# MAINTENANCE APPROACHES OF POWER ELECTRICAL EQUIPMENTS FOCUSED ON CONDITION MONITORING OF POWER TRANSFORMERS

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## ABSTRACT

The paper is focused on maintenance strategies of power equipments. At first, the basic types of maintenance strategies will be discussed and then their optimization methods. Second part of the paper describes few methods of condition monitoring of power transformers. This paper represents the first step of the project study, which will be focused on applying new maintenance methods into the practise.

## 1. INTRODUCTION

The availability of equipment depends on its reliability and maintainability. In general, the good maintenance policy ensures the minimum probability of equipment fault.

Maintenance strategy of power equipments is area, which is long time out of consideration in the Czech Republic. We decided to deal with this topic closer to extend this area by new pieces of knowledge and experiences. Next important thing is to discover, if the new technologies and research connected to this area can be practically applied in the Czech Republic. After exploring foreign literature and consultations with some companies, we found out these results.

## 2. MAINTENANCE APPROACHES

Basically, maintenance strategies can be planned or unplanned. Depending on maintenance planning, we can divide maintenances into three basic types – Corrective, Preventive, and Predictive.

Corrective maintenance is a reactive strategy which is unplanned and is performed after failure has occurred. The intention is to restore an item to a state that can perform its required function.

Preventive maintenance alias Scheduled maintenance is planned strategy which is performed at regular intervals. Disadvantage of this strategy could be that it may be quite inefficient, or in other words, it may be too costly and may not extend the component lifetime as much as possible. That is why this strategy is replaced in last fifteen years more often by Predictive maintenance.

Predictive maintenance is planned strategy as well, but maintenance tasks are not carried out in regular intervals. They are performed in dependence on an analysis of needs and priorities, or on a study of information obtained through periodic or continuous condition monitoring.

# 3. OPTIMIZATION MAINTENANCE METHODS

In this chapter will be described three main types of maintenance optimization methods:

## 3.1. APPROACHES BASED ON MATHEMATICAL MODELS

Basically, a maintenance optimization model is a mathematical model in which both costs and benefits of maintenance are required and in which an optimum balance between both is obtained. [1]

In general, maintenance optimization consists of four parts. First is a description of the technical system, its function and importance. Second is a description of the deterioration and what kind of affects it has on the system. Thirdly, a maintenance optimization covers information about system and actions that are possible to implement and fourthly, an objective function and an optimization technique to find balance between costs and reliability.[1]

Area of this part of my research was focused mainly on IEEE publications. 14 papers were found, which were concentrated on optimization of maintenance strategies of power equipments – generators, transformers, breakers or all substation equipment in its entirely. Generally, the survey acknowledged mentioned above – a mathematical model concentrated on finding optimal balance between costs and reliability sometimes with recommendation for optimal maintenance scheduling. As optimization techniques were used a dynamic programming methodology, evolutionary algorithms (genetic algorithms and artificial intelligence), phase-type and Weibull distribution, Game theory and Monte Carlo simulation.

## 3.2. RELIABILITY CENTERED MAINTENANCE (RCM)

This maintenance strategy is mainly type of preventive maintenance strategy. It is more qualitative approach to maintenance strategy where above mentioned optimization models are quantitative approaches.

RCM is a set of methods and tools aimed at helping a utility to determine the minimum set of preventive maintenance tasks necessary to appropriately address critical equipment failures without compromising service reliability. RCM is a structured process used to determine optimal maintenance requirements for equipment in a particular operating environment. It combines the strategies of corrective maintenance, preventive maintenance and predictive maintenance, and applies these strategies where each is appropriate, based on the consequence and frequency of functional failures. This combination produces a maintenance program which optimizes both reliability and cost effectiveness. [2]

The basic ideas of this maintenance strategy can be divided in the 4 points [2]: 1) Preserve system function, 2) Identify dominant failure modes, 3) Prioritize function needs – focus on the most critical functions, 4) Select only applicable and effective maintenance tasks.

To be possible to apply this maintenance strategy, we need data set and informations about quiet long maintenance history of the equipment.

### 3.3. CONDITION BASED MAINTENANCE (CBM)

This maintenance approach is type of a Predictive maintenance method. Presently, there is a trend to implement this strategy for more and more power equipments, especially for the most expensive ones – e.g. big power transformers and HV breakers.

CBM is based on measuring the condition of equipment in order to assess whether it will fail during some future period, and then taking appropriate action to avoid the consequences of that failure. Condition monitoring can be divided into two types – on-line and off-line. Off-line methods usually demand disconnecting the equipment from power network. These methods involve e.g. gas in oil analysis, recovery voltage measurement, tan(δ) measurement, infrared thermography etc. [3]

For on-line monitoring, the equipment has to be retrofitted with sensors. The main advantages of on-line condition monitoring are reducing the probability of unexpected failures and financial saves due to reducing inspections and unnecessary maintenance tasks of power equipments. Presently, there is possible to measure on-line e.g. for transformers different temperatures, gas in oil, partial discharge, winding movement, furfuraldehyde, tan(δ) and on-load tap-changer.

## 4. CONDITION MONITORING OF POWER TRANSFORMER

Big power transformers are one of the most important devices in electric power system. Correct work of these devices is one of the priorities for providing continuous power supply. Condition monitoring could be very useful and helpful tool to avoid transformer breakdown or downtimes and to operate transformer in an optimal fashion. Now will be described few methods for condition monitoring of power transformers.

### 4.1. TEMPERATURE MEASUREMENT

Transformers can be overheated depending on heavy load or e.g. bad function of cooling system. The hot-spot (maximum temperature) of transformer has the direct influence on transformer's insulation aging, which is connected with the maximum service life of transformer. Thermal aging rate of insulation can be expressed by the Motsinger equation. It defines, that aging rate doubles with every 6 °C temperature rise of the hot-spot temperature above a temperature 98 °C. Generally, there are three types of temperature measurement – using Pt 100 thermocouple sensor, a single-point fiber-optic system and a distributed measurement fiber-optic system along the winding. [4]

### 4.2. INFRARED THERMOGRAPHY

Thermography is the process of transforming heat emitted by an object, into a visible image. All objects with absolute temperature above zero emit heat, it means, that are recordable by thermography device. [5]

Presently, thermography has been used more widely for detecting temperature abnormalities in transformers. In this technique, an infrared camera is taken to the field and used to detect temperature gradients on external surfaces of the transformer. Infrared cameras make it easy to detect whether a bushing or fan bank is overheating and needs to be replaced. The method is also useful in determining whether a load tap changer is operating properly. Thermography is also effective for checking many different transformers quickly to see, if there is any outstanding problem.

### 4.3. Dissolved Gas Analysis (DGA)

Monitoring of dissolved gas in oil is another very important measurement which can predict and avoid faults of transformers. Electrical and thermal stresses such as arcing, partial discharges and overheating cause degradation of dielectric oil and solid dielectric cellulose materials. The degradation of insulation produces different gases. Important gases for fault detection are: hydrogen ($H_2$), oxygen ($O_2$), nitrogen ($N_2$), methane ($CH_4$), ethane ($C_2H_6$), ethylene ($C_2H_4$), acetylene ($C_2H_2$), carbon monoxide (CO) and carbon dioxide ($CO_2$). For detecting insulation problems are used the relative ratios and the concentration of these gases in oil sample. When the value of concentration or the relative ratio is exceeded, then a fault is expected. [6]

Analysis of dissolved gasses in insulating oil provides very valuable informations for evaluating the health of a transformer. DGA has become an important part of preventive maintenance. [6]

### 4.4. Partial Discharge Monitoring

Dielectric breakdowns in power transformers are most frequently preceded by partial discharges. Because partial discharge (PD) often occurs before a complete breakdown, partial discharge monitoring can provide a warning of future and perhaps catastrophic failure. [7]

For PD detection, there are commonly used two methods: detection of the acoustic signals and measurement of the electrical signals produced by the PD. PD can also be detected indirectly, using chemical approaches. The acceptable PD limits for new transformers are dependent on the voltage and size of the transformers and range from $< 100$ to $< 500$ pC. Acoustical sensors serve to detecting mechanical stress waves produced by PD and can be used in the frequency range from 100 to 300 kHz. These sensors are mounted on the transformer tank wall or in the oil inside the transformer tank. [6]

Electrical sensors can detect high-frequency low-amplitude disturbances on the applied voltage and current waveforms caused by PD. Techniques using detection of ultra-high-frequency (UHF) signals (typically 1–2 GHz) have been developed to detect PD in gas-insulated substations. [6] More about UHF detection method of PD include basic principles is written in [8].

Because acoustic methods of PD detection are limited by signal damping, and electrical measurements are limited by electromagnetic interference problems, the best solution for monitoring should be combination both methods. This is commercially used for on-line PD monitoring. [6]

## 5. CONCLUSION

Because results seem to be very interesting and due to the fact that this area is not explored enough in our country, we decided to continue with this research in the future. Next step should be discussions this new methods with some Czech transmission company, if these new methods can be applicable into the practice. Results of the research should lead in the PhD thesis focused on the same area.

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