Computer Applications in Electrical Engineering
Vol. 12 *2014*

Reliability level versus load-carrying capacity of the uninterruptible power systems (UPS)

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The paper addresses the electric energy power supply, with particular emphasis on the functioning of the uninterruptible power supply systems (UPS). There were conducted considerations associated with the possibilities of covering the increasing demand for energy (as a result of the load infrastructure development) by parallel combining of the UPS power supplies. There were also analysed the possibilities of providing the expected reliability of the power supply of the priority loads as the effect of the redundancy introduction in the system. There are described the functional properties of the basic redundant UPS structures. The obtained results of studies performed in the UPS EVER POWERLINE GREEN 33 systems have been presented and commented on.

KEYWORDS: uninterruptible power systems, equipment reliability, load of the power supply systems, redundancy

1. Introduction

In the human economic activity – due to the prevalence of using the increasingly advanced devices and systems in all areas of his functioning – the meaning of issues of the reliability of energy supplies and the quality and reliability of power supply is constantly growing [1-3, 5, 7, 10].

The quality of the supplied power is mainly connected with performance parameters of voltage (energy) and with the reliability (continuity) of power supply. Research shows that even the best electrical power distribution systems may be unreliable (can crash), and therefore they do not meet the critical requirements, connected with the powering of the priority loads.

Most entrepreneurs, in order to maximally limit the risk of data processing errors or costly downtime of the devices or systems caused by failures or abnormal voltage quality in the electricity network, decide to install the uninterruptable power supply systems (UPS) between the energy distribution system and the strategic loads [1-5, 7-12].

Depending on the required reliability level of the power of the secured energy loads, it is possible to further increase the operational reliability of the power supply systems by applying the redundant systems, that is by introducing additional units, which could be used in case of damaging of the basic units. This is inextricably connected with the evident increase of the investment costs of the system [2, 3, 7, 8, 10].

In many cases, during the development of the economic units' infrastructure, there appears the need to adjust (increase) the delivered power, what is realized by replacing the existing solution with the power supply system with a higher rated power or by the parallel connection of further units in order to obtain the increased system load.

The paper addresses the issue of increasing the capacity and reliability (operational reliability) of the uninterruptable power supply systems. It refers to the functioning of priority loads. There are presented the functional properties of basic redundant UPS systems. The results of studies conducted in the physical systems, on the example of UPS EVER POWERLINE GREEN 33, have been posted and commented.

2. Uninterruptible power systems

The task of the uninterruptable power supply systems (UPS) is the uninterrupted powering of devices during mains voltage irregularities, such as short-term fluctuations (drops or rises) or power failures, or in case of long-term shortages of power. By using the energy stored in batteries the powering of the secured loads in the specified time is carried out (depending on the amount of the stored energy), which is necessary for the safe completion of the implemented processes, saving the processed data and turning off the devices or systems in accordance with the specified procedures [1-5, 7-12]. In places of common long-term power outages it is also possible to configure the cooperation of UPS units with the autonomous power supply systems (e.g. power generators) and continuous powering of sensitive devices with the voltage of the required quality.

The costs of power outages are calculated depending on the industry branch in tens of thousands, even up to millions of zlotys (PLN). Increasing the reliability of supplying energy to loads by using the uninterruptable power supply systems is therefore dictated by both the technical and economic reasons.

3. Loads of strategic importance

Loads of strategic importance (priority) are the devices and systems, in which the improper energy quality or power outages (and therefore their correct operation) entail significant economic costs, pose a threat to the safety, health or human life, are connected with the loss of the processed information and data, or in any other way are particularly burdensome for the user. Qualification of devices and systems as loads of strategic importance is a subjective decision, it depends on the priorities defined by the user. It should be noted that the recognition of loads as receivers of priority importance should be connected with further actions, consisting of the increasing of reliability of the system of their powering, which entails an increase of investment and operating costs of the supply system organised this way. However, in general, the resulting additional costs are disproportionately lower than the costs of removing the effects of the occurrence of random, uncontrollable power failures of these devices.

Commonly, the loads of strategic importance are the computer networks, data processing centres, technological processes management systems, production lines, in which the resulting downtimes are especially costly for the companies, or devices and systems connected with the direct effects on the human body (e.g. supporting the vital functions) or in which the unexpected power failures may lead to the elimination of the possibility of their further use (to their damaging). Given the importance of their proper, trouble-free operation, the priority issues is the reliability of providing the energy with proper parameters [1-3, 5, 12].

4. Parallel ups operation

With the increase of the power required by loads the expansion of the power system consists of the replacement of the UPS unit with a unit of a higher power (adjusted to new load conditions). A better solution in this situation is the parallel attachment of additional UPS power supply units (or modules) and thus obtaining higher output power, delivered to the secured loads. However, one should remember that this is possible with the proper selection and actuating the devices and modules connected in parallel.

UPS is a complex device and you should always bare in mind that there is a possibility of damage to any of the components, what may lead to the formation of a power outage, and consequently to the loss of data or downtime in the work of the secured systems. In order to reduce the possibility of the occurrence of the uninterrupted power supply system failure, there is used the multiplication of the critical systems or their elements so that the consequently created powering structure is able to provide the achievement of the desired level of reliability. This redundancy is the introduction of redundant (spare) elements in relation to what is required, so when the failure of the specified systems happen one can use the redundant elements and obtain the uninterrupted, proper operation of the considered system [2, 7, 8, 12].

From the considerations presented so far it results, therefore, that the parallel connection of the uninterruptible power supply systems can be used in order to achieve:

- increase of the load of the backup power supply (multiplication of the power of the attached devices of critical significance),
- increase the reliability level (operational reliability) of the power system.

5. Redundant systems

In many cases the power of the uninterruptible power supply system is selected to the power of the secured loads P_{ODB} and is slightly higher from their power in order to ensure the supply even during temporary overloads of the receiving system. This is the so-called performance configuration, designated as "N" (with the number of power supplies resulting from the full coverage of the desired power – without redundancy) – simple, with relatively low costs, energy-optimal due to the adjustment to the power of loads. Its main drawback is the low reliability. When the UPS unit failure takes place, reliability of powering the strategic loads is limited to the reliability level offered by the electricity network. Similarly, switching to the service bypass (e.g. for maintenance purposes) eliminates the protection of the secured loads. This configuration can be treated as the minimal requirement in order to provide the priority load protection [2, 3, 5-10, 12].

One of the elementary determinants of the uninterruptable power supply systems selection is the desired system reliability. In case of systems, in which even the short outages in their work entail serious consequences in the form of substantial financial losses or when the loss (and no possibility of recovery) of the processed data constitute the existential problem for the company, one should take into account the need to increase their safety, and thus the increase of their reliability level by introducing the redundancy elements and elimination of the so-called single points of failure. The selection of the optimal solution then always involves the compromise between the required reliability and the incurred investment and operating costs. In the redundant systems, depending on the way of cooperation and degree of the multiplication of the UPS units, most often we can distinguish the solutions: serial, parallel, multiplication of systems, mixed or dispersed [2, 7, 8, 10].

A) Parallel redundant power system (also called the system with active redundancy), with the configuration (N+1) – redundant UPS is attached (operates) in parallel (Fig. 1a) taking the part of the system load (it partially relieves the power supplies, which would normally cover the required power). In the event of the failure of one of the power supplies it is automatically disconnected (Fig. 1b), while others (with the redundant) take the load without a break, still providing the full coverage of the required power P_{ODB}. Physically, this can be achieved by the parallel connection of the classic UPS or by using the module systems.

The advantages of this system variant are: completely uninterruptible power of loads (there is no time delay, resulting from the UPS switching), the possibility to expand the system both in terms of performance, as well as the reliability, extending the life of components as a result of their smaller load and batteries by more favourable conditions of their work in the buffer mode (when each unit has own batteries), as well as the possibility of the uninterrupted servicing. While the unfavourable facts are that the cooperation of only the same UPS is possible, this is a technically more complicated solution (where it is necessary to meet the specific conditions of the UPS cooperation) and that the system efficiency decreases due to the normal operation with the partial load [2, 7, 8].

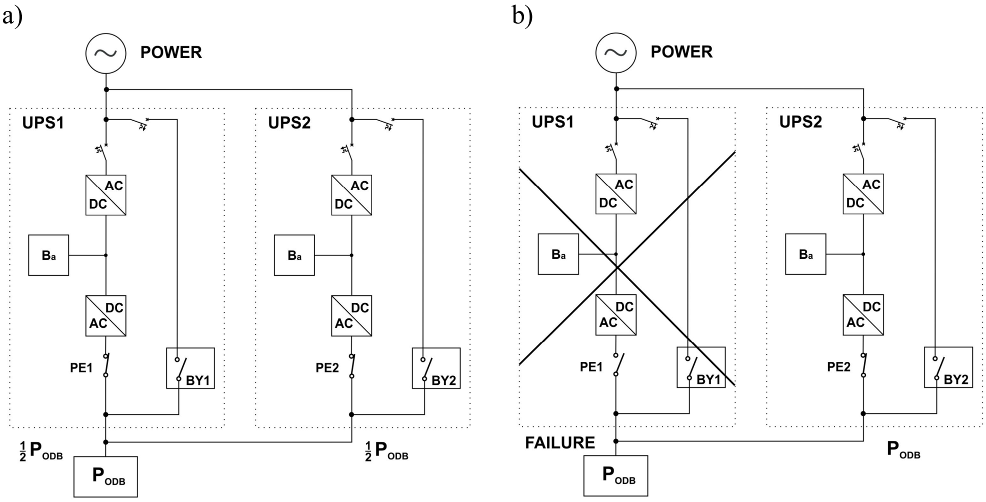

Fig. 1. The parallel redundant uninterruptible power supply system (1+1)
a) normal operation of the system, b) operation of the system in case of the failure of one of the UPS units

B) Serial redundant power supply system (also called the system with the static switch, redundant insulated or with passive redundancy), with the configuration (N+1) – powering the loads of strategic importance fully takes place through the main UPS (basic), while the redundant UPS is attached to the (Fig. 2a) static bypass of the main power supply (it is not loaded). During the failure of the main UPS, it is disconnected, the load is switched to the static bypass and the redundant power supply fully takes the load (Fig. 2b). UPS units do not have to have the same parameters, but each of them must independently fully cover the required power P_{ODB}; this solution is also called the work in the "hot reserve" [2, 7, 8, 10].

The advantages of the presented configuration are: the possibility to use different UPS (even from different manufacturers and of different performance), greater system efficiency due to the full load of the working UPS, no need to synchronize the operating units, the possibility to introduce the redundancy (by adding the additional UPS) in the system, which did not previously have it. Among the disadvantages of this solution one can list the need to ensure the strength of the UPS redundant for the sudden load spike at the moment of switching of the main module to the bypass (its greater susceptibility to the occurrence of defects is related to the sudden connection states at the full load of the system), the possibility of a short (several ms) break in powering the loads during the failure of the main UPS or service works (resulting from the switching time to the redundant UPS), as well as the formation of additional costs connected with the operation in the idle state of the redundant UPS (operational readiness state).

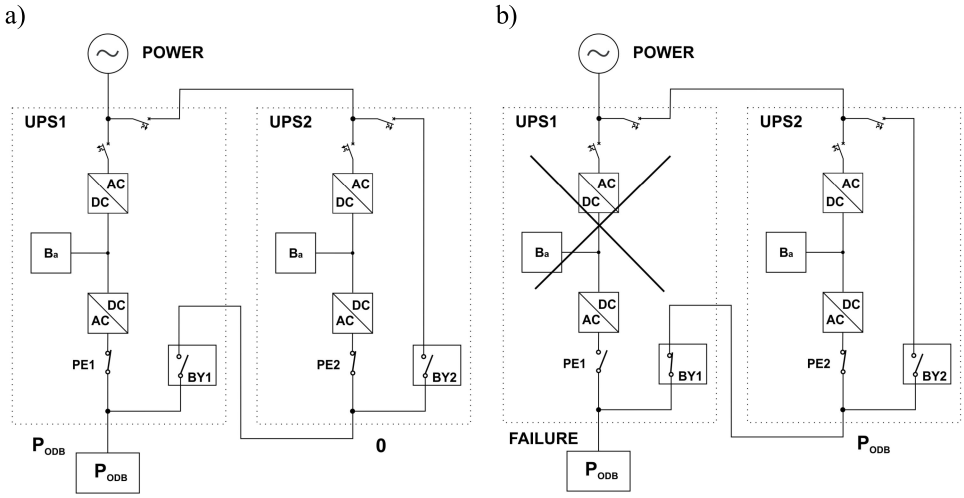

Fig. 2. Serial redundant uninterruptible power supply system (isolated) (1+1)
a) normal operation of the system, b) the operation of the system in case of the failure of one of the UPS units

The number of redundant UPS units may be greater than 1, then you receive a higher reliability of the system (e.g. redundant systems N+2, N+3), but the costs of its construction and exploitation increase in this case. There are also performed more advanced and complex redundant systems (system + system structures or systems with the scattered redundancy), in which you can achieve even greater levels of reliability, but this takes place in more expanded powering networks, at the cost of subsequent substantial financial expenditures [2, 7, 8].

C) Redundant "system + system" power supply system. An example may be the system with the configuration 2(N+1) – this system is powered from two different sources: separate switchboards or even from separate power grids and (if possible) generators, additionally reserved by power generators. In each of these power tracks there is the redundant (usually parallel) system of UPS units with the configuration (N+1). In the optimal performance, the secured loads have two power supply circuits (input) and then each of them is powered from a different path (source). This configuration allows to create systems, in which all single failure points which may be predicted can be eliminated. Each element of the system can be deliberately disconnected (for a specific purpose) or it may fail, without causing the need to switch the loads of strategic importance to the network power supply. Therefore, it results that in general there may be no need to switch the loads to the external electric power network. However, this is always connected with the increase of the implementation and functioning costs of the system and with the increase of the level of its complication. Moreover, it is required to create the right infrastructure related do the arrangement and installation of all components of the system and formation of their right environmental conditions, and at the same time providing location, excluding the possibility of the formation of disorders as a result of interactions of the objects located in the immediate vicinity. It is a system selected mostly by the users, for whom the high reliability of powering is more important than the costs of its obtaining.

The undoubted advantages of this configuration are: the highest degree of reliability (full redundancy from input to output), the possibility to eliminate all (observed) single failure points, a clearer way of functioning and logical system management, the possibility to service and temporary disconnection of particular components without the need to switch the critical loads to the network powering, etc. The disadvantages should include: very high costs of construction and exploitation of the system, formation of additional energy losses in particular component elements of the expanded system, their low efficiency due to incomplete power utilization of subsequent elements in normal operating conditions, the need to provide the proper facilities and the whole infrastructure connected with the system installation [2, 7, 8].

D) The distributed redundant power system in the part of leading the external (separate) power supply networks to the UPS units inputs is similar to the "system + system" system. Both systems provide the possibility to eliminate single failure points and servicing of the components during the operation while maintaining the full security of loads. Differences mainly result from the way of leading the power supply from the UPS to the secured loads and from the number of UPS units required to bring the redundant power tracks to the loads of the priority importance. In the distributed system the UPS outputs are attached on the independent rails connected to the strategic loads with the help of a greater number of static transfer switches (STS) and power strips. The distributed configuration is a cheaper solution than "system + system", but more expensive than the serial and parallel systems. The critical points of the system with the distributed redundancy are the STS switches (constituting the single failure points). In the complex systems, this configuration is very complex and difficult to manage (it may cause troubles in the orientation which systems power the loads and in maintaining the uniformity of the load). The system efficiency is high due to the incomplete load of the power supplies in normal operating conditions (the occurrence of greater energy losses) [2, 7, 8].

The choice of the redundant system configuration, which should be applied to secure the specific object, is not easy. It is a compromise between the required level of the power system reliability and the incurred additional financial expenditures (investment and operational costs) associated with the expansion and functioning of the redundant hardware. When making decisions in this scope, one should take into consideration and analyse the following factors [2, 7, 8, 10]:

a) the required level of the power system reliability – it is connected with the effects, which could arise in the event of irregularities or power outages. These analyses often take into account the costs of downtimes in the technological processes or failures of the receiving devices. You should also consider the possibility of the occurrence of more severe consequences in the form of damages, which cannot be estimated financially, like e.g. the loss of life or health (e.g. as a result of non-functioning or damages of the medical equipment) or the processed information or data (often constituting the existential problem for the company). In this case there is analysed the acceptance level of the risk of damages, resulting from the lack or failure to supply the loads of strategic importance,
b) the expected level of power supply availability – that is the specification what annual downtime in the object functioning is allowed by the company (both connected with the servicing and the formation of potential failures and removal of their consequences),
c) types of powering the loads – in order to achieve the full redundancy (elimination of single failure points in the receiving devices) there are currently often used the special solutions of loads with double power. This has an additional effect on the increase of the reliability level of the work of the secured loads,
d) financial aspects – all redundant systems are unambiguously associated with the incurring of additional costs: investment (resulting from the use of additional relief devices and providing the place for their installation) and operational (associated with lower levels of component loads of the power system, with the formation of additional losses in their circuits, with the increased service costs and maintenance, etc.).

The further considerations in more detail addressed the redundant system most often used in practice, which is the parallel system.

6. Test and analysis results

UPS EVER POWERLINE GREEN 33 were the studied devices, powered by three-phase low voltage from the low voltage distribution network and having three-phase voltage on the output. The apparent output power of each of the power supplies is 20 kVA, while the active power is 16 kW. In these devices, apart from numerous additional functionalities (like e.g. passive power compensation and the additional mode of the hybrid work), there was introduced a possibility to implement the parallel operation – depending on the needs in order to obtain greater system reliability (redundancy) or to increase the load of the supply system [2]. The studies were realized separately in the systems consisting of two and of six UPS EVER POWERLINE GREEN 33 connected in parallel.

In case of power elements operating in parallel it is necessary to have a precise selection of parameters of attached elements and synchronisation of generated voltages, what in turn should lead to uniformity of the load of the connected sources. For this reason, there were conducted tests of the voltage in the parallel system of two UPS EVER POWERLINE GREEN 33 and currents taken from each of them by the attached load. The measurement results are provided in Fig. 3. Analogous studies were carried out for six loads connected in parallel, what is presented in Fig. 4. Due to the fact that signals of currents connected with UPS during the presentation on the oscilloscope and registration overlapped, their runs were slightly shifted vertically in order to distinguish them.

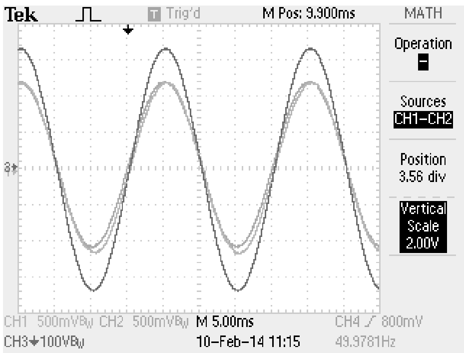

Fig. 3. Results of voltage and current studies in the system of two UPS connected in parallel

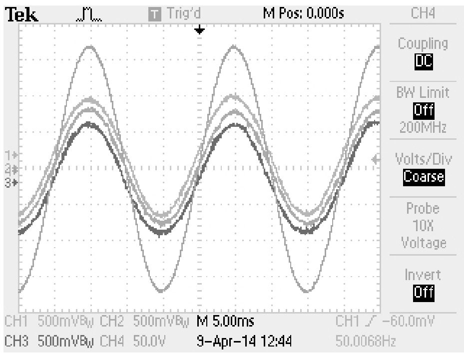

Fig. 4. Results of voltage and current studies of three out of six UPS connected in parallel

For a more detailed analysis of the parallel work of the considered UPS there were also registered the voltage courses and the combined currents of the power supplies in the dynamic state (step) of the load change (Fig. 5 and Fig. 6). Even in these transient states there was the uniform load of particular UPS, and the output voltage remained almost at the unchanged level (it was stable). The maximum change of the amplitude change (with the step change of the load) arising within one (the first) period after connecting the loads was smaller than 4%. After this takes place the full stabilization of the voltage value. Such small change of the voltage value with the step load change and the shape of the registered signal prove the high parameter quality of the voltage supplied through the UPS units connected to the loads in parallel.

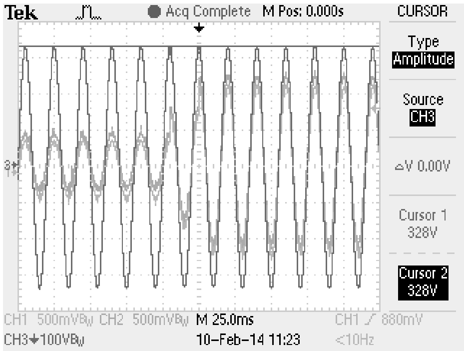

Fig. 5. Signals of voltage and currents during the dynamic load change for the system of two UPS connected in parallel

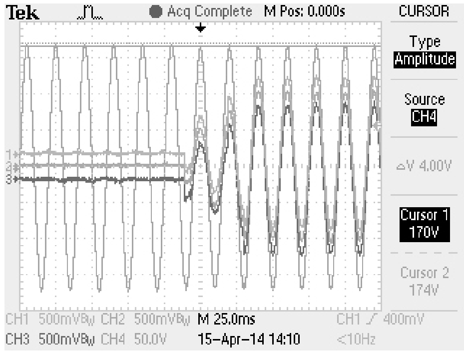

Fig. 6. Signals of voltage and currents during the dynamic load change for the system of six UPS connected in parallel

UPS units operating in parallel very often supply energy to several lines, in which the secured loads are attached. Each of these lines should be secured with a separate linear fuse. UPS EVER POWERLINE GREEN 33 have a high short-circuit current. This is very beneficial operationally, because in case of a short circuit in one of the supplied lines (thanks to high UPS short-circuit) the linear security will work, disconnecting the circuit, in which it occurred, and the other lines will still work uninterrupted. If the UPS used in such system have a small short-circuit current, the security of the adapter may work faster than the linear one and then the loads of all lines would be deprived of the power supply.

In order to verify the behaviour of the system of six UPS connected in parallel in the previously described conditions in one of the powered lines, secured with the B63 fuse, a short-circuit has been made. The linear fuse disconnected the circuit which was short, and other lines were still properly working. The course of the recorded short-circuit current is presented in Fig. 7.

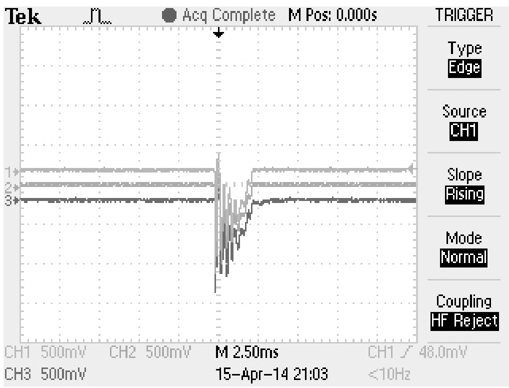

Fig. 7. The recorded course of the short circuit current in one line powered by the UPS EVER POWRELINE GREEN 33 operating in parallel

The time of removing the short circuit, that is the operation of the linear fuse in this particular case can be read, because the course of the short circuit current and time of the fuse's operation depend (apart from the short-circuit impendence) on the instantaneous value of the voltage, at which the short circuit occurred in the system.

7. Summaries and conclusions

Uninterruptible power supply systems in many cases are important elements of the power supply system, enabling the achieving of the proper functioning of the secured fuses, even in cases of the power failure or abnormal parameters of the voltage. Thanks to the introduction of additional UPS units one can achieve great ease of adjustment of the reserve power supply to the increasing energy needs of receiving devices of strategic importance (scalability of the system), as well as high flexibility in shaping the level of reliability (safety) of the systems under consideration (their redundancy).

During the selection of the redundant system configuration for powering the loads of special availability requirements, what is required is the multi-faceted approach to the task and the simultaneous consideration of reliability, economic, infrastructure and environmental factors, while taking into account the acceptance level of the risk of power outage, as well as the advantages and limitations of each of the considered structures.

The properly selected power supplies in terms of parameters, driven and synchronised, connected in parallel, have stable voltage, are evenly loaded even in dynamic states, what ensures their proper cooperation and has a positive influence on their reliability.

The lack of use of the uninterruptible power supply systems UPS in the power supply systems of the loads of priority importance (especially sensitive to the disturbances and irregularities of the voltage) may lead to serious consequences in the form of distortion of the proper functioning of the electrical or electronic components, damages or the change of technical parameters and the performance of the loads, formation of costly downtimes of the equipment, accelerated aging of the hardware, the loss of processed information, formation of additional power losses, prevention of the proper functioning of the heating systems, the loss of the possibility to use the access control devices, etc.

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