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# Using the FTA method to analyze the quality of an uninterruptible power supply unitreparation UPS

***Abstract**. The paper presents the simplest methods for preventing the occurrence of low energy quality. The problem of the quality of electric current was also discussed, indicating its defects. A scheme for a power failure tree was developed using the FTA method. The obtained results were compared and discussed.*

***Streszczenie.** W pracy przedstawiono najprostsze metody zapobiegania występowaniu niskiej jakości energii. Omówiono również problem jakości prądu elektrycznego, wskazując na jego wady. Opracowano schemat drzewa awarii zasilania korzystając z metody FTA. Uzyskane wyniki zostały porównane i omówione. **(Zastosowanie metody FTA do analizy jakości zasilacza bezprzerwowego UPS).***

**Keywords:** uninterruptible power supply, power quality, supply voltage parameters.
**Słowa kluczowe:** bezprzerwowe zasilanie, jakość zasilania, parametry napięcia zasilania.

**FTA (Fault Tree Analysis)**

Among the most important methods of hazard analysis and risk assessment, the authors applied the FTA method.
The error tree method is a qualitative risk analysis method using logical tree structure, allowing to model the course of failure and then its analysis.

In the FTA method, individual factors that can lead to an event and their potential effects are depicted in the so-called fault tree that shows the interdependencies between the potential main event and its causes. Identified factors (causes) plotted on the fault tree are interrelated and can be referred to as: specific failures (e.g. machines and devices), human errors (e.g. on the production line), first and second type errors, environmental conditions and other events that could lead to failure.

In the 1990s, the use of FTA was started in the design of systems guaranteeing a high level of safety and reliability in the chemical, railway, IT and medical industries. It has also become a frequently used method in risk analysis and risk assessment alongside PHA and FMEA.

Analysis of the FTA fault tree is therefore a graphical model of cause-and-effect relationships. The FTA scheme illustrates the causes whose effect is referred to as an uncertain event or risk.

The result of the FTA analysis can be, for example, a logical tree showing the pressure tank crack scenario with highlighted errors of the first and second type. The first type of errors are production defects that appear while operating under design conditions. The second type of errors are errors of an element working in conditions for which the device was not intended. This is usually a mistake related to the wrong selection of an element for the process conditions.

**PHA (Preliminary Hazard Analysis)**

Preliminary Hazard Analysis (PHA) focuses on identifying any potential hazards and accidental events that can lead to a failure or accident. It is a non-standard method, based on knowledge available at the initial stage of designing an installation, process or technical facility. The analysis can be used as soon as flow diagrams (PFD – Process Flow Diagram), basic heat and mass balances, plot plans and layout are available. In the PHA analysis, P&ID (Piping & Instrumentation Diagram) schemes are not required.

The aim of the PHA analysis is to assess the risk taking into account the severity of possible effects, which in turn translates into the planning of preventive measures and remedies. Early identification and assessment of threats enables easier implementation of design changes at much lower costs.
The main stages of the PHA analysis are:

- preliminary findings (specification of the purpose and scope, selection of the team, gathering information, etc.)
- hazard identification
- estimation of the probability of the occurrence of damage and the severity of effects according to the assumed scale
- risk ranking and follow-up.

The analysis process is carried out using the brainstorming method, through a systematic review of the available project documentation. Depending on the complexity of the system, it may be necessary to divide it into parts, e.g. to process units. For each element selected, all potential threats are determined, followed by possible causes and effects. On the basis of the collected information, a table is constructed in which the estimated probability of effects, their scale and risk are given. Risk ranking is to determine if the risk is acceptable/unacceptable. Threat assessment, carried out at the pre-design stage, due to the limited amount of information gives the initial possibility of identifying areas of danger, thanks to which certain preventive actions can be predicted at an early stage of the project. However, as the project develops, new factors appear which have not been taken into account in the PHA assessment, which may significantly jeopardise security. It is then necessary to consider further hazardous areas taking into account these factors. In addition, remedial measures already implemented are also subject to verification.

The results of the PHA analysis can be used to compare different design concepts or as input to a more detailed risk analysis.

**FMEA (Failure Mode and Effects Analysis)**

The main task of FMEA is to assess the risk in the individual phases of the designed process and to indicate the improvements necessary to implement the detection of nonconformities or the frequency of their occurrence.

The FMEA method relies on the analytical determination of causal relationships resulting in the occurrence of potential defects in processes and taking into account the criticality (risk) factor in the analysis.

The method is carried out in the following steps: determining the subject of the analysis, identifying all potential nonconformities and their causes, determining control measures with regard to identified nonconformities, determining the significance of noncompliance, calculating the number of risks for each noncompliance cause and planning improvement actions for those causes that are characterized by the highest risk.

Thanks to the FMEA method, it is possible to constantly improve processes by subjecting them to subsequent analyses and, based on the obtained results, introducing new solutions that effectively eliminate sources of defects. FMEA analysis includes:
- an effective method of process improvement
- indicates in detail all potential problems and incompatibilities that may occur in a given process
- identifies the causes of problems that may occur in a given process and estimates the frequency of occurrence of these causes
- defines the significance of problems and inconsistencies for the client
- it allows to calculate the risk for each cause of noncompliance with the indication of the priority number of risk (to what extent the given cause of noncompliance is serious)
- enables planning improvement activities in relation to the most risky causes.

**Uninterruptible power supply UPS**

UPS is a device whose primary objective is to eliminate defects of electric energy that the receiver is powered with [1-5]. These defects are understood as specific disturbances in the frequency, voltage level or shape. Fig. 1 shows a graphical definition of selected disorders [6-9].

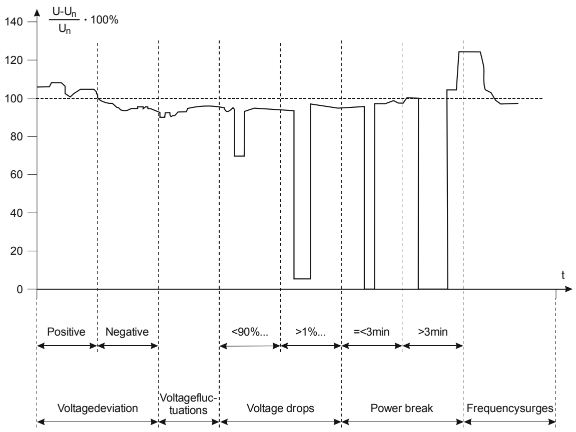

Fig. 1. Voltage disturbances

The structure of the UPS indicates that, depending on the type of configuration used, there may be some characteristic transients [10]. For an off-line power supply, such a condition will be a disturbance in the voltage value at its output when switching the basic power supply to reserve and then from reserve to basic. However, in the case of an on-line power supply in which only one path occurs, the transient will be the moment in which the power supply will disappear at the power supply input, i.e. the moment when the battery or other energy container, e.g. the supercapacitor, takes over responsibility for the receiver's work and the moment of power return. In both cases it was assumed that the quality characteristic will be the duration of the disorder, additionally described in the shape of the recorded current and/or voltage.

**Case study**

The subject of the research was two off-line and on-line UPSs, from different manufacturers, intended for professional applications, which provided power supply to individual desktop computers. The power supplies were characterized by identical requirements regarding the quality of the input power supply. The devices had a similar technical level, confirmed by comparable output power parameters. The devices were chosen so that the price difference was negligible. The tests were carried out at nominal conditions, consistent with the manufacturer's specifications for each device. The measurements were carried out using an electronic oscilloscope and high-voltage measuring probes. In each case, 50 replications were done, and the least favorable case was shown in the drawings. Fig. 2 shows the recorded course of current and voltage consumed by the computer during the experiment.

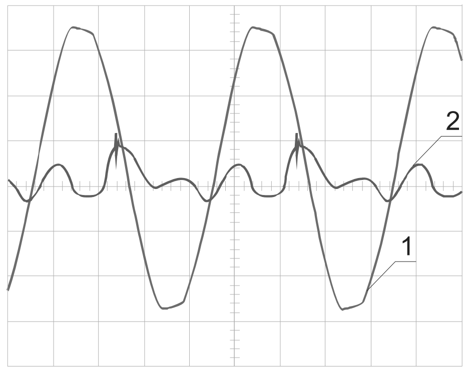

Fig.2. Diagram of voltage (1) and current (2) consumed by the computer (50ms/cm,> 50V / cm).

The shape of current (2) shown in Fig. 2 clearly indicates that the receiver is nonlinear, hence there is an increased probability of disturbances in operation with significant changes in power parameters [11].

Fig. 3 and 4 show the voltage waveform when switching from direct power supply to UPS and the opposite at idle an mode of the off-line power supply.

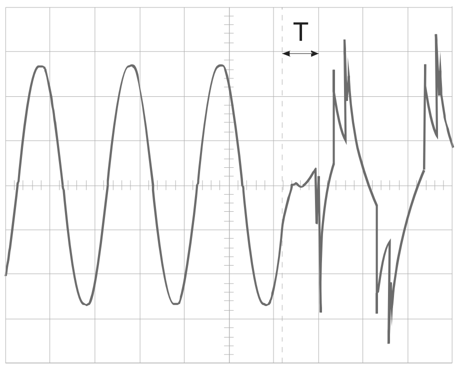

Fig.3.Diagram of the voltage shape while switching the power supply from the grid to the battery (10ms / cm and> 50V / cm).

Fig. 3 shows that the maximum switchover time from the grid current to the battery ($T_{SAmax}$) is 9.07ms.

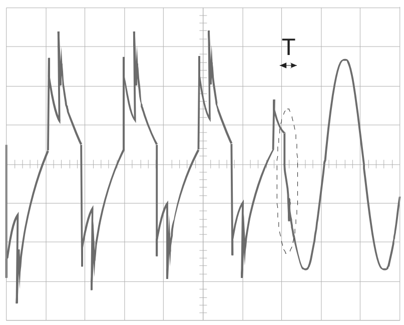

Fig. 4. Diagram of the voltage shape, switching the power supply from the battery to the network (10ms / cm and> 50V / cm).

Fig. 4 shows that the time of switching the power source from the battery to the grid ($T_{ASmax}$) is 0.98 ms.

Fig. 5 and 6 show the voltage waveform when switching from grid to battery and the opposite while the on-line power supply is in operation. Theoretically, for this power supply, $T_{SAmax}$ and $T_{ASmax}$ times should be equal and should be zero. Fig. 6 shows that the return time for the battery power supply is 1.4 ms ($T_{ASmax}$). In summary: the maximum switching time for two types of power supplies and two different events is 9.07ms. The return time for classic or network power supply in both cases is shorter than the decay time. In the case of a "better" on-line adapter, it is longer and amounts to 1.4 ms.

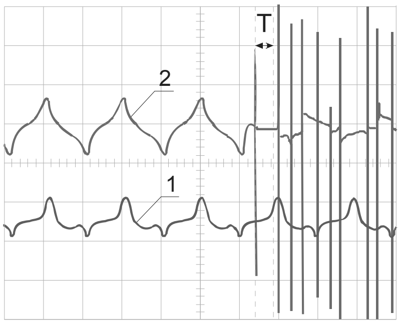


Fig. 5. The shape of the current diagram, switching the power supply from the grid to the battery (10ms / cm and> 20V / cm); 1 - current waveform at the input of the power supply, 2 - current waveform at the output of the power supply.

Fig. 6 shows that the disconnection of the grid fro m the battery or power supply loss (TSAmax time) is 4.72 ms.

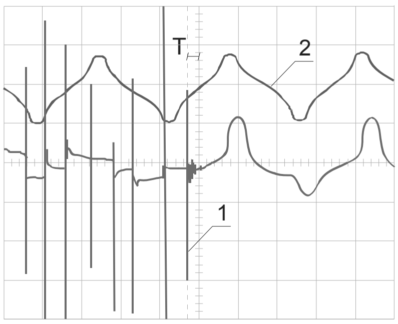


Fig. 6. The shape of the current diagram, switching the power supply from the battery to the grid (5ms / cm and> 20V / cm); 1 - current waveform at the UPS output, 2 - current waveform at the UPS input.

TABLE I. Basic statistics determined for collected measurements of tested UPS

| Statystyka | UPS typu off-line | | UPS typu on-line | |
|---|---|---|---|---|
| | $T_{SAmax}$ | $T_{ASmax}$ | $T_{SAmax}$ | $T_{ASmax}$ |
| Minimum value | 0,20 | 0,02 | 0,03 | 0,03 |
| Average value | 9,07 | 4,72 | 0,98 | 1,40 |
| Average | 5,00 | 2,71 | 0,51 | 0,69 |
| Medium value | 4,96 | 2,81 | 0,52 | 0,75 |
| Variance | 5,28 | 2,32 | 0,09 | 0,14 |
| Standard deviation | 2,30 | 1,53 | 0,30 | 0,38 |
| Confidence interval of standard deviation - 95,00% | 1,92 | 1,27 | 0,25 | 0,31 |
| Range of confidence interval of standard deviation -95,00% | 2,86 | 1,90 | 0,78 | 0,47 |

The measured times are relatively short and for the vast majority of devices they are not a problem. However, in selected devices, e.g. complex CNC controls, complex medical devices, it is very important to obtain appropriate quality of energy from the power supply, defined not only by the duration of the irregularities, frequency of the waveforms, but also the shape of the voltage. From the drawings (Fig. 3-6) it appears that the shape of the voltage in UPSs is not correct. Table 1 provides basic statistical data on registered measurements.

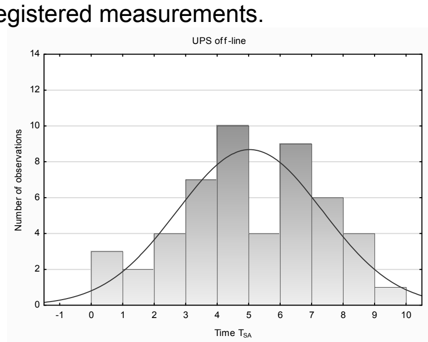


Fig. 7. Histogram of recorded power supply decay times from grid to battery for the off-line power supply.

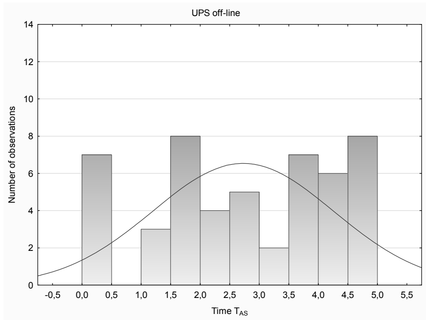


Fig. 8. Histogram of recorded power supply decay times from grid to battery for the on-line power supply.

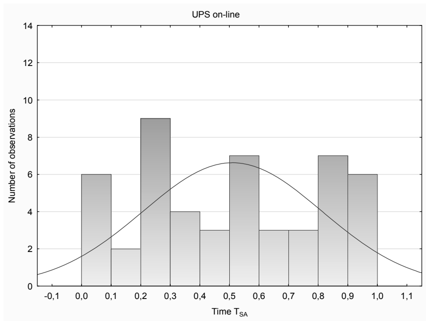


Fig. 9 Histogram of recorded power supply decay times for the on-line power supply

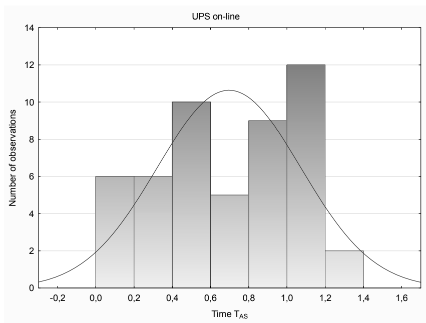


Fig. 10 Histogram of recorded power supply decay times for the off-line power supply

TABLE II. Technical requirements for the UPS

| Feature | Ideal UPS | Off-line | On-line |
|---|---|---|---|
| Voltagestabilisation | Perfect | Good oraverage | Verygood |
| Frequencystabilisation | Perfect | Weakoraverage | Verygood |
| Resistance to overvoltage | Perfect | Good oraverage | Verygood |
| Input voltagetolerance | Very high | Small | High |

| | | | |
|---|---|---|---|
| Input frequencytollerance | Very high | Small | High |
| Distortion of outputwave | No | High | Small |
| Network suppression | Verygood | Averageorweak | Good |
| Switch time | 0 | from 2 to 100ms | Theoretically 0 |
| Supply time | Verylong | minutes | Up to a few hours |
| Galvanicisolation | Yes | No | Yes |
| Volnurability to frequent voltage dips | No | Yes | medium |
| Interference with grid | No | Yes | No |
| Input powerfactor | 1 | c.a. 0,6-0,8 | >0,9 |
| Automatic battertytesting | Yes | Rarely | Yes |
| Weight and dimensions | Small | small | Large |

## Conclusions

In the case of an off-line power supply (Figure 7 and Figure 8), based on the definition of the power supply, a fairly long switching time should be expected in both directions. Both charts confirm expectations. The time of returning to work from the network grid supply is clearly shorter. In case of switching from network to battery, most times are within 4 to 5 ms, and the longest time of 9.07ms was registered only once. The time of return to the grid power usually is in the range from 0.8 to 1.0 ms, which accounts for 26% of the observations, with the time from 0.2 to 0.3 ms with twice the probability. The maximum time in this case is 0.98 ms

In the case of an on-line power supply (Fig. 9 and Fig. 10), the expected times should be definitely shorter, this is due to the design of the power supply. The results obtained partially confirm the presented thesis. Power supply loss results in a very even distribution of recorded times. There are very short times of 14% of cases with a time of up to 0.5 ms and a lot of short cases (42%) with a time of 3.5 to 5 ms. Even more favorable times were recorded for the case of mains return. Almost one quarter of cases is related to a time of 1 to 1.2 ms.

Analyzing descriptive statistics (Tab. 2), a close approximation of the mean and median value was observed along with the observation of the shape of the graphs (Figures 7 to 10), indicating a poor fit of the obtained distributions to the Gaussian distribution. The results obtained in the same way confirm that the on-line UPS has more advantageous operational features evaluated in terms of the time of disturbances accompanying changes in the primary power source. Table 3 presents technical expectations in relation to UPS resulting from the analysis of Fig. 3-6, statistical analyzes and observations made during measurements.

Subsequent drawings (Figs. 7-10) show histograms of the registered switching times obtained during all the attempts.

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## REFERENCES

[1] Salomonsson D, Sannino A., Low-voltage DC distribution system for commercial power systems with sensitive electronic loads, *IEEE Transactions on Power Delivery*, 22 (3), pp. 1620-1627, 2007.

[2] Brown D. R., Chvala W. D., Flywheel energy storage: An alternative to batteries for ups systems, Energy Engineering: *Journal of the Association of Energy Engineering,* 102 (5), pp. 7-26, 2005.

[3] Lasseter R. H., Eto J. H., Schenkman B., Stevens J., Vollkommer H., Klapp D., Linton E., Hurtado H., Roy J., CERTS microgrid laboratory test Bed, *IEEE Transactions on Power Delivery,* 26 (1), art. no. 5673682, pp. 325-332. 2011.

[4] Lasseter R.H., Smart distribution: Coupled microgrids, *Proceedings of the IEEE*, 99 (6), art. no. 5768104, pp. 1074-1082, 2011.

[5] Buso S., Fasolo S., Mattavelli P., Uninterruptible power supply multiloop control employing digital predictive voltage and current regulators, *IEEE Transactions on Industry Applications*, 37 (6), pp. 1846-1854, 2001.

[6] Musiał E.; Ocena jakości energii elektrycznej w sieciach przemysłowych. *Automatyka, Elektryka, Zakłócenia* 1 (2010): 30-45.

[7] PN-EN 50160:2010/A1:2015-02, Parametry napięcia zasilającego w publicznych sieciach elektroenergetycznych.

[8] Cheng P.-T., Huang C.-C., Pan C.-C., Bhattacharya S., Design and implementation of a series voltage sag compensator under practical utility conditions, *IEEE Transactions on Industry Applications*, 39 (3), pp. 844-853, 2003.

[9] Moreno-Muñoz A., Gonzáles de la Rosa J.J., Flores-Arias J. M., Bellido-Outerino F. J., Gil-de-Castro A, Energy efficiency criteria in uninterruptible power supply selection, *Applied Energy*, 88 (4), pp. 1312-1321, 2011.

[10] PN-EN 62040, Systemy bezprzerwowego zasilania (UPS).

[11] Przystupa K., Kozieł J., Analysis of the quality of uninterruptible power supply using a UPS , *XXVIII Sympozjum Środowiskowe PTZE „Zastosowania elektromagnetyzmu w nowoczesnych technikach i medycynie",* 9-12.09.2018r., Racławice - 2018, s. 258-260.