

Suppression of higher harmonic components introduction to the networks and improvement of the conditions of electric supply of electrical equipment

Abstract. *The paper is devoted to the research of power quality in the systems including electrical equipment of nonlinear type. Quantitative and qualitative analysis has been carried out in order to assess whether a UPS system may reduce higher harmonic components that are introduced to supply networks in result of connection of a nonlinear load. Moreover, interaction of the disturbances arising in the network with electrical equipment connected to UPS has been tested, with a view to check possible elimination of the interaction by means of a guaranteed supply system.*

Streszczenie. *W pracy badano jakość energii w układach z odbiornikami o charakterze nieliniowym. Analizowano ilościowo i jakościowo możliwość ograniczania wprowadzania przez system UPS do sieci zasilającej wyższych harmonicznych generowanych przez załączane obciążenia nieliniowe. Badano również eliminację przez system zasilania gwarantowanego oddziaływania zakłóceń występujących w sieci na odbiorniki podłączone do UPS. Ograniczanie wprowadzania wyższych harmonicznych do sieci oraz poprawa warunków zasilania elektrycznego odbiorników.*

Keywords: supply quality, higher harmonic components, uninterruptible power systems, equipment operating conditions.

Słowa kluczowe: jakość zasilania, wyższe harmoniczne, zasilacze bezprzerwowe, warunki pracy urządzeń.

Introduction

The parts, devices, and electrical systems are commonly used in all domains of human activity, in private and professional circumstances (the industry, administration, science, the whole sphere of services, etc.). It should be noticed that any electrical device is endangered to be disturbed and, in result, may fail to operate properly or to be damaged.

Any current or voltage bearing part is a source of electromagnetic interaction. At the same time in the elements subject to the electromagnetic interaction the electric signals (i.e. voltage and current) are generated. They may be useful (i.e. generated intentionally with a view to achieve some determined effect) or unwanted, leading to disturbance of proper operation or to damage of the parts they are generated in.

Taking into account common use of electric equipment and frequent occurrence and interaction of many various devices in the vicinity, the need to ensure proper and undisturbed operation of all these elements becomes particularly important. In order to achieve this, the procedures related to electromagnetic compatibility define acceptable levels of the interactions for every electric and electronic element, with respect to emissivity (introduction to the environment) and to immunity (i.e. delimited sensitivity to the disturbances), in order to attain harmonious operation of these devices in the environment [1-8].

The electric, electronic, and computer equipment is permanently modernized during its usage, thus reaching higher and higher level of technological development. Power input to these elements is often of discretized, pulse character, and, therefore, such an element consumes a distorted current. This, in turn, results in interaction and introduction of higher harmonic components to the network. On the other hand, correct operation of electrical equipment depends, to large extent, on the supply voltage quality (reduced occurrence of high harmonic components, voltage dip or loss of voltage, overvoltage). Operation quality and correctness becomes particularly important in case of strategic objects, related to information processing or realization of the processes the break of which is conducive to large economic loss [1-8].

The paper is focused on the research of electric power quality in the systems of nonlinear character. Comparison of the contents of voltage and current harmonic components

at input and output of an emergency power supply is made, spectral distribution of the distorted signal is presented. Quantitative and qualitative analysis was carried out, in order to assess the effect of the guaranteed supply system UPS EVER Superline on reduction of the disturbances in the form of higher harmonic components introduced by nonlinear electrical equipment into the supply network, and on possible elimination of transmission of network disturbances in the form of overvoltage, voltage dip or loss of voltage to the equipment supplied through the UPS.

Disturbance transmission to the supply network

Quality parameters of the electric energy depend on correct design and assembly of the wiring and correct operation of all the receiving devices. Most of the disturbances arising in the supply network are of short duration, but they may cause a heavy failure or long-lasting outage of the system or equipment operation. Unfavourable changes in voltage parameters may be a result of the phenomena arising in the transmission network, receiving systems, or of the effect of external factors, as for example atmospheric discharge. Frequent problems related to the electric energy quality consist in voltage dips (short-lasting voltage drop), frequency oscillation, loss of voltage (short- or long-lasting supply failures), interaction with temporary phenomena, overvoltage, and harmonic distortion (caused by nonlinear load of the electric power system) [8].

Nonlinear equipment connected to the supply network is usually conducive to introduction of disturbances to the circuit, that may impede proper operation of other devices connected to the network.

Decidedly most of the equipment operated at present are reckoned among nonlinear devices. They consume distorted current and, therefore, their spectral distribution includes higher harmonic components. Connection of a distorted current consuming device to an electric circuit causes nonlinear character of the whole circuit. In case of heavy current (high power) devices the disturbance generated by them, taking the forms of higher harmonic components, transient state or unsteady conditions introduced into the electric power network, may disturb operation of other electrical equipment connected to the same network (i.e. they induce distortion or disturbance of the network voltage) [2,4].

The effect of power quality on proper operation of electrical equipment

The power quality affects proper operation and durability of the equipment, continuity of manufacturing processes or data processing, and the power losses.

Basic parameters that determine the power quality are as follows:

- voltage value;
- frequency;
- distortion of the voltage curve;
- continuity of the supply (with some definite voltage parameters kept at proper levels).

In the age of common use of electronic equipment, operating often on pulse mode, one of the most important factors that enable assessing the electric power quality is the current and voltage harmonics contents, i.e. determination of the extents of their distortion. The most frequent and, at the same time, leading to the heaviest consequences, are the odd harmonic components (mainly 3, 5, 7, and 9). The effect of the 3rd order component and other zero-sequence components is predominant. In case of delta connection these harmonic components sum up in particular phases, while for star connection the neutral conductors is subject to overheating [8]. These harmonic components may result in untimely disconnection of overcurrent protection and overload of the capacitors serving for reactive power compensation [5]. The higher harmonic components enhance the interaction related to skin effect (the higher the frequency, the nearer is the electron flux to the outer conductor surface). They may be conducive to faulty operation of computer equipment, to growing power loss, and overheating of motors and transformers, to resonances in the electric circuits, etc. [3]. Occurrence of higher harmonic components in the electric power network leads to premature aging of the equipment and, finally, to the need of its earlier exchange [2,8].

In general, any disturbance appearing in the supply system and affecting the electrical equipment may lead to:

- additional power loss;
- overheating of the devices;
- operation disturbance and premature aging of the equipment;
- damages of electric and electronic subassemblies;
- shutdown of the equipment operation (in result of breakdown or protection activation);
- loss of processed data and information;
- change in technological parameters and worsening of equipment effectiveness, etc.

It is a matter of fact that any electrical equipment requires to be supplied with the power of definite quality. Therefore, these problems are subject to standards. Parameters of the power quality are specified in the documents [9,10,11]:

- PN-EN 50160 – Supply voltage parameters of public distribution networks;
- PN-EN 61000 – Electromagnetic compatibility
- Journal of Laws No 93/2007, pos. 623 – Directive of the Minister of Economy of May 4, 2007, related to detailed conditions of electrical power system operation.

In many cases, particularly in the equipment of strategic meaning, proper and often much severe conditions of electric supply become extremely important. Such conditions include appropriate procedures aimed at eliminating unfavourable random events, break-down circumstances etc. [1].

Devices of strategic meaning

The devices serving for processing particularly important data or related to manufacturing processes, the shutdown

of which is conducive to significant economic loss or affects human life and health, are often called the devices of strategic meaning. Priority problem of their operation consists in ensuring their continuous supply and proper supply voltage quality (with minimum disturbing effects).

The following examples of the devices of strategic meaning may be mentioned:

- data processing centres;
- medical equipment the operation of which directly affects human life and health;
- production lines that stopped even temporarily induce extremely large expense (inclusive of the ones used during solid materials melting);
- machines with computerized numerical control (CNC);
- security systems of particular meaning, etc.

Classification of an electric equipment to the group of the devices of strategic meaning is a subjective decision depending to large extent on the user (apart from some obvious cases). Anyway, such a classification is usually a result of economical reasons, safety or protection of the information files.

The effect of UPS on the conditions of operation of electrical equipment and supply network

In case the voltage dip, voltage loss, or incorrect supply voltage parameters often occur and, at the same time, the disadvantageous interaction of the equipment with the supply network should be eliminated, the guaranteed supply systems (UPS) operating in VFI (Voltage Frequency Independent), i.e. in accordance to another nomenclature: on-line (Fig. 1) is a very helpful solution.

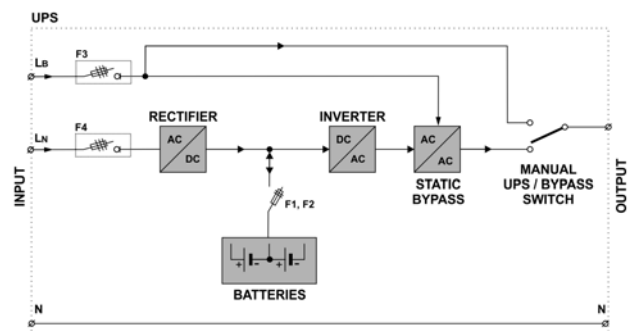


Fig. 1. Block diagram of a guaranteed supply systems UPS ON-LINE (Voltage Frequency Independent)

Such a supply system transforms the energy twice: the network voltage is rectified and transmitted to the inverter, where is transformed again into output alternate voltage of required rated parameters. The output voltage supplies the protected equipment during standard operation. At the same time, the accumulators are charged with the current from the DC circuit. In case of voltage dip, voltage loss, or other disturbances, the equipment is continuously supplied with undisturbed voltage since the inverter is then supplied with the power from the accumulators. In case of nonlinear equipment the UPS effectively restrains transmission of so generated disturbances in the form of higher harmonic components back to the supply network. In result the electrical equipment does not degrade the quality of the supply network and, at the same time, is supplied with the voltage of required and strictly controlled parameters.

Results of the tests

The voltages, currents, power, THDi and THDu coefficients, contents of particular harmonic current and voltage components at the network supply and UPS output sides were measured by the authors for various power

levels and various load type (nonlinearity, signal symmetry) in the Research & Development Division of EVER Ltd. Company. The tests were carried out with the UPS EVER Superline 12kVA device, operating in VFI technology, the output of which was connected to a device of adjusted values of the power and the degree of load nonlinearity. The considered adjustable device was firstly subject to large nonlinearity and then the currents and voltages were observed at the device side (i.e. at UPS output) and in the network supply circuit of the UPS.

Measurement results shown in the present paper are obtained for the UPS load equal approximately to 7.7kVA/7.7kW (for each load type).

Figure 2 presents the following oscillograms: (1) of the current absorbed by a nonlinear symmetrical device connected to the UPS output, and (2) the current absorbed from the network by the UPS. Figure 3 includes spectral distributions (contents of harmonic components) of the distorted current at UPS input and output, in case of connection of a nonlinear symmetrical device.

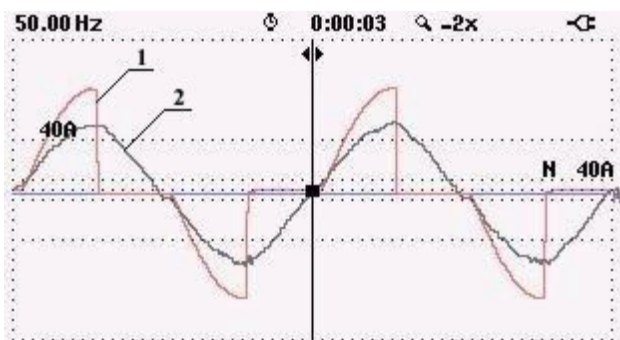


Fig. 2. Electric current oscillograms at the output (1) and input (2) of the UPS EVER Superline system with a nonlinear symmetrical device connected to it

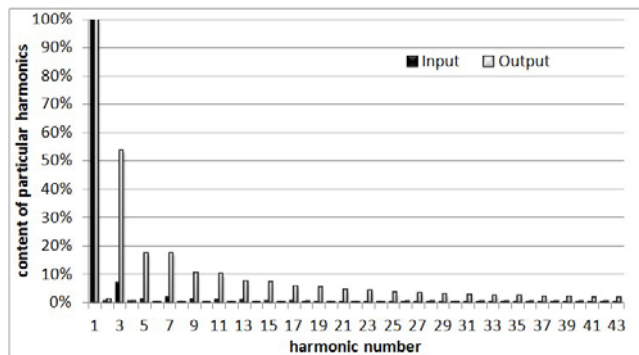


Fig. 3. Spectral distributions of distorted current at output and input of the UPS EVER Superline system, in case of connection of a nonlinear symmetrical device

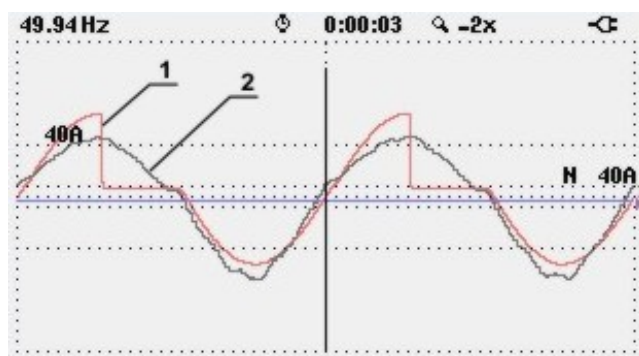


Fig. 4. Electric current oscillograms at the output (1) and input (2) of the UPS EVER Superline system with a nonlinear symmetrical device connected to it

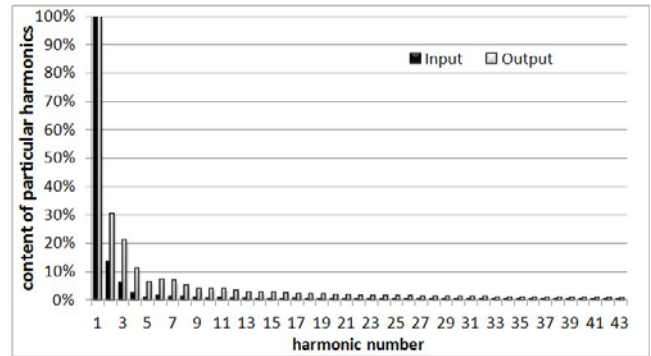


Fig. 5. Spectral distributions of distorted current at output and input of the UPS EVER Superline system, in case of connection of a nonlinear symmetrical device

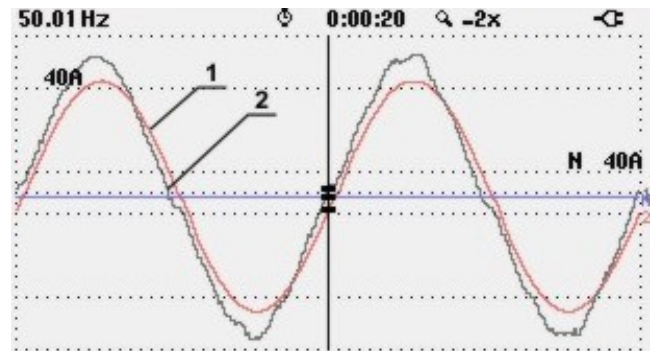


Fig. 6. Electric current oscillograms at the output (1) and input (2) of the UPS EVER Superline system with a linear device connected to it

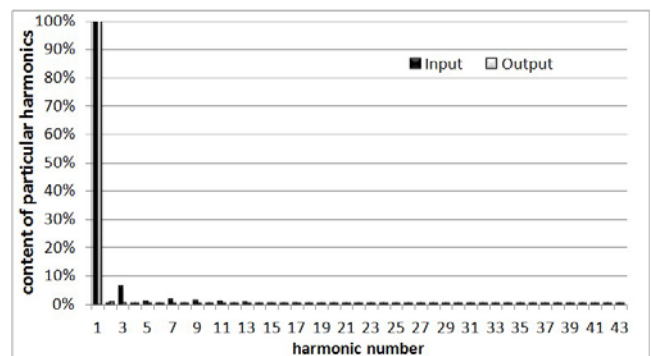


Fig. 7. Spectral distributions of distorted current at output and input of the UPS EVER Superline system, in case of connection of a linear device

Electric current oscillograms at the input (1) and output (2) of UPS EVER Superline with nonlinear symmetrical device connected to it, and the spectral distributions of distorted currents at the input and output of the system are shown in Figures 4 and 5. Similar patterns and current spectral distributions obtained in case of connection of a linear device are presented in Figures 6 and 7.

Moreover, the signal at the UPS output (i.e. the signal supplying the equipment) was observed during network voltage dip and loss (at the UPS input). Irrespective of the disturbances arising in the supply network, the UPS output supplied voltage of required and properly adjusted parameters (which is a result of the UPS on-line operation).

Notes and conclusions

The paper presents analysis of the effect of UPS EVER Superline no-break power supply on possible reduction of the disturbances taking a form of high harmonic components that are introduced to the supply network. At

the same time behaviour of the UPS output voltage signal was observed during short-lasting network voltage dips and losses (at the UPS supply side).

Analysis of the pattern and parameters of UPS output voltage (i.e. electrical equipment supply voltage) and UPS input (absorbed from the network) has shown that in case of nonlinear devices (symmetrical and asymmetrical ones) the THDi coefficients and reciprocal harmonic components at the system input are several times smaller than the ones characterizing the current of the supplied equipment (at the output). For example, for the current in the circuit supplying the nonlinear symmetrical device (Figures 2 and 3) the THDi coefficient was equal to 63.3% and the 3rd order harmonic component exceeded 53%. It should be noticed that so large distortion level arises only in the loaded circuit (at output side of the emergency power supply). The disturbance induced by device nonlinearity did not transmit to the electric power network – the THDi coefficient at the UPS output was equal to 7.5% and the contents of the 3rd order harmonic component only slightly exceeded the value of 6.8%. These values are approximately 9 times smaller than the ones related to nonlinear device operation. It gives evidence that UPS significantly restrained transmission of the harmonic components to the network supply circuit. Similar situation arose in case of connection of a nonlinear asymmetrical device. On the other hand, in case of the linear devices the effect of UPS is not so advantageous, since these devices do not distort the electric current. The output system of the device generates then the harmonic components at a certain acceptable level.

The UPS system also eliminates the effect of network voltage disturbance on the supplied devices. The rms value of input voltage depends on the load (during these tests it amounted from 210.6V to 225.5V), while rms output voltage was permanently kept in the narrow range from 230.5V to 232.3V. It is a result of the design and operational properties of the on-line emergency power supply, that delivers the voltage of definite, required parameters, irrespective of the quality of the delivered electric power.

The tests have shown that the guaranteed supply systems UPS VFI not only ensures no-break supply of the equipment, but provides an effective method of reduction of

the transmission of harmonic components to the electric power network. At the same time, it enables supplying the equipment with the voltage of strictly controlled parameters, irrespective of the anomalies arising in the network voltage.

Innovatory solution of the UPS from EVER Company consists in compensation of reactive power as an additional option of the supplier operation.

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