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# New Methods of Maintenance of Electricity Devices in Hydroelectric Power Stations and their Influence on Reliability and Costs and Environment

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*Abstract:* The paper presents conventional and new maintenance methods with a special focus on advantages for reliability and costs and environmental protection of operation of electric power systems.

*Key - Words*: Electric power supply, hydroelectric power stations, maintenance, reliability, safety, costs, environment

## 1 Introduction

Technical systems provide an important support and help in performing numerous activities satisfying the needs of mankind. In the today's world it is impossible to imagine the functioning and development of human society without electric power. Production, transmission and distribution of electric power are primary tasks of the electric power supply system. In the recent years, this system has been under strong influence of numerous changes above all related to deregulation - introduction of market mechanisms.

Restructuring of the electric power sector and transition to the electric power trading require a lot of efforts from the companies towards an increase of efficiency and improvement of business results. This applies also to individual business processes inside companies, of which maintenance is one of the most important. Therefore, it is necessary to analyze in detail the existing conditions in the field of maintenance and operational reliability of individual equipment components, and prepare a review of necessary maintenance costs. Related to hydroelectric power plants, the said activities represent a basis for further actions in respect of introduction of up-to-date methods and organizational aspects directed at reliability centered maintenance (RCM) or live cycle management (LCM). It has to be noted, however, that electric power supply systems are built with redundancy which means that outage of one unit does not necessarily lead to a blackout at electric power consumers. Therefore, certain indicators of reliability linked to availability have been introduced. These indicators show in principal the interdependence between of the ability of individual units to produce electric power in the monitored time period and the required planned and efficient performance of maintenance works. Therefore the simplest concept of corrective maintenance, i.e. maintenance after occurrence of defects, was extended by several new concepts, as follows:

- first generation – corrective maintenance,
- second generation – planning of overhauls, introduction of systems for planning and monitoring of operation, pioneering use of computers,
- third generation :
  1. status monitoring
  2. reliability and maintenance centered design of components,
  3. risk studies,
  4. small and fast computers,
  5. analysis of defects and their effects,
  6. expert systems,
  7. multitasking in the execution of activities and teamwork.

## 2 Maintenance

In the last decades, the progress of science and technology has made it possible to apply a systematic approach to the maintenance issue. Worldwide, a completely new branch of science has emerged which deals in upgrading and optimization of maintenance, development of maintenance concepts and methods and their application in practice. This branch of science is called Maintainability Engineering and is developing very quickly.

Three basic maintenance concepts are being applied in setting-up maintenance systems worldwide. These are:

- Reliability Centered Maintenance,
- Total Productive Maintenance,
- Results Oriented Maintenance.

Basic characteristics of individual maintenance-related concepts are shown in Fig. 1.

Reliability centered maintenance is applied in connection with permanently changing condition of equipment components and reliability of their operation.

Preconditions for the use of this approach are: adequate information system (providing collection, processing, follow-up and analysis of a relatively large volume of data about the operation of equipment components) and adequate software for processing of these data and display of results.

Total productive maintenance is based on real-time monitoring of operation of equipment components, on assessment and identification of the condition of the system at any moment and on experience of the operator taking the decisions. This approach requires total accountability of all staff members and the aim is to ensure totally defect-free operation of the equipment components.

Results oriented maintenance is an intermediate approach between the two above concepts. Decisions regarding maintenance are taken on the basis of the results of the observed system.

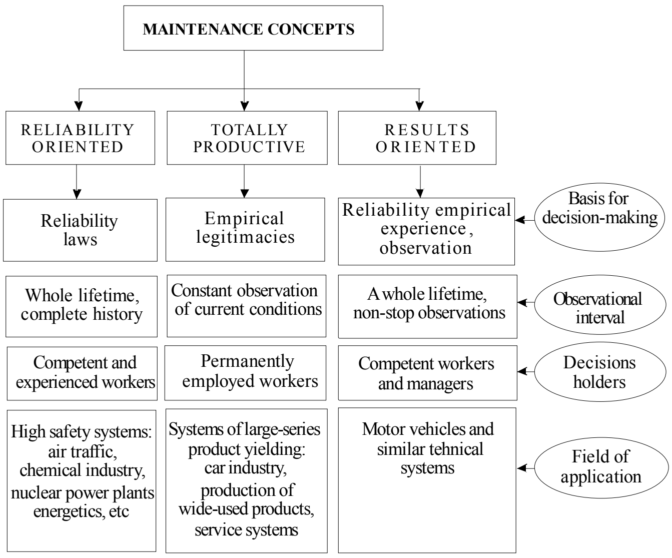


Fig. 1: Maintenance concepts for technical systems and their characteristic properties

Maintenance systems can first of all be divided in:

- corrective maintenance and
- preventive maintenance.

It is typical for the corrective maintenance that action is taken after occurrence of a defect. As a rule, this approach is applied to sections of technical systems that do no have a large impact on the reliability of vital system functions.

Preventive maintenance is applied to systems that perform vital functions, and includes:

- Preventive maintenance based on time:
  1. Time determined model,
  2. Time adjustable model.
- Preventive maintenance based on condition:
  1. With checks of the condition of equipment components,
  2. With checks of reliability of equipment components.

It is typical for preventive maintenance based on time according to pre-determined time intervals for performance of individual maintenance activities that its application requires knowledge of the system and of time periods when the system stops functioning properly and a defect occurs. If these time periods are evenly distributed, also the intervals of maintenance interventions can be pre-determined. If this is not the case, the adjustable time model is applied where maintenance intervention intervals are being adjusted to the capability of the system components to function properly.

The starting idea of preventive maintenance based on condition with checks of condition parameters is monitoring and evaluation of the condition of the equipment components which is used as a basis for decision taking on required maintenance interventions. Condition monitoring makes it possible to identify trends and predict time periods when the parameters are going to reach the allowable limit which results in action i.e. execution of adequate maintenance interventions.

An important activity with this type of maintenance is diagnosis which continuously or in selected time intervals assesses the magnitude of individual factors as indictors of the equipment component (system) condition.

As a rule, in the power supply sector preventive maintenance with checks of the condition of equipment components is used. This applies to key system components (generation units, transformers etc.) which are provided with diagnosis capabilities enabling proper assessment of their condition.

In any case, there are certain pre-conditions for successful introduction of preventive maintenance method with checks of equipment component condition:

- Know-how and tools for performance of diagnosis and adequate methods,
- Adequately trained staff,
- Adequate maintenance organization,
- Existence of a condition monitoring and control system,
- Suitable IT supports enabling fast and reliable processing of data and their use.

## 3 New maintenance methods in hydroelectric power plants

The production part of the electricity system, which includes the hydroelectric power plant companies, belongs to technical systems whose reliability and availability has to be at a maximum. The risk of major breakdowns has to be minimised, particularly because of the high costs arising from the elimination of potential damage. The analyses of the following factors are important as regards decision-making about the application of a particular maintenance method:

- Functional roles of an individual device, its part or whole set in system operation,
- Reliability of individual components of devices (system),
- The existence of technical diagnostic methods suitable for individual devices,
- Operating characteristics and suitability for device (system) control,
- Technological qualifications and equipment of the maintenance groups and
- Cost-effectiveness of maintenance.

In addition, the criterion function based on which we decide and select a method falls within the scope of the goals to achieve:

- Maximum effects,
- Maximum quality,
- Maximum reliability,
- Maximum economy, etc.

The maintenance task implementation usually consists of three primary goals:

- Maximising the operating time of devices (system), which means that their operating availability is maximised,
- Maximising reliability (with approximately equal maintenance expenses by variant),
- Minimising maintenance expenses, which is provided by variant:
  1. For those maintenance methods which ensure approximately the same reliability,
  2. For methods which ensure different reliability levels and
- Maximising expected income per time unit of the system's (device's) life span.

Table 1 shows six groups of criteria for selecting the most optimal maintenance method, whereby the methods of preventive maintenance by time and methods of preventive maintenance by status are compared. The selection is made based on the following factors:

- Ratio between the availability and reliability of the device (system) in question in view of the applied maintenance method,
- Ratio between total maintenance costs by method and
- Selected optimality criterion.

In the first two cases the expenses based on the selected method are the same (or approximately the same), while the optimality criterion represents either maximum availability or maximum reliability.

In the third and fourth cases, the availability or reliability of compared methods are the same, but expenses differ, while the minimum cost criterion prevails. The fifth and sixth cases point to the cost minimisation criterion with different availability or reliability values.

Table 1: Optimality criteria and the selection of maintenance method

| Ser. No.: | Ratio of availability (A) and reliability (R) | Total maintenance expenses (E) | Optimality criterion |
|---|---|---|---|
| 1. | $A_{tbm} \leq A_{cbm}$ | $E_{tbm} = E_{cbm}$ | max $A_{tbm}$ or max $A_{cbm}$ |
| 2. | $R_{tbm} \leq R_{cbm}$ | $E_{tbm} = E_{cbm}$ | max $R_{tbm}$ or max $R_{cbm}$ |
| 3. | $A_{tbm} = A_{cbm}$ | $E_{tbm} \neq E_{cbm}$ | min $E_{tepm}$ or min $E_{tecbm}$ |
| 4. | $R_{tbm} = R_{cbm}$ | | |
| 5. | $A_{tbm} \neq A_{cbm}$ | $E_{tbm} \neq E_{cbm}$ | min $E_{tepm}$ or min $E_{tecbm}$ |
| 6. | $R_{tbmt} \neq R_{cbm}$ | | |

In electric power plant companies, the introduction of preventive maintenance by condition is proposed for key devices, such as aggregates (generators and turbines), energy transformers and circuit breakers with an emphasis on diagnostics of these devices' condition. During the set-up of the information system which will enable comparisons of various maintenance methods, it is proposed that maintenance interventions be additionally conditioned by the number of working hours. When the selected number of working hours of a device is exceeded, a suitable maintenance intervention is planned, and the hourly quota is defined based on the equation:

$$U_{operat} = U_{op\ ac.} + k_1 N_1 + k_2 N_2 + k_3 N_3 + k_4 N_4 + \ldots \qquad (1)$$

In addition to previously stated factors, the following has to be taken into account when the most suitable maintenance method is being selected:

- Importance of the technical system for the operation of the hydroelectric power plant,
- Structural role of the device (element) in the system's operation (subsequent, parallel or mixed connection, etc.),
- Availability of spare parts,
- Working conditions (type of load, environmental conditions, etc.),
- Characteristics of operating technology and suitability of devices (system) for diagnostics,
- Development of units in the future,
- Automation level and
- Technical education (culture) of management and other staff.

The selection of the maintenance method depends on numerous factors, which can be rationally monitored only with a suitable information system. In this respect, adequate application software would be of great help, enabling automation of decision-making.

It has to be stressed that the selection of the maintenance method for individual devices and their sets can be based on completely different decisions, meaning that different maintenance methods can be used for the same device and components.

## 4 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 [12]. 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. 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) [10]:

$$R_{device} = \frac{1}{8760}\left[8760 - \left(\frac{12}{p}24\,d\right)\right] \qquad (2)$$

Functional dependence of variables in the equation (2) is presented in Figure 2. 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.

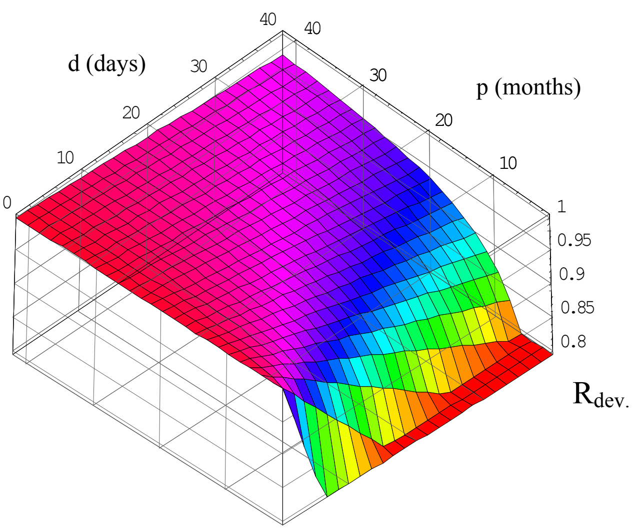


Fig. 2: Influence of intervals of overhauls (p) and their duration (d) on availability

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 3.

$$S_r = \left(1 - R_{device}\right)\cdot 8760 \cdot 20 \cdot 0.03 \cdot 1000 \qquad (3)$$

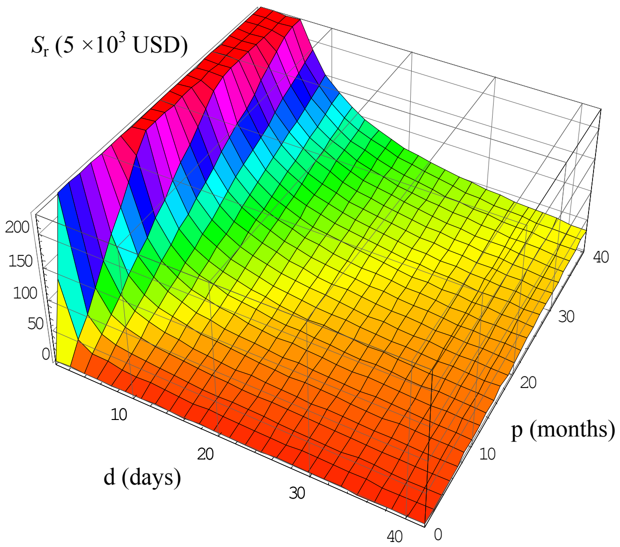


Fig. 3: Influence of intervals of overhauls (p) and their duration (d) on loss in income capacity

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.

# 5 Conclusion

Based on conducted analyses and experience from throughout the world, it can be concluded that further development in the field of maintenance of electricity systems has to focus on the introduction of modern maintenance methods, particularly the maintenance method by condition, involving the control of parameters which enables monitoring of the condition of equipment and taking measures in cases when key parameters reach the permitted limits. With the proposed method, the utilisation of individual devices improves and maintenance costs decrease since actions are taken only when the devices are approaching the capacity limits (in terms of maintenance). These methods are applied only to vital equipment, while for others, simpler maintenance methods can also be used. Above all, the scope of maintenance works on redundant devices has to be considered.

The maintenance system has to be supported by a suitable information system for only in this way is it possible to manage additional functions attributed to maintenance. The system should enable the collection, processing, storing and analysis of a large number of data about the operation of individual devices. Moreover, data about costs will be available, which provides the basis for further analyses of the efficiency of maintenance works. We have to be aware that computerisation would have to enable the use of knowledge about functioning and maintenance of devices in the past as well as, algorithms produced for the status analysis of individual devices (know-how). In this way, decision-making about maintenance interventions would be automated to a certain extent leading to additional time and funds saved.

The result of good maintenance work is reliability of the equipment. To ensure reliability [12] 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.

Undoubtedly, the system of continuous personnel training has to be introduced so as to ensure that personnel is qualified for demanding maintenance works as well as, research in the field of valuation of maintenance efficiency, comparable with studies carried out by developed economies in the EU.

# 6 Symbols

$E_{tbm}$ total expenses of time based maintenance,
$E_{cbm}$ total expenses of condition based maintenance,
$E_{tepm}$ total expenses of preventive maintenance (direct and indirect),
$E_{tecbm}$ total expenses of condition based maintenance (direct and indirect),
$A_{tbm}$, $A_{cbm}$ availability when using time or condition based maintenance,
$R_{tbm}$, $R_{cbm}$ reliability when using time or condition based maintenance,
$U_{operat}$ total number of operating hours as a maintenance intervention criterion,
$U_{op\ ac.}$ actual number of operating hours,
$k_1$ specific working hours for start-up/shut down (circuit breakers: switch on/switch off),
$N_1$ number of start-ups/shut downs (switch on/switch off),
$k_2$ specific working hours in exceptional operating conditions (short circuits, etc.),
$N_2$ the number of exceptional operating conditions,
$k_3$ specific working hours per functioning of individual types of protection,
$N_3$ number of times when individual types of protection are functioning.
$R_{device}$ 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

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