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Analysis of power supply outages aftereffects

Streszczenie. (Analiza następstw awarii zasilania energią elektryczną). *W artykule przedstawiono analizę skutków przerw zasilania energią elektryczną. W części wstępnej zwrócono uwagę na analizę niezawodnościową zasilania urządzeń przemysłowych. W części drugiej zanalizowano skutki ekonomiczne przerw w zasilaniu. Przedmiotem analizy były uszkodzenia bezpośrednie i pośrednie. W zakresie urządzeń przemysłowych stwierdzono, że wygodniejsze jest stosowanie funkcji uszkodzeń. W referacie przedstawiono funkcję uszkodzeń dla badanego obiektu. Funkcja ta dostarcza informacji o stratach ekonomicznych podczas awarii zasilania.*

Abstract. *We analyzed after-effect of electrical power supply outages in this paper. In the first part of the paper we focused on reliability analysis of industrial enterprise power supply. In the second part of the paper we analyzed economical aftereffects of power supply outages. We analyzed structure of direct and indirect damages. For industrial enterprise we find out that using of damage function is the most comfortable. Finally we express damage function for studied enterprise. This damage function provides information about economical losses during power supply outages.*

Słowa kluczowe: awaria (przerwa), niezawodność, linie WN, koszty awarii.
Keywords: outage, reliability, HV lines, outage costs.

Introduction

In 2006 the process of gradual liberalization of the electricity market in the Czech Republic was finished. As a consequence, problems brought by the liberalization are to be solved. These problems are especially legislative and economic. Another area of newly arisen problems is that of relations between power suppliers and customers. Here it is necessary to determine the optimal quality of power supply using reliability indices limits; when these limits are not met, a penalty should be paid by the supplier to customers. The amount of penalty can be determined by using several methods.

For industrial companies supplied by the high-voltage networks, the utilization of damage function seems to be most suitable for the determination of costs arising from the power outage. The amount of damage is specific for each industrial enterprise. However, for specific industrial sectors, some partial costs can be generalized.

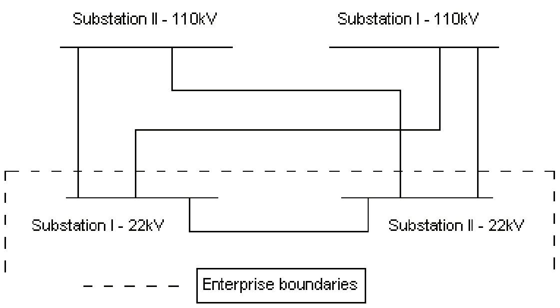

Fig.1. Diagram of supplying the industrial enterprise studied

In this paper, results of one of these analyses focused on the determination of the damage function for a specific industrial enterprise and on the calculation of annual costs incurred by this enterprise owing to power outages are presented. The enterprise analyzed is situated in Northern Moravia and is supplied by the 110 kV network from two independent 110 kV substations (Fig. 1). The position of these substations can be seen in the Figure 2.

Description of production cycle

The theoretical relations were practically applied to the calculation of costs caused by a power outage in the industrial enterprise concerned with aluminum processing. In the enterprise, we selected main production unit, where the most products are produced. The main production unit consists of casting furnaces, rolling mills, annealing furnaces, cutting machines and electric resistance furnaces. For illustration, the structure of production unit analyzed is schematically presented in the Figure 3.

Black cross – enterprise supplied
Black dots – 110 kV substations

Fig.2. Position of 110kV substations and enterprise supplied

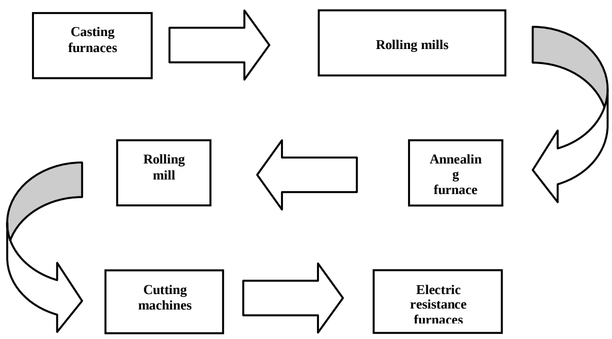

Fig. 3. A simplified diagram of production unit observed

Description of supply reliability

The industrial enterprise under analysis is supplied by two HV lines of 110 kV from the substations I and II (Fig. 1). This way of supplying provides the high reliability of power supply; nevertheless, Outages in the supply of power occur several times a year.

On the basis of calculations done by the Monte Carlo method according to the input data, by the methodology used in the Czech Republic, the following reliability data were found for this 110 kV network node from measurements in the period of winter 2005:

- Probability of non-failure operation
  R = 0.988879602
- Mean outage duration
  τ = 44.56356819
- Failure rate
  λ = 2.185971407

Interruption statistics is given in the graph for the years 2002 to 2006. Data presented were provided by the industrial enterprise according to real observation.

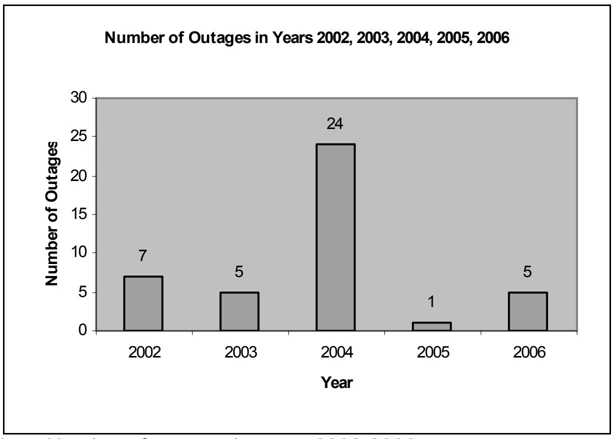

Fig.4. Number of outages in years 2002-2006

The over-average number of outages in the year 2004 was caused by extreme climatic conditions (windstorm) in July and December (Fig. 5). Numbers of outages are lower in the other years.

An overview of outage distribution in the given node during the year is presented in Fig. 5.

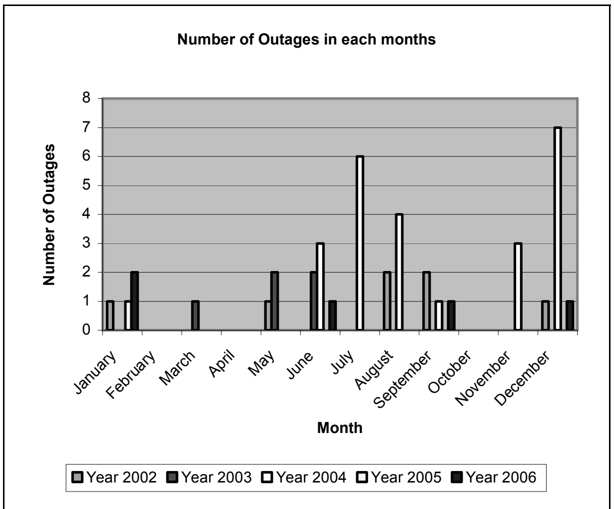

Fig.5. Number of outages in individual months

The monitoring of outages in the given industrial enterprise began just in the year 2002; outage durations are monitored since 2003. With reference to the fact that rather great differences existed in the outage duration, the average outage types were determined, for which calculations of costs caused by interruptions in power supply were executed. When determining the outage type, it was necessary to respect different effects of various outage durations on manufacturing technologies and also on total costs caused by power supply interruption so that each outage type might be different from the point of view of the extent of manufacturing technology damage. On the basis of consultation with technologists of the given industrial enterprise, possible outage types were defined.

- Outage type I – the duration of power outage lasting less than three minutes
- Outage type II – the duration of power outage lasting from three minutes to three hours
- Outage type III – the duration of outage lasting from three hours to three days

In the real situation, merely outages of types I and II occurred; the type III was not recorded in the period of observation. However, according to information provided by the technologists, several outages of type III have occurred in the history of enterprise, and thus it is necessary to consider this type as well.

The analysis of outages can be used as basis for the preparation of protective measures, or emergency plans leading to the limitation of such a type of outage with all consequences.

During the analysis, the essential difference was found between the duration of outage and the time, when the condition of production unit was identical with that before the outage. Therefore, it is necessary to determine the time to full restoration of service of production unit for each outage type. On the basis of consultation with the power engineer and operating personnel of production unit, times to full restoration of service were assigned to particular outage types.

- Outage type I – average time to full service restoration 5 hours
- Outage type II – average time to full service restoration 8 hours
- Outage type III – average time to full service restoration 111 hours

The times to full service restoration presented above are the average values determined by expert estimation.

Total costs incurred by the customer

The total costs due to an interruption in power supply can be obtained by summing up individual partial costs. In individual industrial sectors, these costs are different.

The common relation can be expressed as follows (1):

$$(1)\quad C_{CUSTOMER} = C_{DP} + C_{WI} + C_{COR} + C_{START} + C_{LP} + C_{APL} + C_{PEN} + \sum C_I + \sum k_{IC} \cdot C_{IC}$$

C_{DP} - costs of damaged products
C_{WI} - costs of worker idleness
C_{COR} - costs of production equipment correction
C_{START} - costs of equipment starting
C_{LP} - costs arising from lost production
C_{APL} - costs of the alternative to production lost
C_{PEN} - costs of penalty payment
C_I - other relevant direct costs specific of the given customer.

C_{DP}, C_{WI}, C_{COR}, C_{START}, C_{LP}, C_{APL}, C_{PEN} are functions of many variables and their mathematical expression is difficult. However, we can simplify the situation by regarding these functions as functions of a single variable, namely the duration of outage.

In the Figure 6 the behavior of costs incurred by the industrial enterprise due to an outage of power from the HV network is given. Functional dependence was simplified for one variable, i.e. outage duration. The result of graphical solving is a linear function.

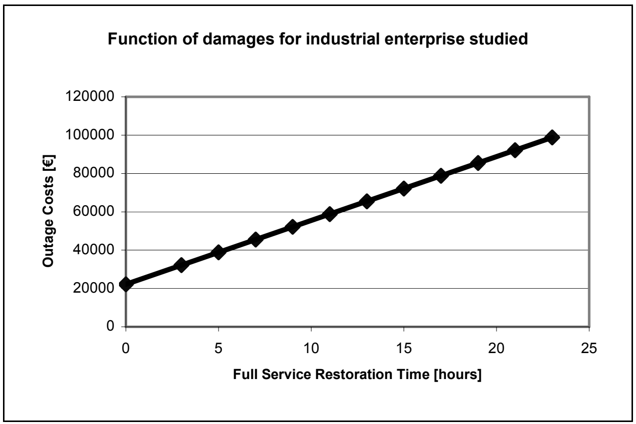

Fig . 6. Function of damages for industrial enterprise studied

Conclusion

Results of reliability analysis presented in this article are valid merely for this specific example; in the case of the same analysis in other enterprises, we can expect that achieved results will be different. The curve of costs due to a power outage is linear.

The analysis of outages can be used as basis for the preparation of protective measures, or emergency plans leading to the limitation of such a type of outage with all consequences.

The knowledge of total costs due to a power outage is important especially to planning investments in measures leading to an increase in power supply reliability.

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