Compensation of reactive power and hybrid operation in the systems of uninterruptible power supply (UPS)

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The paper presents analysis of possible compensation of reactive power by internal input blocks of Uninterruptible Power Systems (UPS), without the use of additional power electronic converters or stationary passive elements (on the example of UPS EVER POWERLINE GREEN 33). Moreover, the consideration related to additional UPS functionality consisting in hybrid operation, enabling longer duration of supply maintenance within a definite region of the mains voltage variations. The results of measurements and calculations are presented, that have been carried out in a given physical system. Final part of the paper includes a summary of the obtained results.

KEYWORDS: the systems of uninterruptible power supply, reactive power compensation, hybrid operation

1. Introduction

Taking into account common use of electric and electronic parts, devices, and systems in all the areas of human activity, both in private and professional realm (science, industry, administration, services, etc.), the problems related to the quality of delivered power and to reasonable power management become very important. The faults or interruptions in electric power delivery are not only burdensome to the users, due to precluded operation of the electric equipment, but may be conducive to severe consequences. These consequences may be of economic, technological, and information nature, in the form of data loss in computer systems, damage to electric equipment, expensive shutdowns of the equipment operation, or the discomfort related to insufficient heating of usable premises (mainly in winter) or operation of the access control devices (automatic gates, the parts of intelligent buildings, alarm systems etc.).

A good solution to such problems is the use of a guaranteed power supply provided by UPS emergency power supply devices. In the reserve operation mode (actuated in case of improper parameters or decay of the mains voltage) these devices use the electric energy stored in the accumulators (batteries), in order to ensure feeding of the secured receivers (of key meaning) within a predefined time, with a view to terminate the current processes [1-5]. These systems often offer many additional functions that enable more optimized power management, financial savings, or improved quality and security of operation of the equipment.

Incessant need of reasonable power management and growing cost of the electric energy force the undertakers to permanent control of its consumption. Any energetic savings are justified not only from the economical but also from technological and good management point of view. One of the factors of energy saving consists in reactive power compensation [6,7]. An important question related to this problem is how to reduce the apparent (total) power absorbed from the supply source without the change in active (usable) power of the receivers? The present paper formulates the question in slightly different way: namely, how to reduce the total power absorbed from mains by the system of guaranteed power supply, without reduction of the effective power of the receivers connected to its output, inserting no additional parts or devices compensating the reactive power.

One of the most important utility parameters of UPS power supply devices is the supply maintenance time in the reserve operation mode (in case of improper parameters of the mains voltage). The time may be extended by connection of additional battery modules, i.e. by increase of the energy stored in the accumulators. Hence, another question may be formulated: is it possible to extend the supply maintenance time of a receiver on other way, without changing the power consumed by it? It appears that another possibility of extension of the autonomous mode under definite UPS operation conditions consists in the use of hybrid operation [1-3,8-9].

The paper presents two new functions of the guaranteed power supply in the form of compensation of UPS reactive power and the hybrid operation, that allow the user to attain both economic and technological (operational) advantages. Moreover, results of the studies and calculations are presented that are relative to the considered problem for a real physical object, namely the UPS EVER POWERLINE GREEN 33.

2. VFI systems of guaranteed power supply (UPS On-Line)

The VFI systems of guaranteed power supply (on-line) are reckoned among uninterruptible power supply devices (Fig. 1), in which the value and frequency of output voltage do not depend on the parameters of the input (mains) voltage [1,2]. The most frequent operation mode of these devices is the mains (normal) mode. The energy absorbed from the mains is then processed twice: the mains alternating voltage applied to UPS input is rectified by a rectifying system and, afterwards, supplied to the inverter by a DC bus duct. Then, it is converted to alternating voltage of required parameters (i.e. voltage value and frequency). In result, properly processed voltage is applied to the secured receivers connected to the UPS output (Fig. 1). At the same time, a part of the energy coming from the DC bus duct is used for supplementing the energy of the accumulators (Fig. 2). In case of occurrence of improper value, improper frequency or decay of the mains voltage the system automatically switches to the reserve (battery) mode of operation. The receivers are then supplied with undisturbed voltage as the inverter is supplied by the accumulators (until the energy accumulated there is exhausted) – Fig. 3. Once proper mains voltage is restored, the mains mode is reinstated (when the charge of the accumulators takes its minimum value). The operation is switched from mains to reserve mode and vice versa in fully uninterruptible way – only the source of the energy applied to the inverter is changed.

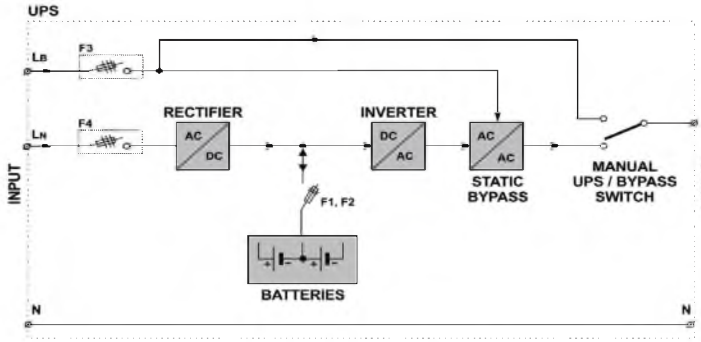

Fig. 1. Block diagram of the UPS VFI (on-line)

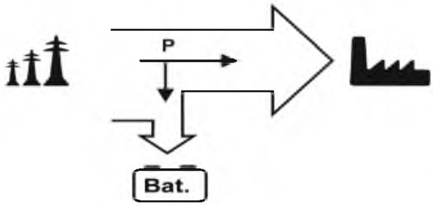

Fig. 2. Energy propagation in the mains (normal) mode of operation

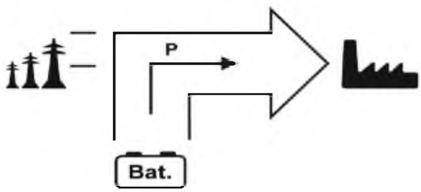

Fig. 3. Energy propagation in the reserve (battery) mode of operation

In this system the energies of the input and output lines are separated. An exemplary solution of the system of VFI guaranteed power supply is the UPS EVER POWERLINE GREEN 33, the additional functions of which, together with the results of the tests, are presented in further part of the paper [7, 8].

3. Compensation of reactive power

Receivers of electric energy, apart from absorbing the active (effective) power, often absorb the reactive power too (i.e. the power related to generation of definite physical conditions of the systems, and to generation of magnetic and electric fields, to the energy accumulated in these fields, etc.). In case of the use of e.g. transformers or chokes, the systems including them absorb the active and reactive inductive power. Not long ago it was the most common (resistance-inductive) type of the load, that occurred in industrial plants and in housekeeping equipment. At present many devices (inclusive of computer equipment) are distinguished rather by resistive-capacitive character. Hence, the power network is loaded both with effective and reactive-capacitive power. Total effective power must be delivered to the receivers with the help of the mains network (which always results in power losses arising in the production and transmission equipment). Reactive power should not be transmitted since it is conducive to additional losses and, moreover, restrains the power transmission capacity of the existing transmission equipment. Absorption of reactive power may be avoided on the spot by connecting a device that charges the system with reactive power of opposite character as compared to the one primarily absorbed. Such a procedure is referred to as compensation of reactive power.

In practice the reactive power may be compensated by:

a) connection of a systems of capacitors (in order to compensate the inductive reactive power) or system of coils (in order to compensate the capacitive reactive power);
b) the use of electric-machine controllers;
c) connection of the systems of electronic phase shifters;
d) switching off the idling equipment that spontaneously absorb reactive power (a natural method).

The companies are charged with very high costs for extra-contractual absorption of reactive power (i.e. any levels of capacitive and inductive reactive power for the tan φ coefficient exceeding its contractual tan φ_o value) [10]. Since UPS input is provided with capacitor systems, each UPS power supply device, apart from the active (effective) power absorbs the capacitive reactive power too. When the mains supply system includes many additional devices provided e.g. with impulse feeders located at the input (like computers) or other reactive power absorbing receivers, total cost of absorbed reactive power may even exceed the expense born for the effective power.

Reactive power compensation in UPS EVER consists in such control of the feeder input current (the current absorbed by the rectifying system) as to ensure full compensation of capacitive reactive power of the UPS, i.e. the power coefficient cos φ of the system is adjusted to 1, irrespective of the level of absorbed effective power. Hence, the charges for UPS extra-contractual power absorption are fully eliminated, resulting in significant financial savings. Moreover, a specialist software may enable to adjust properly the compensation process with a view to compensate reactive power (i.e. its definite values) in the system of other receivers connected in parallel with the UPS power supply device to the same mains network. This innovatory functionality of the system of guaranteed power supply has been submitted by EVER Ltd. Company to the Patent Office [7, 8].

4. Hybrid operation

Technical parameters of the systems of guaranteed power supply (UPS) are defined with declared ranges of admissible variation of the value and frequency of the input voltage. They are assumed as the tolerance within which the mains mode of operation is kept [1-3]. Once any of the parameters takes a value beyond the predefined range, the UPS switches to the battery operation and the receivers are supplied by the power from the accumulators until the energy accumulated there is exhausted. Duration of the supply maintenance depends mainly on the quantity of the accumulated energy (the battery capacity) and the power of the connected load. In commonly used emergency power supply devices the declared range of admissible input voltage variation is rather narrow, in consequence, any excess of the limit values results in full load of the energy accumulator (the battery system).

In the power supply devices from EVER Ltd. Company a broad range of input voltage variation and hybrid operation are provided [8, 9]. This is attained so that in order to fulfill power demand of the receivers (at the UPS output) under decreased level of the mains voltage (remaining within the declared range) the current absorbed at the input is increased. It is possible until the maximum current I_{max} of the rectifier circuit is reached. In these conditions the UPS operates in mains mode as before. In case of further reduction of input voltage (however, remaining within the broad voltage range) the operation is switched to hybrid mode. The power equal to the product of the maximum current and the present voltage value is absorbed from mains (of worsened parameters), while its missing part required for covering the receivers demand is drawn from the battery modules. The energetic balance is shown in Fig. 4.

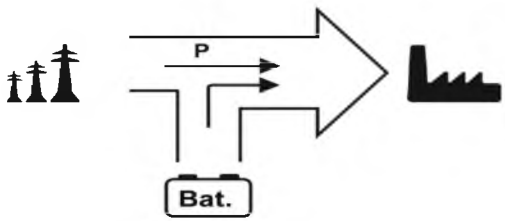

Fig. 4. Energy distribution under hybrid mode

It becomes clear that the accumulators deliver only the power equal to the difference between the receivers demand and the power absorbed from the mains of faulty parameters. Hence, the time of power supply maintenance in the hybrid mode should be considered as the discharge time of the accumulators (under reserve mode) loaded only with the power equal to the power difference. This allows to extend significantly the time of power supply maintenance of the receivers. In case of common solutions the reserve operation mode is then accomplished instead of the hybrid mode. In such a case the whole energy delivered to the receivers is absorbed from the battery and, in consequence, the time of supplying the receivers is shorter. [7-9].

5. Results of the studies and analyses

The device under investigation was UPS EVER POWERLINE GREEN 33. It has a three-phase supply, and delivers three-phase output voltage. Apparent output power of the feeder is equal to 20 kVA, with effective power of 16 kW. Apart from many additional functions, the device is provided with the functions of reactive power compensation and additional hybrid operation mode [7-9].

During the tests related to reactive power compensation a controlled inductive receiver was connected to the power network and the power values at its particular phases have been measured (Fig. 5a). Afterwards, the UPS was connected with effective load adjusted to 100% P_{max} and the power values absorbed from mains was measured for the UPS subject only to resistance load (Fig. 5b). During the next measurement the total power absorbed by the UPS and the inductive receiver was measured (Fig. 5c). Afterwards, proper adjustment of reactive power compensation for the whole system was made with the use of a service software. Figure 5d displays the results of power measurements made with the above adjustment of reactive power compensation [7, 8].

Among the most important parameters measured during the tests there were the effective, reactive, and apparent values of total power and the power in particular phases. Moreover, the power factor and phase voltage and current factors have been measured for the considered systems.

The whole measurement procedure was repeated with a three-phase controlled receiver of capacitive character connected instead of the inductive load. Figure 6 shows the results of these tests [7, 8].

Similar tests have been made for the variant with the UPS loaded with the power 100% P_{max} [7, 8]. Results of the tests are presented in Figures 7 and 8.

In commonly used VFI systems of guaranteed power supply the high values of the power factor are usually obtained for full load of the UPS device (when discrepancy between the values of effective and reactive power is high). In case of decreasing effective power of the receivers the reactive power absorbed by UPS (being independent on the loading current) remains constant (in effect of structural features of the UPS input circuit) and, in consequence, the power factor obviously decreases.

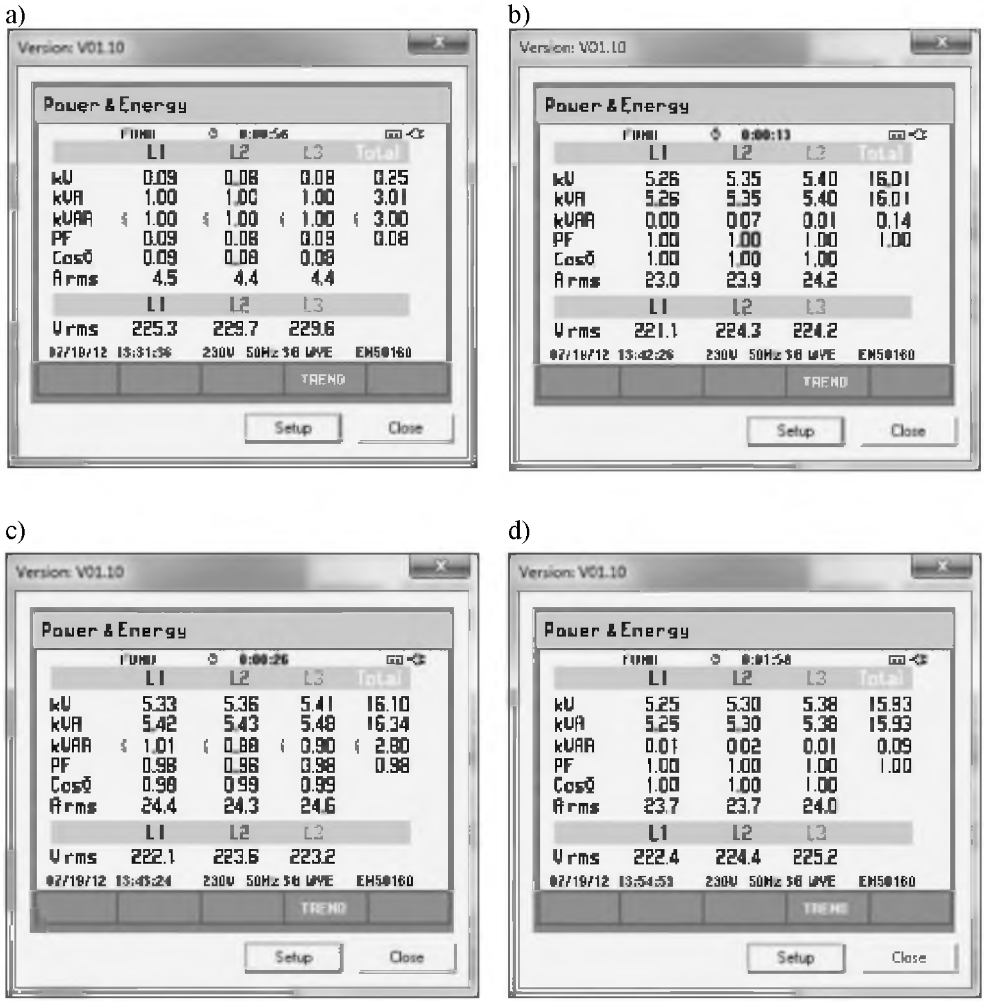

Fig. 5. Measurement results of active, reactive, and apparent power values (total values and in particular phases), the values of phase current and voltage and the power factors in case of the following devices connected to the mains: a) a three-phase inductive receiver; b) the UPS operating at effective load equal to 100% P_{max}; c) the UPS and inductive receiver connected in parallel; d) the UPS and inductive receiver connected in parallel with adjusted reactive power compensation

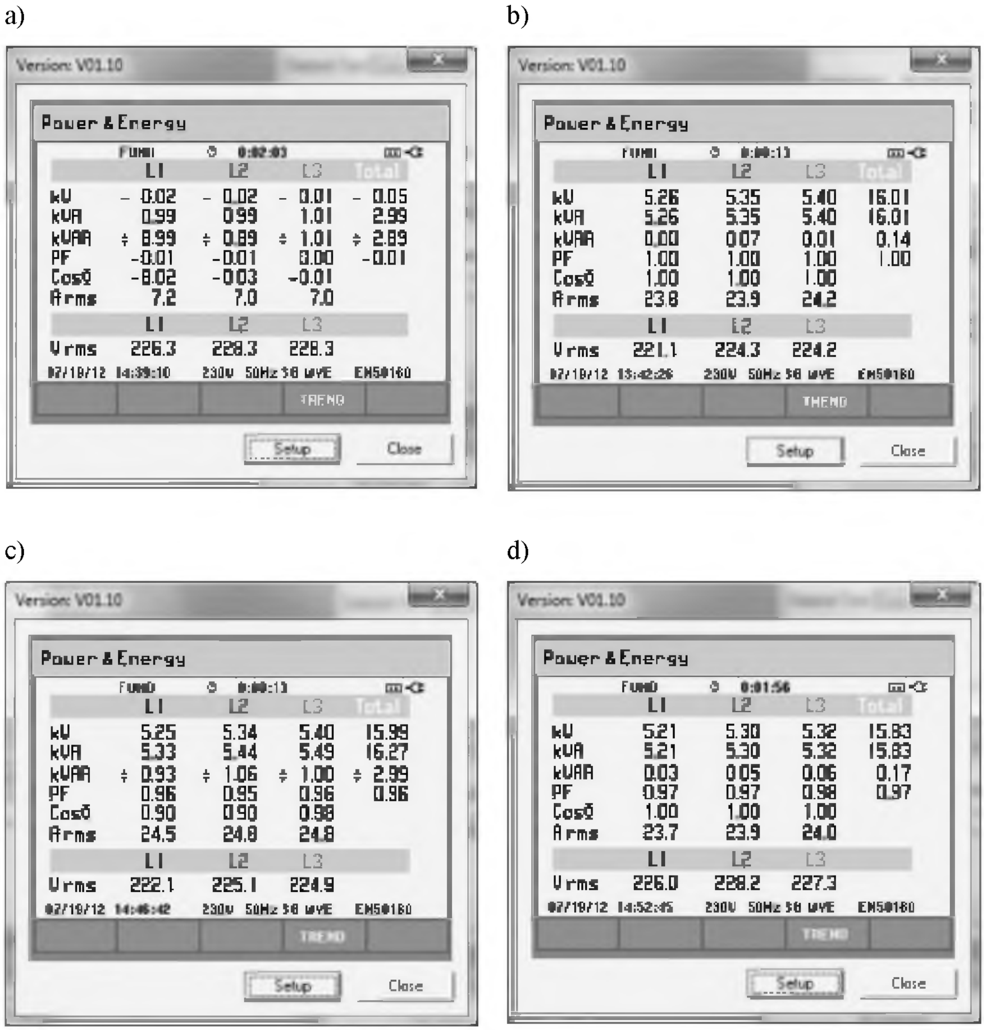

Fig. 6. Measurement results of active, reactive, and apparent power values (total values and in particular phases), the values of phase current and voltage and the power factors in case of the following devices connected to the mains: a) a three-phase capacitance receiver; b) the UPS operating at effective load equal to 100% P_m; c) the UPS and capacitance receiver connected in parallel; d) the UPS and capacitance receiver connected in parallel with adjusted reactive power compensation

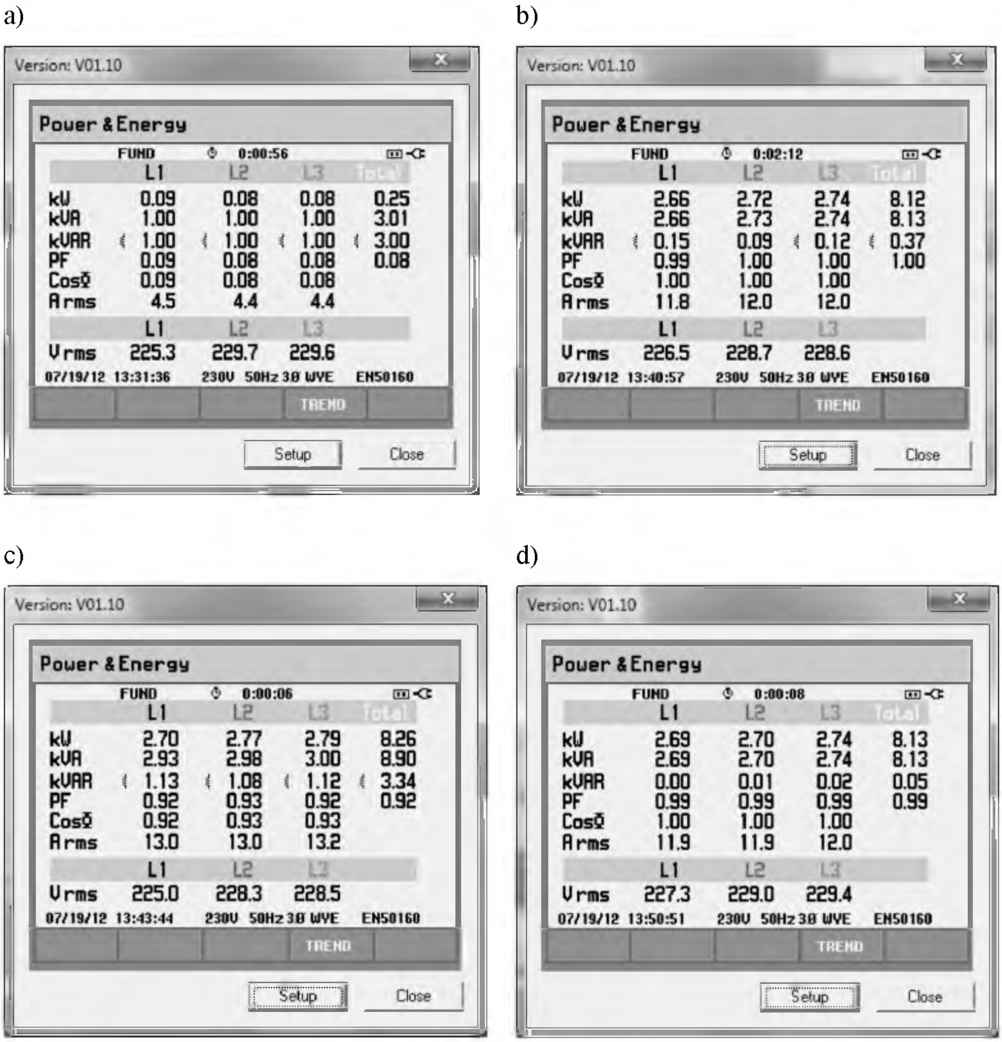

Fig. 7. Measurement results of active, reactive, and apparent power values (total values and in particular phases), the values of phase current and voltage and the power factors in case of the following devices connected to the mains: a) a three-phase inductive receiver; b) the UPS operating at effective load equal to 50% P_{max}; c) the UPS and inductive receiver connected in parallel; d) the UPS and inductive receiver connected in parallel with adjusted reactive power compensation

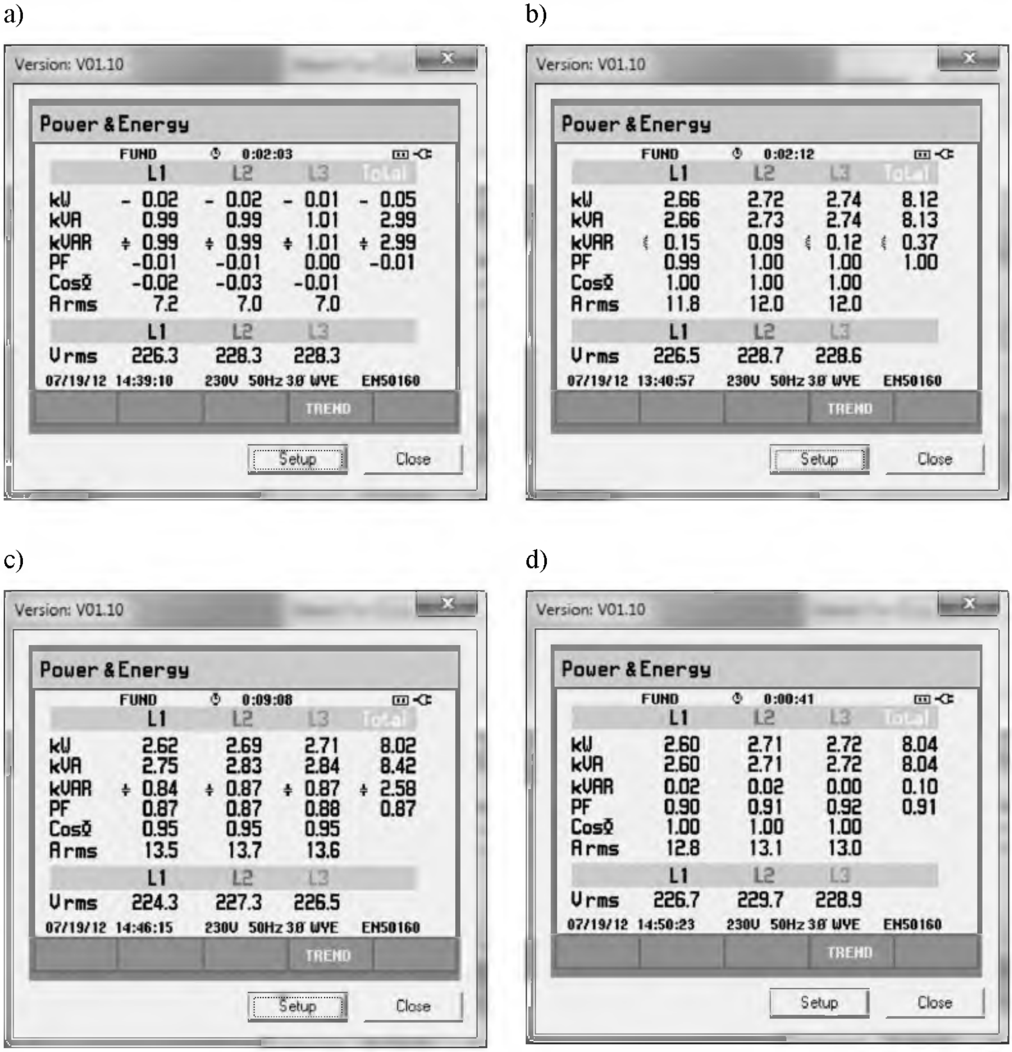

Fig. 8. Measurement results of active, reactive, and apparent power values (total values and in particular phases), the values of phase current and voltage and the power factors in case of the following devices connected to the mains: a) a three-phase capacitance receiver; b) the UPS operating at effective load equal to 50% P_m; c) the UPS and capacitance receiver connected in parallel; d) the UPS and capacitance receiver connected in parallel with adjusted reactive power compensation

When the function of reactive power compensation is used in UPS EVER POWERLINE GREEN 33 the power factor remains constant not only in very large range of the load, but the UPS reactive power absorption may be adjusted nearly to 0 var. Moreover, reactive power of the equipment connected in parallel with the power supply device (i.e. total reactive power absorbed from mains) may be compensated too [7, 8].

During the tests reported here the reactive power absorbed by UPS from mains at full effective load of the device was below 0.15 kvar (the points b in Figs 5 and 6). Once a reactive inductive load was connected in parallel with the power supply device the power absorbed from mains amounted to 16.1 kW and about 3 kvar, respectively (Fig. 5c). Adjustment of reactive power compensation in the UPS EVER POWERLINE GREEN 33 resulted in decrease of the power absorbed from mains below 0.2 kvar. Similar values of power absorption in particular stages of the tests have been found for the case of capacitive load (Figs 7 and 8).

According to analyses of the measurement results shown here the power compensation in the considered case may be carried out both for capacitive and inductive character of the load. The input system of the power supply device operates additionally as phase shifter of the mains supply circuit.

In order to justify the considerations of hybrid operation presented in the paper the UPS power supply maintenance time was calculated for faulty mains voltage (decrease below the bottom level of classical voltage range) in the cases of common design of the emergency power supply device (in reserve mode) and the UPS EVER POWERLINE GREEN 33 (in hybrid mode). The calculations have been made for the voltages 160 V and 120 V (in common systems such voltage values result in switching to the reserve mode). All the analyses have been carried out for two variants of accumulator modules (various accumulator capacities): 2×32×12V/7Ah VRLA and 2×32×12V/9Ah VRLA. The results so obtained are shown in Fig. 9.

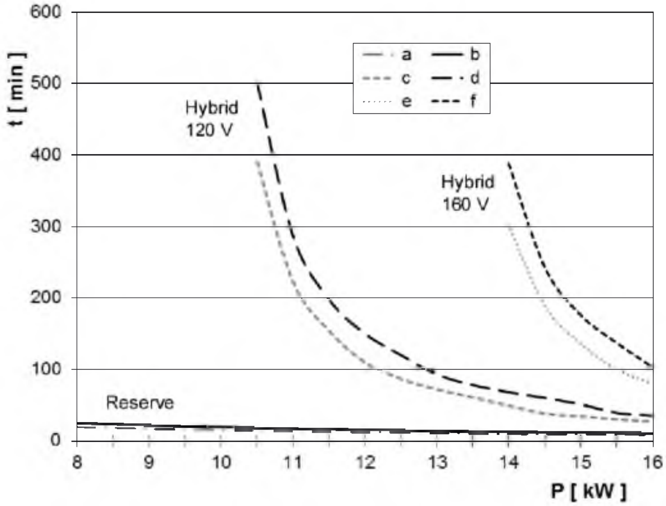

Fig. 9. Approximate power supply maintenance times of the uninterruptible power supply device vs. the load power for: the reserve (battery) operation mode and accumulator capacity (a) 7 Ah and (b) 9 Ah; for hybrid operation of UPS EVER at mains voltage 120 V and accumulator capacity (c) 7 Ah and (d) 9 Ah; for hybrid operation of UPS EVER at mains voltage 160 V and accumulator capacity (e) 7 Ah and (f) 9 Ah

The calculated power supply maintenance times are of approximate character, since they depend not only on the quantity of accumulated energy and the power of the connected load, but, to significant degree, on the charging degree, internal resistance, and type of the accumulators, as well as on the operational and environmental conditions [9].

In hybrid mode the duration of power supply maintenance is many times longer as compared to duration of autonomous operation in reserve mode (undergoing in the same conditions in common guaranteed supply systems), since the accumulator battery is loaded only with the difference of the powers (i.e. the difference between the receivers demand and the power delivered by the mains of faulty parameters) [3, 9].

6. Summarizing notes and conclusions

The systems of guaranteed power supply are, in many situations, important parts of the supply system, that enable proper operation of the secured receivers.

A very advantageous function of UPS consists in reactive power compensation. This enables evident economic benefits and energy savings at many levels of the supply system.

The tests and analyses reported here gave clear evidence that introduction of the hybrid operation mode (a broad range of input voltage changes) allows to extend duration of autonomous UPS and VFI operation for a definite range of the mains voltage variation. At the same time, the life of the accumulators used for this purpose is extended too (in result of partial relief of the battery during the hybrid operation mode, as a certain part of the energy is absorbed from the mains of faulty parameters). At lower value of the load power the total energy delivered to the receivers under the whole declared voltage range, is absorbed from mains (without the use of the battery). Relinquishment of a UPS power supply device in the supply systems of highly sensitive receivers may be conducive to significant consequences, namely the loss of processed information, damage or disturbance of operation of electric and electronic equipment, change in technical parameters, and efficiency of the receivers, additional power loss, premature aging of the equipment, expensive stoppage of the equipment operation, precluding proper operation of heating systems, etc.

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