized loads in the case of computer lab is similar to many facilities where the main receivers connected to the electric power network are elements of the IT structure (computers, servers, uninterruptible power supplies, etc.) as well as elements and devices related to lighting and air conditioning systems.

Switching power supplies in computers draw current from the power supply circuit only during the maximum voltage sinusoid (then, the capacitors in the input circuit are charged). The waveform of the current is distorted and the consumption of the reactive capacitive power takes place. The reactive power of a single computer power supply is small, and the drawn distorted current has an excessively low value to consider any negative effects of their occurrence in the system consisting of the power supply circuit and the energy receivers. There are many computers used in the computer lab or data processing centre, therefore in view of their cumulative nature, the consumption of reactive power and the distortions of the total current drawn from the power supply circuit affect significantly the evaluation of quality of the energy management and effects of disturbances in such a system [2, 3, 11-15].

Additionally, the energy-saving lighting is used in these facilities. In older solutions of discharge light sources, stabilization systems were used; glands which occurred in them caused both the active power and the inductive reactive power to be consumed. In the present energy-saving light sources, glow starters, stabilizers and other applied electronic lighting element control systems are more often than not of resistive-capacitive nature. These systems are characterized by consumption of active and reactive energy (most frequently the capacitive one) and also the current drawn by them from the power supply circuit is distorted [2-4, 6, 7].

A great majority of computers in IT facilities (laboratories, data processing centers) – in order to ensure protection against uncontrolled power supply decays and possibility of losing of the processed information – is powered from uninterruptible power supply systems (UPS). These are devices which in view of the operation of input circuits (rectification of voltage supplied from the power network and its stabilization) consume reactive-capacitive power in spite of the PFC (Power Factor Correction) systems applied in them [2-7, 19].

In accordance with the requirements of the current standards and regulations [16-18] regarding the quality of electric energy in public power grids, the elements and devices connected with them may draw currents, whose distortions do not exceed the levels precisely specified (different for specific groups of receivers) in these documents. Therefore, receiving systems drawing highly distorted currents should have the PFC (power factor correction) systems applied in their input circuits, whose main task (particularly the reactive systems) is limited to the effects of higher harmonics (which is performed with a varying effect), and the reactive power resulting from the basic harmonic is still drawn from the power supply circuit. This is a problem which must be solved separately.

6. Results of performed tests

Tests were carried out in the computer lab provided with 16 desktop computers with LCD monitors. There is a three-phase power network, whereby majority of the operating computers was switched to phase L2. The conducted measurements of values referred to active power, reactive power, apparent power, currents, voltages, power factors, THD (Total Harmonics Distortion) factor and content of the respective harmonics for voltage and current. Also, waveforms and spectral characteristics of voltage and current harmonics in the power network at the laboratory were recorded.

Fig. 1 presents results of measurements of active, reactive and apparent powers in the respective phases and their total values, as well as power factors, values of voltages and currents and electric power network voltage frequencies. The reactive capacitive power consumption was at the level exceeding 60% of the used active power. In the case of inductive reactive power, the consumption of reactive energy is considered to be excessive after exceeding tg $\varphi = 0.4$, while for reactive capacitive power, each reactive energy consumption is treated as excessive. As charges for the excessive consumption of reactive energy are $1.7 \div 2.5$ times higher (depending on the granted tariff) than for active energy, then in objects with a similar reactive capacitive power consumption as in the case of the analyzed laboratory, monthly fees for consumed reactive energy are higher than charges for consumption of active (usable) energy [3].

a) b)

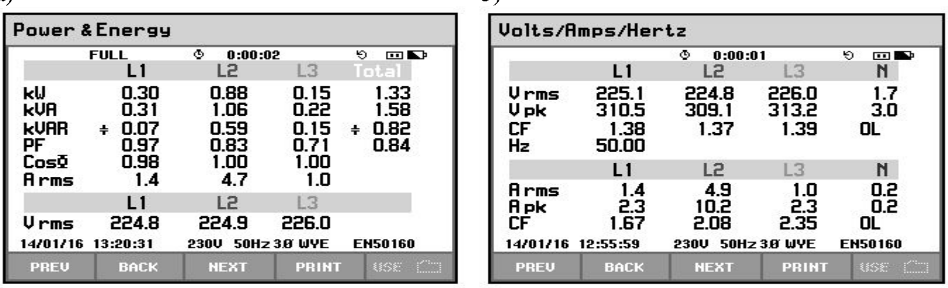

Fig. 1. Results of measurements of power supply parameters in the tested laboratory
a) powers, power factors, currents and voltages, b) currents, voltages, frequency

Figure 2 presents waveforms of phase voltages in the system, and Fig. 3 their harmonics presented in the form of the spectral characteristics and tabularized percentage contents of the respective harmonics. It can be seen clearly that voltage sinusoids have flattened peaks. The total THD factor is 2.4%, thus it is within the permissible normative limits [16-18].

Figure 4 and 5 compares the similar measurement results for power network currents. The signals of currents are strongly distorted, with the waveform characteristic for switching power supplies (momentary power consumption at the peaks of the voltage sinusoid). The total harmonic distortion factor (THD_i) in phase L2 exceeds 64%, whereby of utmost significance are the following harmonics: 3, 5 and 9. It is evident that the THD_i factor has a lower value in phase L1 – at the level of 13% – a multimedia projector was switched on there. The waveform of this phase is different than in phases powering computers (L2 and L3). The comparison of the waveforms and voltage and current harmonics for phase L2 (the most intensively loaded) is provided in Fig. 6 and Fig. 7. They confirm the previous considerations.

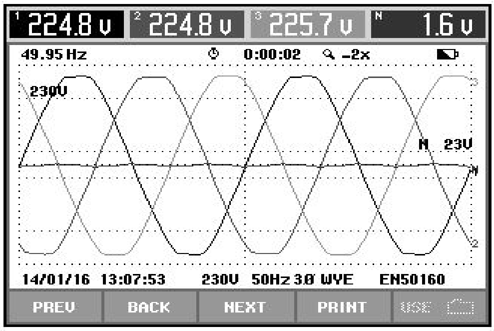

Fig. 2. Waveforms of phase voltages in the tested system

a) b)

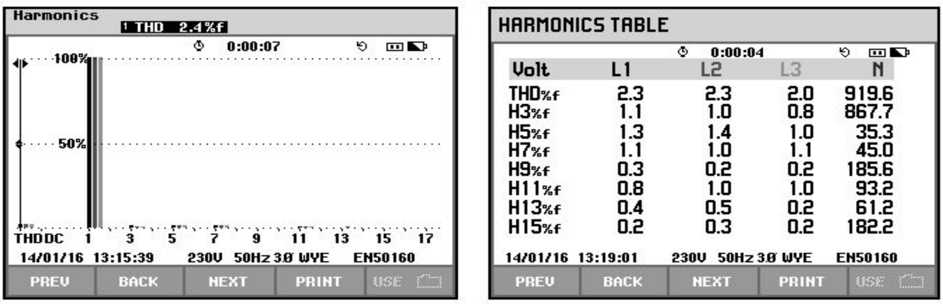

Fig. 3. Results of measurements of supply voltage harmonics
a) spectral characteristics, b) content of the respective harmonics

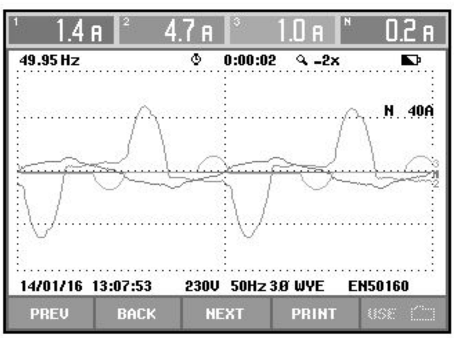

Fig. 4. Waveforms of currents of respective phases in the tested system

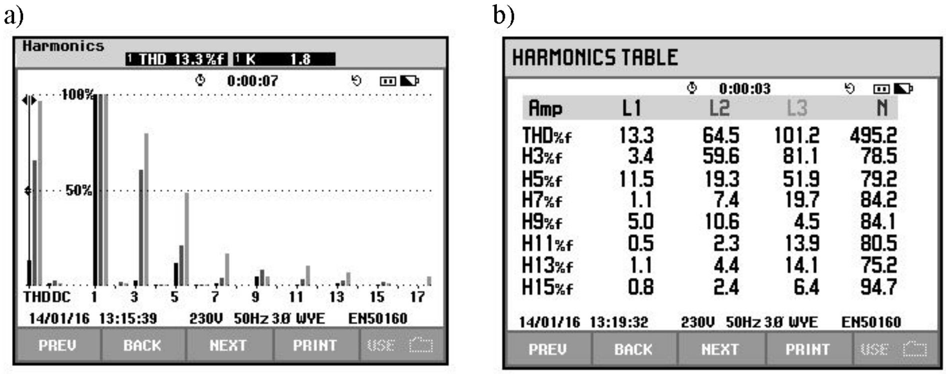

Fig. 5. Results of measurements of current harmonics in the system
a) spectral characteristics, b) contents of the respective harmonics

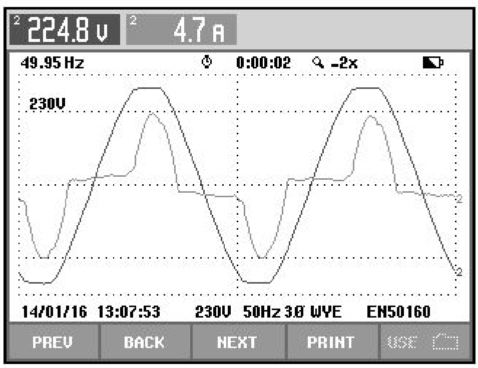

Fig. 6. Current and voltage waveforms in phase L2

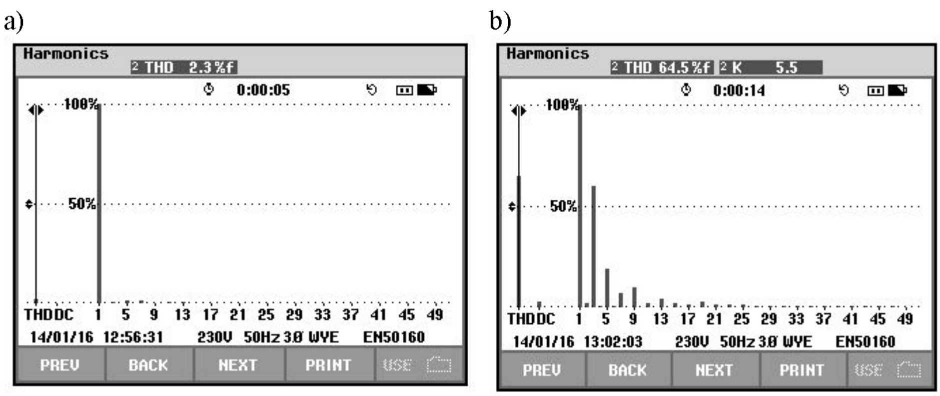

Fig. 7. Results of measurements of spectral characteristics of
a) voltage harmonics in phase L2, b) current harmonics in L2

7. Elimination of effects of disturbances and reactive power consumption

In order to be protected against the negative effects of electromagnetic disturbances on the used receivers, it is necessary to apply remedial measures in the form of adequately selected protection systems. This allows the avoidance of premature degradation of the operated facilities, the overheating of elements and systems, the occurrence of damage, emergency situations and operating shut-downs of equipment and systems, the risks for human life and health or the loss of data and processed information, thus technical, organizational and economic benefits are achieved.

In order to ensure protection against the effect of excessively high voltages, surge arresters in the form of isolating systems (e.g. gas discharge tubes, thyristors, triacs, overvoltage switches), limitation systems (using varistors, special diodes, etc.) or combined systems – being a result of connection of two previous groups (e.g. including both the gas discharge tube and the varistor).

The elimination of effects of higher harmonics (distortions of current and voltage waveforms) can be ensured by using filters for higher harmonics, installing separating transformers, using automatic switches for higher harmonics, isolating and filtering receivers that introduce current distortions (generating higher harmonics), and, to a significant extent, also using uninterruptible power supplies (UPS), operating in the on-line topology (VFI).

Uninterruptible power supplies (UPS) are also the basic solution for issues related to dips and decays of power network voltage. They supply energy with the expected voltage value to the receivers on a permanent basis (until the energy accumulated in the energy storages is exhausted. Such storages should be sufficient to end the ongoing processes in a safe and controlled manner). Voltage dips can also be eliminated by using stabilizing transformers (including the ferroresonant transformers), energoelectronic fast transfer switching systems and various types of static generators of basic harmonic currents and voltages.

In the case of facilities, where large reactive power consumption is present, reactive power compensators are commonly used in the form of adequately selected and activated reactive elements: compensation capacitor banks or sets of chokes (depending on the nature of the consumed reactive power) On top of this, also the PFC systems are used, but very frequently their task is to eliminate higher harmonics, and the reactive power of the basic harmonic is not eliminated.

In consideration of the protection against supply voltage dips and irregularities, which is required in the case of most loads of priority importance, and also in view of the use of uninterruptible power supply systems for this purpose, it is worth selecting a technically advanced power supply, which is provided with relevant functionalities, and eliminating the effects of disturbances and consumption of reactive power by means of it (without using additional filters or compensation devices). Such devices include UPS EVER POWERLINE, which, except supplying voltage of hardly traceable distortions to the receivers (THD_U at the level of 0.4÷1.2%), are provided with the function of reactive power compensation (owing to the appropriate management of current in the input circuit, without the need for connection of any additional reactive elements) both its own, as well as other loads connected in parallel with the power supply to the same power network. The results of operations of such a power supply are presented in Fig. 8. For the purpose of carrying out the tests, UPS EVER POWERLINE GREEN 33 with the apparent power of 20 kVA and three-phase resistive and capacitive receivers were used.

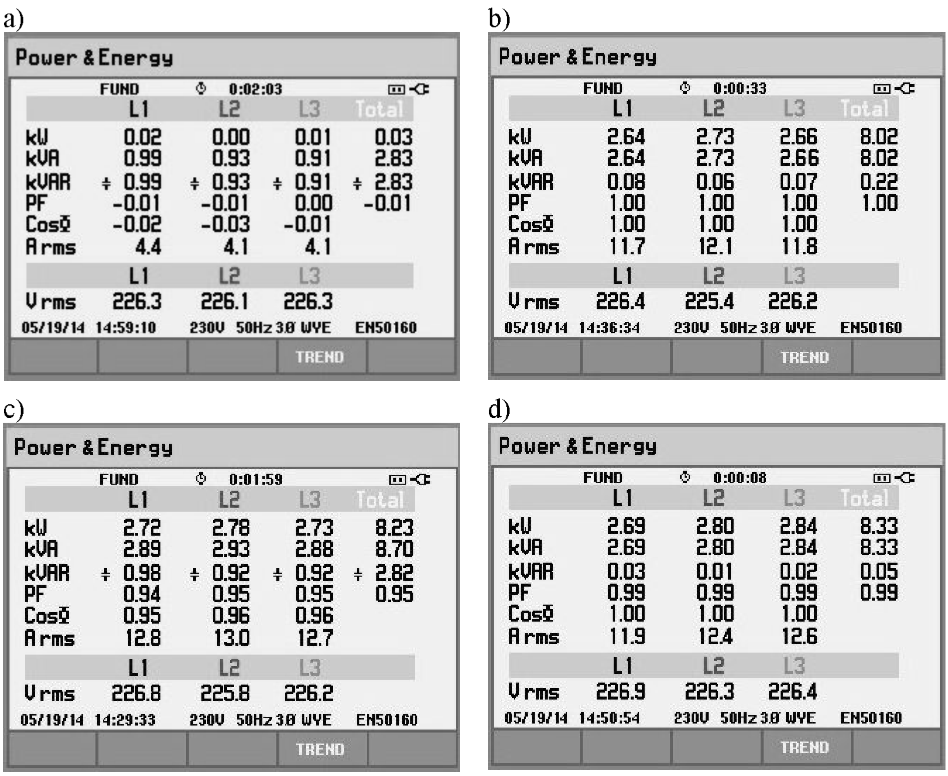

Fig. 8. Results of measurements of active, reactive and apparent powers (in phases and total ones), phase currents and voltages and power factors for: a) 3-phase capacitive receiver, b) UPS operating with active load 50% P_{max} (compensation of its own reactive power), c) activated in parallel: UPS and capacitive receiver (without activation of compensation by UPS), d) activated in parallel: UPS and capacitive receiver after introducing reactive power compensation settings

UPS EVER POWERLINE GREEN 33 compensated its own reactive power (capacitive power consumed by its input circuit, whose rectification system includes operating stabilizing capacitors), which is presented in Fig. 8b, but also its own reactive power as well as reactive power of the capacitive receiver connected in parallel to the power network (Fig. 8d). Reactive compensation devices were not used and the total reactive power consumed from the electric network was decreased almost to zero. It can be concluded that this UPS protects energy receivers against uncontrolled decays or other supply voltage irregularities and at the same time brings economic benefits, resulting from the elimination of consumption of reactive power from the power network.

8. Summary and conclusions

In order to ensure the long-lasting and proper operation of energy receivers, it is necessary to protect them against the effects of disturbances, i.e. to ensure good care for the quality of the energy supplied to them. Frequently, this is additionally related to gaining savings in their operation. Additional financial savings and technical benefits may be achieved by limiting the consumption of reactive power by the used receivers.

In IT facilities, in view of the structure of energy receivers characteristic to them (computers, servers, UPS, energy-saving lighting, air conditioning systems), it is possible to encounter effects of electromagnetic disturbances (mainly higher harmonics) as well as reactive capacitive power consumption. An important aspect of their use is the elimination of effects of higher harmonics on the electric equipment connected to the electric power network and the use of reactive power compensation.

Care for the quality of energy and energy efficiency of business facilities is particularly important in view of the achievement of an increase in the durability and reliability of the electric equipment used in them (elimination of effects of disturbances), reduction of costs of use of these facilities (reduction of energy losses and charges collected for the reactive energy consumption exceeding the agreed limit), and from the point of view of the energy operator – reduction of losses in transmission-distribution equipment and unblocking of transmission capacities of the owned technical infrastructure. This implies that both technical and economic benefits gained at the same time by energy users and operators are related to this.

Methods of management of energy quality and efficiency in business facilities will be varied, depending on the number and type of energy receivers operating in them, their nature, functional properties and tasks fulfilled by them. Therefore, the proper identification of the occurring reactive power disturbances and consumption as well as the proper selection of technical remedial measures adequately to the problems occurring in specific facilities, are all key elements in ensuring the best conditions for operation of the electric equipment and rationalizing the energy management in the given business unit.

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