Proceedings of the 5th WSEAS Int. Conf. on Power Systems and Electromagnetic Compatibility, Corfu, Greece, August 23-25, 2005 (pp6-10)

Analysis of Costs of Reliability of Electrical Equipment in Hydroelectric Power Stations

M. SMON, D. GORICANEC*
Dravske elektrarne Maribor,
Obrezna ulica 170, 2000 Maribor
*Faculty of Chemistry and Chemical Engineering
University of Maribor
Smetanova ul. 17, 2000 Maribor
SLOVENIA

Abstract: This article represents the importance of reliability, safety and availability of electrical equipment focusing on the increase of efficiency and effectiveness of maintenance work on generation facilities in hydroelectric power stations. Additionally, the influence of availability of electricity equipment is analyzed, which is an important measure of functional reliability of equipment and is connected with the economic efficiency rate.

Key-Words: Energy supply, hydroelectric power stations, reliability, availability, income

1 Introduction

Generation facilities are the key element in every electricity supply system as they ensure sufficient quantity of electricity, and a balance between produced and consumed power in the system. In particular, this is true for hydroelectric power stations, which are an indispensable renewable source of electrical power in every electricity supply system. The production of electricity in an electricity supply system influences the price of electricity and furthermore the costs of functioning of the whole system [1].

The reliability and stability of supply of electrical power to the consumers is one of the main factors of quality of electrical power in the system. The generation facilities play an important role, because they have to produce enough of electrical power. That means that the maintenance work at generation facilities has to be planned and performed so that enough electrical power is produced in the system. Only in that way we can achieve a high rate of electrical feed-troughs, independently of maintenance work in specific units in the system.

The next factor, which has to be thought out carefully in order for maintenance work to be efficient, is safety; the maintenance work has to be carried out not to put people's lives and property at risk. The level of risk depends on the size and quality of the equipment and its evaluation is different in different countries. A safe working environment has to be provided for workers and is a subject of regulation by law.

Furthermore, reliability of operation of generation facilities is an important factor, because the electricity supply systems are build redundantly, which means that a power failure of a particular unit does not mean a failure of supply of electrical power to the consumers. In this respect, certain parameters of reliability are introduced and are used in particular parts of electricity supply system. For generation units, these parameters are in connection with availability of generation facilities and explain the capability of particular unit for production of electrical power in a certain time period. The basic task of maintenance in every system is to establish the condition of equipment, the changing of their condition during operation and to determine the critical boundaries to the extend of which the devices can function normally without maintenance work. In this way, the optimization of the functioning of equipment is achieved and maintenance work and the costs are reduced to the minimum.

In theory and practice, there are two basic ways of performing maintenance work:

- corrective maintenance and
- preventive maintenance.

According to the method of corrective maintenance, an equipment item does not need maintenance work until its malfunction; after that, it is being repaired and starts functioning normally again. This method does not require any additional supporting elements, diagnostics or informational support. It can be used in the case of suitable redundancy of elements and components, where their malfunctioning does not affect the functioning and operation of the device as a whole.

On the other hand, the method of preventive maintenance is based on keeping the system and the equipment in the condition, where it functions normally.

The decision about maintenance work is based on anticipated time intervals or according to the condition of the device. The usual practice in hydroelectric power stations is closer to this method.

2 Reliability

Reliability in general has become very important in a number of industry sectors especially due to its practical usability in connection with the optimization of production, operation and maintenance of systems or their components [2].

The electric power supply system is consisting of three technologically interconnected sections – production, transmission and distribution. They have several layers of mutual links and interdependence. Due to its redundancy, the production system has no deterministic values as regards its influence on the reliability of power supply to consumers. To ascertain the reliability of power supply, two probabilistic indices are used:

- LOLE - loss of load expectation and
- LOLP - loss of load probability,

expressed in the annual number of hours. They depend on the structure and availability of generation units in system.

The continuity of supply has to do also with reliability. According to definition, reliability is the probability that the device, assembly or system will be able to function under certain condition and in the selected time interval [3].

Assessment of reliability is based on the monitoring of reliability indices that can be calculated according to the probabilistic or deterministic methods. The probabilistic methods are used in assessing reliability in development plans. The requirement for more precise reliability assessment call for the use of deterministic methods, which is defining reliability indices on the basis of actual data on events.

In the research carried out so far [4,5] extensive calculations of the reliability indicators based on data about actual functioning of electric power distribution systems were prepared.

For this purpose, two basic system indicators covering the number and duration of outages were applied.

- SAIFI - system average interruption frequency index and
- SAIDI - system average interruption duration index.

Recently, the rule of nines [6] is used to measure the suitability of availability of power supply to consumers, rendering the value of availability in percentages – Table 1. The annual duration of outages is depending on different levels of availability. The annual availability expressed with one nine defines the annual duration of outage of 36.5 days and is somehow typical of developing countries.

In the Slovenian electric power distribution system, conditions in this field are slightly lower than three nines; the long-term aim is so achieve the availability of four nines, which is the case already in some European countries.

Table 1: Duration of outages for availability expresses with number of nines

Availability (%)	Number of nines	Annual duration of outages
90	1	36.5 days
99	2	3.7 days
99.9	3	8.8 h
99.99	4	52.6 min
99.999	5	5.3 min
99.9999	6	31.5 s
99.99999	7	3.2 s
99.999999	8	0.3 s
99.9999999	9	1.57 cycles (50 Hz) 1.9 cycles (60Hz)

2.1 Influence of maintenance on reliability

Reliability is a probability category showing the ability of equipment to function properly in the future. The decisive influence in this respect is maintenance – its effects depend on:

- Type of performed maintenance intervention (inspection, audit, overhaul),
- Method of individual equipment item maintenance (applied maintenance methods),
- Potential use of diagnostic interventions and the efficiency of their application.

Maintenance work has a decisive influence on the increase of reliability of equipment. To increase the reliability of an equipment item, the decisive influences come from the overhaul, revision and, last of all, inspection. As a rule, the frequency of damages and the reliability of an equipment item are changing like shown in Figure 1. The period of childhood diseases and frequent malfunctioning (A) is followed by a period of normal functioning with stable and low frequency of malfunctioning (B). Maintaining a low level of malfunctions is in connection with maintenance work, which is carried out according to the practice of every single equipment user. By the end of the life-period of the equipment, the malfunctioning increases. The decision whether the equipment will be replaced or not depends on techno-economic analysis of its further usage [7].

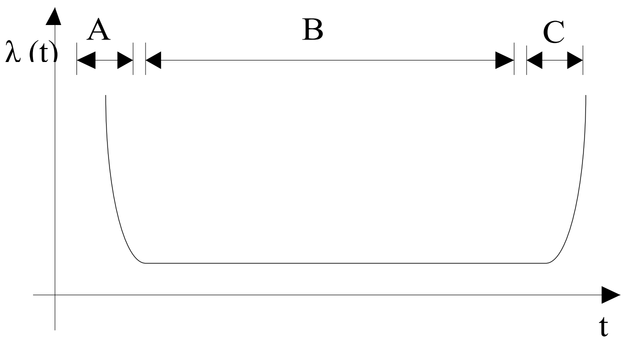

Fig. 1: The frequency of malfunction of the equipment during its life-period

2.2 Influence of maintenance on safety

Safety of people and property is of great importance for the operation of any system, thus also the electricity supply system. By maintenance, equipment is kept in good condition so that it can perform their functions according to the requirements stated in relevant documentation, which summarizes the key parameters of system operations on the installation site of each equipment item. On the international level, the risk of damage to property and the risk to the safety of people (death casualties) are distinguished:

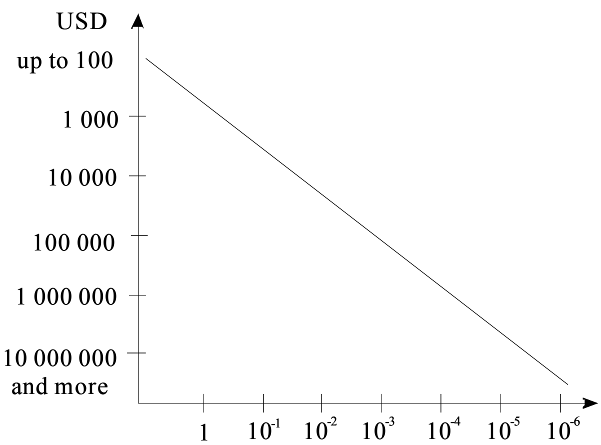

Fig. 2: Considered and acceptable economic risk

Economic risk in relation to event probability and its cost consequences were analyzed. The acceptable risk level is approximately – 10 USD/year, which means that the expected event probability is 10 : 3 (one event in thousand years) with cost consequences of 10000 USD.

The acceptable probability of a death casualty event among employees is specified in a similar way, as shown in Figure 3. These analyses define the tolerance limits for one single death casualty in million years. In simple terms, this means that in a company employing one million staff every year there is one accident resulting in a death.

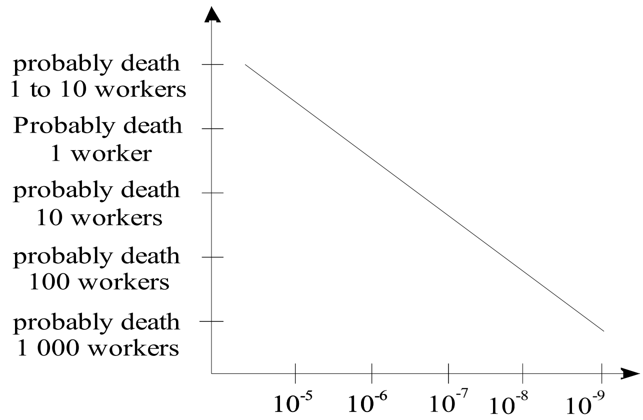

Fig. 3: Considered risk of death injury of employees

2.3 Influence of maintenance on availability

The availability is one of the basic values representing an important measure of reliability [8] of particular equipment item operation. The following values have been monitored:

- Operating time (functioning) of an individual equipment item,
- Reserve time,
- Monitored period and also
- Time in repair and downtime.

On account of annual overhauls, lasting for a few weeks, the availability of units is measured with one or maximum two nines. This means that their non-availability ranges between a few days (three or more) and a few periods of ten days (30 or more) per year.

3 Influence of operational reliability of equipment on income

Reliability of operation of production equipment is usually not questionable, since the applied maintenance methods – especially preventive maintenance by time – have ensured a high level of reliability [8]. However, the question arises to what extent the risk caused by the prolongation of such measures with suitable diagnostics procedures would be responsible so as to ensure as accurate insight into the status of such devices as possible. Chapter 2.2 includes a graph showing acceptable economic risk presenting the following ratios:

- Expenses up to 100 USD representing acceptable risk for one event in ten years,
- Expenses up to 1000 USD representing acceptable risk for one event in a hundred years,

- Expenses up to 10000 USD representing acceptable risk for one event in a thousand years.

Availability is the next important factor which depends on the performance of maintenance works. Availability depends directly on the frequency of overhauls p (in months) and their duration d (in days) [9]:

$$R_{device} = \frac{1}{8760}\left[8760 - \left(\frac{12}{p} 24\, d\right)\right] \quad (1)$$

Functional dependence of variables in the equation (2) is presented in Figure 4. It can be seen that the greatest influence on availability is recorded as the interval of the performance of maintenance works increases in the period from six to twenty months. As the interval of performance of maintenance works (overhauls) further increases, the availability of the equipment does not improve as much, because the duration of maintenance works has a lesser impact on availability.

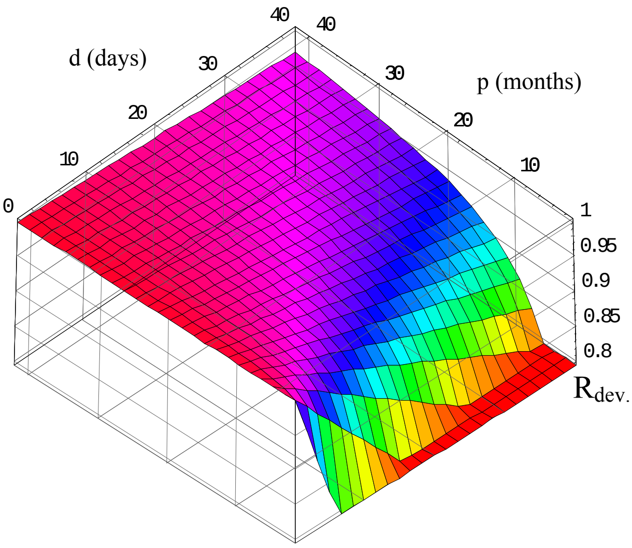

Fig. 4: Influence of intervals of overhauls (p) and their duration (d) on availability

Also important is the time when maintenance works are carried out, which is, as a rule, when the water course is low and when not all units in the hydroelectric power plant are functioning. As they are replaced in the course of overhauls, the utilization of water potential is maximized and losses resulting from production downtime are minimized.

In a similar way, it is possible to estimate the loss in income resulting from low availability caused by too frequent implementation of maintenance works (the possibility of full production of the units in question is assumed). The loss in income due to maintenance works (overhauls) in fact increases production costs on account of poorer performance. Under the assumption that a unit capacity is 20 MW and that the price of electricity is 0.03 USD/kWh, there is a connection between availability and loss in income- as shown in Figure 5.

$$S_r = \left(1 - R_{device}\right) \cdot 8760 \cdot 20 \cdot 0.03 \cdot 1000 \quad (2)$$

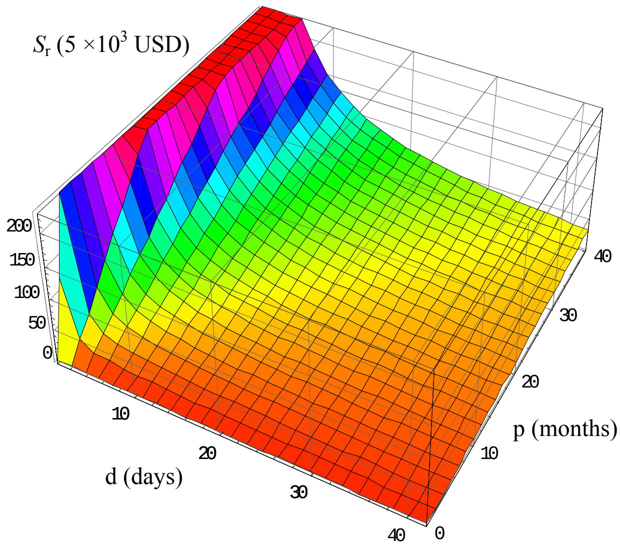

Fig. 5: Influence of intervals of overhauls (p) and their duration (d) on loss in income capacity

Due to great loss in income, which was the consequence of the performance of maintenance, is necessary, enabling better utilization and greater economic effects.

By introducing the above stated approaches to the maintenance issue, it is possible to reduce the number of breakdowns by up to 50%, while the reliability can be increased and costs curtailed by up to 15% and production downfalls resulting from breakdowns decreased by up to 10%. The results of analysis are given, revealing that the expenses of classic analyses are as much as up to 70% higher than that of preventive approach based on diagnostic inspections. It can be easily claimed that a properly selected approach to maintenance can result in:

- Reduction of maintenance costs due to shorter duration of maintenance works, fast identification and the possibility of anticipating breakdowns, which enables planning of resources and spare parts,
- Consequential increase in operating availability of equipment,
- Success in work additionally motivating employees,
- Timely identification of the system’s weaknesses and
- Shared experience with planners and designers of new systems, who thus design equipment with

greater reliability, more suitable for maintenance.

4 Conclusion

Economically successful performance of hydroelectric power stations is conditioned on not only basic operating, production and maintenance of the undertaking, but also on additional subsystems such as supply, marketing, management, development etc. If we restrict ourselves to the system of maintenance only, the goals of maintenance have to be reached with minimum of work, material and other resources in order to achieve high efficiency, reduction of production failure, longer life-period of the equipment, safety and health at work, and environmental protection.

The result of good maintenance work is reliability of the equipment. To ensure reliability [10] and normal functioning of the equipment, and a high economic efficiency, a proper strategy of maintenance has to be predicted and organized. By introducing modern approaches to the strategy of maintenance and consequently reliability of functioning, a reduction by 50% in malfunctioning, and by 15% in the costs can be achieved. Furthermore, the costs of spare parts can be reduced by 15% and the production failure due to malfunctioning by 10%. The results, obtained by making classical analyses, are 70% more expensive than by using preventive approach with the use of diagnostic inspection.

It could be said that with the right approach to maintenance we can:

- Reduce the costs of maintenance by decreasing the duration of work in connection with discovering and predicting malfunctions at an early stage, which helps us plan the resources and spare parts
- Consequently, the increase of production availability of equipment is achieved
- Motivate workers with efficiency
- Punctually ascertain weak spots in the system
- Transfer experience to planning new systems, which design devices of high reliability and those appropriate for maintenance.

Symbols:

λ	the frequency of malfunction of the equipment depend on time
A	area of starting problems
B	normal working area
C	ageing area
R_{device}	availability of the system's component
P	interval of maintenance works – overhauls (months)
d	duration of maintenance works – overhauls (days)
S_r	loss in income capacity

References:

[1] Tobias P., Trindade D., *Applied Reliability*, Second Edition, Van Nostrand Reinhold, A Division of International Thomson Publishinf Inc. New York, 1995

[2] Blanks H., *Reliability in procurement and use*, John Willey and Sons, Chichester, England 1992

[3] Bokal D., Bokal L., Jurse A., Zorman M., Mihorko B., Omahen P., *Pojmovnik s področja obratovanja in vzdrževanja distribucijskega elektroenergetskega omrežja in postrojev*, EIMV, Ljubljana, JP Elektro Celje, Celje, JP Elektro Gorenjska, Kranj, JP Elektro Ljubljana, Ljubljana, JP Elektro Maribor, Maribor, JP Elektro Primorska, Nova Gorica; Ljubljana, oktober 1994

[4] Bokal D., *Uporaba kriterijev zanesljivosti pri povečanju kakovosti napajanja odjemalcev z električno energijo*, ref. št. 1321, EIMV Ljubljana, 1997

[5] Bokal D., *Uporaba zanesljivostnih in stroškovnih modelov v analizi delovanja* DEES, ref. št. 1447, EIMV Ljubljana, 2003

[6] Knezevic J., *Upravljanje procesima održavanja i obnavljanja tehničkih sistema na osnovu teorije pouzdanosti, I deo*, Teorija pouzdanosti u inženjerskoj praksi, OMO, Beograd, 1988

[7] Smith D., *Reliability and Maintainability in Perspective, Technical management and commercial aspects*, The Macmillan Press Ltd, 1988

[8] Thorne D., Endrenyi J., Kariger J., McGILLIS D., Mastrocola J., Prince J., Ringlee R., Wellssow W., Concepts, principles, objectives and criteria, Task force, Power system reliability analysis application guide, *CIGRE WG 03 of SC 38* (Power system analysis and techniques), 1987

[9] Salvatore D., Diulio E., *SCHAUM'S Outline of Theory and Problems of Principles of Economics*, Second Edition, McGraw Hill, 1996

[10] Billinton R., Allan R.: *Reliability Evaluation of Power System*, Second Edition, Plenum Press, New York and London, 1996