ELECTRICAL EQUIPMENT MAINTENANCE, COMPONENT OF THE ASSET MANAGEMENT

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REZUMAT. Astăzi, în condiţiile liberalizării şi dezvoltării pieţei româneşti de energie, gestionarea activelor în industria energiei necesită o abordare nouă, deoarece activele companiilor electrice necesită activitate de mentenanţă specifică fiecărui echipament gestionat şi implică luarea deciziei în legătură cu acestea. În aceasta lucrare se prezintă evoluţia în timp a strategiilor de mentenanţă, clasificarea acestora după criteriul apariţiei defectelor, precum şi tendinţa actuală de trecere de la mentenanţa bazată pe criterii predeterminate la mentenanţa bazată pe starea tehnică a echipamentelor.

Cuvinte cheie: managementul activelor, diagnosticare, mentenanţa, monitorizare, fiabilitate.

ABSTRACT. Nowadays, according to the liberalization and development of Romanian energy market, asset management in energy industry require a new approach, because the assets of electrical companies need a specific maintenance strategy for all electrical equipment and also involve the decision-making process about the company assets. This paper present the time evolution of the maintenance strategies, the maintenance strategies classification by the criterion of fault occurrence and also the current trend to pass from time-based preventive maintenance to condition-based maintenance.

Keywords: asset management, diagnosis, maintenance, monitoring, reliability.

1. INTRODUCTION

The importance of discussed topic comes from the fact that electricity companies must handle a large number of electrical equipment (circuit breakers, transformers, cables etc.). Most of them have been in exploitation for years and are close to the end of their useful lifetime and then, they are more likely to fail, being necessary an assistance in making an appropriate and timely decisions about their assets. Based on the information acquired from asset management activities (monitoring and diagnosis, maintenance strategies and risk management), the decision-making process is designed to maintain electrical equipment in operating state, in safe condition and economical efficiency for electricity companies.

In the context of energy market deregulation for any company in the electricity field either generation, transmission and distribution, its overall objective is to reduce costs while increasing equipment reliability, extending equipment lifetime and ensuring high levels of health and safety for operation and maintenance personnel, for the public, and for the environment.

Due to this fact, proper operation and maintenance of major electrical equipment (transformer, circuit breakers, and overhead lines) becomes significant because:

- they belong to the expensive equipment category;
- the costs for maintenance of these equipment represent a large percentage of maintenance budgets;
- them failures, adversely affect the system reliability and the existing monitoring technologies within the power station.

Overall objective of the electricity companies is now, more than ever, to minimize operational costs of the electrical equipment and also to ensure that the system is working more economically. An important operational cost is the maintenance cost. Maintenance optimization is one possible technique to reduce life cycle costs while improving reliability. The electricity company needs to implement new strategies for more effective maintenance techniques. Thus, making decisions about the equipment maintenance activities must have a clear idea about what the maintenance can perform, what maintenance strategies are available, what assets to perform maintenance on, what level of maintenance to perform, what specific maintenance steps to perform, and when to perform the selected maintenance.

2. ASSET MANAGEMENT TYPES

Company assets have been managed and are managed to obtain the most out of investment (return on

investment-ROI). It is obvious however that even though are taken a lot of actions, measures to reduce costs, to reorganize, to increase productivity and quality, etc., an increasing number of opportunities are lost due to the contradictory objectives of the organization and due to the lack of organization between companies departments, [1].

Electric power supply, regarded like a business, has importantly changed, not only due to deregulation of the energy market, but also due to the development of information technology (Information Technologies-IT).

Electricity companies of transmission and distribution have an significant base of equipment (circuit breakers, transformers, cables, etc..) to be managed. In this sense, to maximize the return on investment is necessary to minimize installation, operation and maintenance costs of the equipment and to increase safety in operation, keeping a high level of their reliability.

Asset management (AM) decision problems within an electricity company have the following characteristics, [2]:

- there are strong interdependencies between physical performance of individual assets, physical performance of the overall system, and economic system performance;
- there are limited resources;
- there are important uncertainties in individual component performance, system loading conditions, and available resources;
- there may exist multiple objectives, e.g., system performance and economic efficiency.

A definition of the asset management is: the set of methods, disciplines, procedures used for the entire lifetime of business, to optimize its cost, performance and risk exposure, [1]. It can be observed therefore that AM affects all sectors of business: design, operation, maintenance, safety etc.

Electrical equipment management can be of two types: tactical, respectively strategic management.

Tactical management of the electrical equipment is defined by specific programs of maintenance of each type of equipment, programs that generate norms and maintenance activities. For example, circuit breakers have maintenance programs to help establish their technical condition, respective the maintenance activities to be performed. These programs consist of inspections, online and off-line monitoring, diagnosis etc.

Regarding the strategic management of equipment there are two essential strategies to maintain the performance in the electrical equipment management, [3]:

- to optimize the lifetime of the equipment for long term, respectively short term;
- to optimize the equipment reliability. Optimal reliability level is determined by minimizing the maintenance activities of the electrical equipment to maintain the required availability.

Specifically for electricity company is that those two types of Asset Management should be combined to identify all the processes that determine the financial basis for management, operation and maintenance of physical assets of the company.

Among the electrical equipment management objectives can be found, [3],[4] and [5]:

- ensuring monitoring and diagnosis of the technical condition of the equipment;
- maintaining the equipment functions at a high level of performance to satisfy the needs and expectations of consumers;
- determination of proper maintenance strategies;
- balancing between maintaining in exploitation and replacement the assets to ensure continuity of power supply and a high level of safety in operation;
- optimizing the balance between investment risk and investment in aging assets;
- delaying investment and reducing operating and maintenance costs by prioritizing the maintenance activities based on technical, economical and social objectives of the electricity company.

3. MAINTENANCE STRATEGIES

In Romanian energy system there are in exploitation equipment operating since 1970, which will soon reach the normal operation lifetime and require especially attention from the transport network management through implementing proper maintenance strategy for the individual equipment.

This paper intends to establish, starting from the concept of efficiency, respectively the business performance level and the need for safety operation of the electricity transmission installations, the most adequate types of maintenance that can be applied for the electricity transmission system, so that it achieve maximum economic efficiency, in terms of assumed risk.

Maintenance strategies have evolved over the years from time-based preventive maintenance to condition-based maintenance, to reliability-based maintenance and also to risk-based maintenance, which leads to cost savings, an important element in terms of liberalization the market, [1] and [6].

A time evolution of maintenance strategy is presented in Fig.1, in which, with the human society development, it is emphasizes the need to introduce new concepts to reduce the risk of system failure by implementing some strategies based on multicriterial

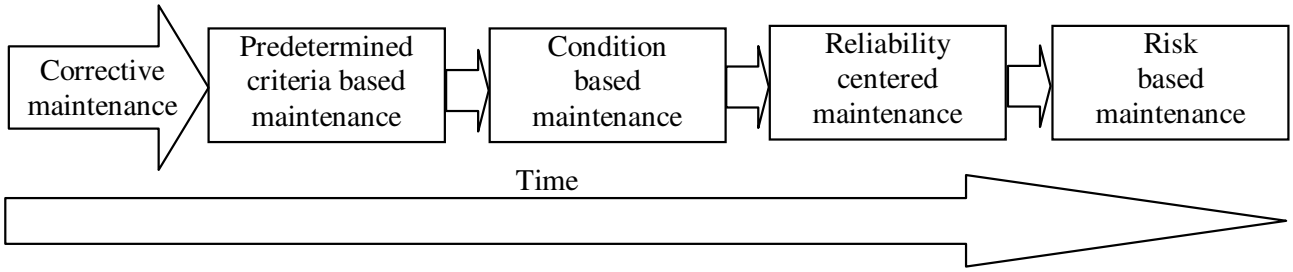

Fig. 1. Time evolution of the maintenance strategies

analysis, more complex, which ultimately will lead to increase safety in operation, to ensure continuity in supply, to minimize the system lost and will also lead to qualitative satisfaction of consumers.

Maintenance is defined as "all technical and organizational actions that are performed on the installations and their components to maintain or compliance the capacity to realize the function for which they were designed", as in [7].

The operation of any installation requires financial resources for its maintenance. The allocated budget size depends on the complexity of installation and also on the obligation to ensure the continuity in operation etc. The necessity to reduce costs on the entire lifetime of the asset, has led to various maintenance systems and concepts. These concepts of maintenance are classified on the criterion of fault occurrence (after and before fault), according with Fig.2, [1], [6] and [7].

Corrective maintenance represents all of the maintenance activities that are performed to restore the asset condition in order to perform their functions for which it was designed after occurrence of a fault or after an wilful interruption of the asset mission when becomes imminent the occurrence of a fault which could not be provided.

Preventive maintenance represents the overall maintenance activities which are performed at predetermined time intervals or corresponding to predetermined criteria to prevent the occurrence of a fault or reduces the probability of failure evolution in time. This type of maintenance can be of two types: maintenance based on predetermined criteria and maintenance based on condition and it aims to ensure the long life of the asset.

Predetermined criteria based maintenance (PCBM) is the set of regular maintenance activities performed, no matter what the technical condition of the electrical equipment is, through which are maintain/restore them performance. This kind of maintenance is performed, usually, after the criterion of time interval. In the case of some electrical equipment (circuit breakers, switchgears) in addition to the criterion of time interval is the criterion of occurrence of events. These criteria may include: frequency of the short-circuit commutations; short-circuit commutations number and the operation time.

PCBM is current maintenance strategy and is used in electricity companies and also in many industries and utilities.

PCBM is based on inspection and maintenance activities of electrical equipment operating at a constant time period set by the manufacturer of electrical equipment and the staff experience.

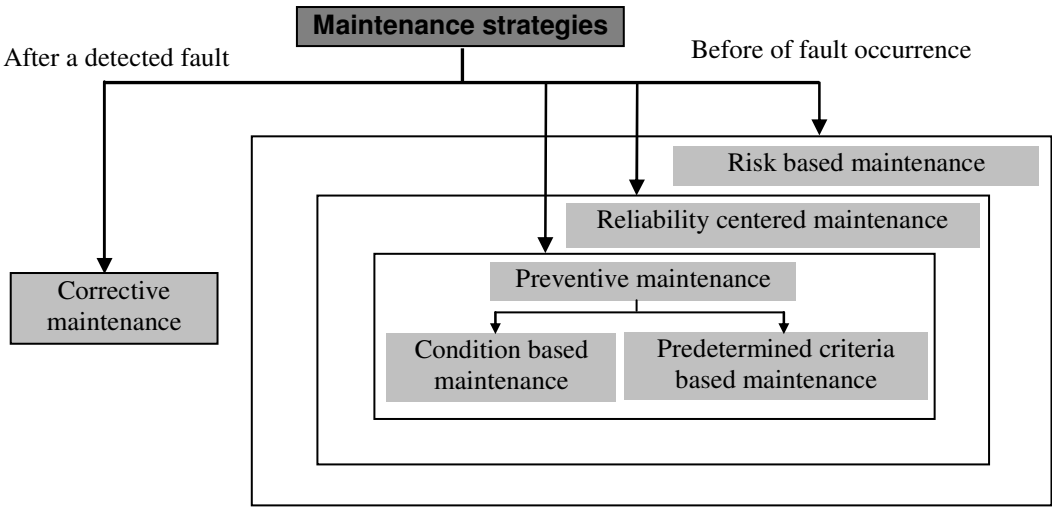

Fig. 2. Maintenance strategies

PCBM can prevent many failures but can cause unnecessary interruption, operator costs, waste of money and time, if the maintenance interval is too small. In addition, if the maintenance interval is too large unexpected accidents can occur at intervals of inspection and maintenance activities in the operation state of the asset.

Condition based maintenance (CBM) is the overall activities of determining/forecasting the electrical equipment technical condition and the activities of maintaining/ restoring the performance, as required, arising from the carry out such activities.

CBM is the maintenance activity which aims to eliminate unnecessary maintenance activities and also to act over the equipment condition when one parameter of the equipment is not functioning at its normal capacity. Maintenance strategy based on knowledge of the technical condition must be well established and implemented to significantly reduce maintenance costs by reducing the number of inspections and unnecessary maintenance activities. Using this type of maintenance it reduces the risk of total failure, because that will know when a parameter is not in normal operation limits and when the operator has to intervene.

Historical database about electrical equipment such as operating parameters, diagnostic tests and environmental influences can identify which component of the equipment should be monitored and then identify the correct method of monitoring.

Reliability centered maintenance (RCM) represents a series of actions and measures that aims to determine the schedule and the content of the preventive maintenance activities that should be performed to maintain and eventually restore, when is necessary, the technical condition of an asset using the failure mode analysis, safety analysis, operational analysis and criticality analysis.

Reliability centered maintenance is a technique initially developed by commercial airline industry. The fundamental purpose of RCM is to preserve function or operation of a system with a reasonable cost. RCM can be defined as a combination of maintenance strategies in an optimal way in order to reduce the risk in the system, [1].

This type of maintenance involves the replacement of electrical equipment or an ensemble, considering the recommendations of the designer, about its lifetime. RCM has the advantage of reducing maintenance costs and improves safety indicators of the power stations and power system as a whole, but keeps a certain risk of failure for the important equipment such as transformers, circuit breakers, overhead lines, etc., [8].

RCM is a powerful tool for prioritizing the activities of replacement and refurbishment, because the equipment failed state can leads immediately to the question whether it is more economical to do maintenance or equipment should be replaced. This analysis it can be realized for a single equipment, and also for all equipment from a power station of the electricity company, in the case when is considered a combination of various states of the components.

Risk based maintenance represents all the preventive maintenance activities based on a high volume of monitoring, the knowledge of the parameters evolution from the important equipment, the knowledge of the component characteristics and performance of the equipment, the knowledge of the replacement cost of the equipment itself and its components, also the knowledge of the associated costs.

This type of maintenance requires the existence of a database on:

- equipment performance;
- evolution of the operational parameters;
- monitoring and diagnosis of the equipment;
- recording of the events in each important equipment (transformer, circuit breaker, etc.);
- interruption cost in electricity supply in function of the nature of consumers.

4. TENDENCY TO PASS FROM TIME BASED MAINTENANCE TO CONDITION BASED MAINTENANCE TO SWITCHING EQUIPMENT

In the competitive economy of the third millennium the companies are forced to reconsider the strategies and focus over the effectiveness. Electricity supply considered as a business has changed importantly. Company assets should operate on the principle of maximum return on investment.

The research focused on circuit breaker maintenance because the maintenance costs for these equipment represent a large percentage of maintenance budgets; failures adversely affect system reliability and monitoring technologies within substations.

The purpose of maintenance, as generally perceived, is to increase the lifetime of equipment and extend its time between failures, by restoring it to a better condition. This is an important objective, because it would help to increase component and system reliability. Electricity company has the maintenance programs which allow to keep their equipment in good working condition, [2], [8] and [9].

The maintenance programs of HV circuit-breakers have been long performed by using the manufacture guidelines and operator experiences. Nevertheless, this strategy is no optimum in terms of performance and

costs. The costs of these activities can become prohibitive if certain works are not necessary and other works performed improperly affects the technical condition of the electrical equipment. Planned preventive maintenance, according to nowadays norms, applies periodically to all equipment regardless their importance in terms of the damages that would occur due to the lack of electricity supplying for the consumers.

With the appearance of deregulation electricity markets, maintenance costs considered as the large part of operation costs of utilities should be reduced in order to keep their competitiveness. In Fig.3 is presented the weight of the acquisition, maintenance and repair costs of the whole life cycle cost for a high voltage circuit breaker, [10] and [11].

Activities required by the maintenance types, for switching equipment, excepting the corrective maintenance, are performed periodically to predetermined time intervals and/or by the commutations number. Maintenance based on predetermined criteria requires that on each circuit breaker establish the time intervals and specific activities for each inspection (monthly, yearly), extensive inspection (after 1000 operations and 3 years) and revision (after 2000 operations and six years), [10].

In Table 1 is presented a typical maintenance schedule for a 123 kV circuit breaker with SF 6, acting with oleo-pneumatic mechanism, as in [12], and also is presented the availability of equipment during maintenance activities. Routine inspection and maintenance activities usually requires the circuit breaker to be disconnected from power system, which is both costly and time-consuming.

Recent trend in maintenance approaches is to maintain the electrical equipment according to its condition. This could be achieved through passing from time-based preventive maintenance to condition-based maintenance. Monitoring is the first step towards the implementation of the CBM strategy. Monitoring consists basically on acquiring significant parameters from the assets. The collected data allow performing analyses and diagnose of the assets condition, which is of great use as a support to the decision-making

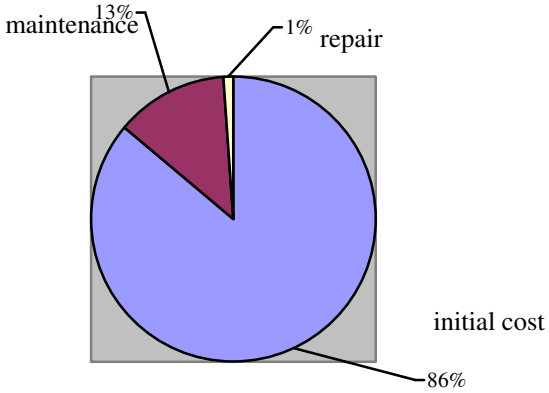

Fig. 3 Operational cost structure of an SF6 HV circuit breaker

maintenance schedule and then, reducing failures and breakdowns.

On-line condition monitoring may be applied in order to improve the reliability of circuit breakers, or to give guidance for condition-based maintenance. It is recommend use of on-line condition monitoring for circuit breakers in the following situations: if the circuit breakers are very important or if the circuit breakers are in the remote substations, where routine inspections are costly and time-consuming.

Maintenance based on condition concerns, [8]:

- collecting a relevant volume of information regarding the actual technical condition of each electric equipment by methods involving as few disassembly, so the fewer stops to operation;
- restoring the reliability and performance potential of the electrical equipment when the information collected about their technical condition indicates the need for some maintaining/restoring work with the aim of preventing faults. Technical condition of the electrical equipment is the result of the exploitation and maintenance activities.

In Fig. 4 is presented a maintenance program based on condition that consists in the following steps:

- data acquisition from sensors (shunt, travel transducer, temperature sensors, SF6 density sensor, current transformers) mounted on the equipment through a monitoring and diagnostic system, to obtain relevant data about the health system.

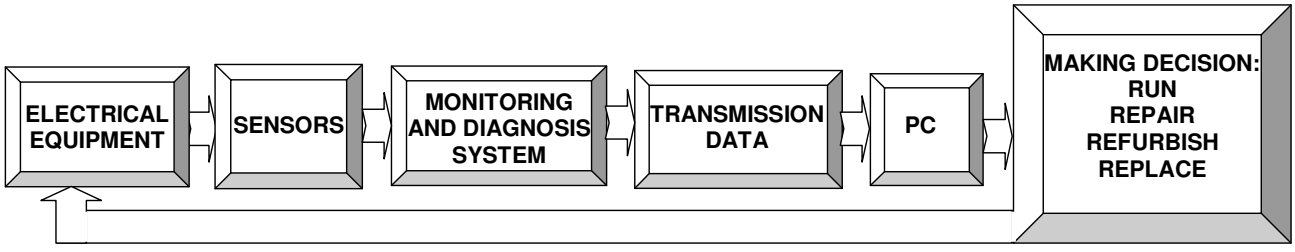

Fig. 4. Maintenance program based on condition

Table. 1 **Typical maintenance schedule for *SF6* HV circuit breaker**

Monthly inspection	Yearly inspection	Extended inspection	Revision	Typical maintenance actions	Availability during maintenance
x	x	x	x	- overall visual inspection;	Yes
x	x	x	x	- notation of the number of open-closing manoeuvres and the interrupted current value;	Yes
	x	x	x	- verification of SF6 pressure;	Yes
x	x	x	x	- state control of coatings (paint, Zn, Cd, etc.) and retouching when it is required;	Yes
Extinguishing chamber					
			x	- disassembly of the extinguishing chamber and visual inspection of contacts, blowing nozzle and cylinder;	Not
			x	- state control of moving rods surfaces and cylinder;	Not
			x	- filters replacement;	Not
Column (support insulator)					
			x	- examination and cleaning the operating insulating rod;	Not
		x	x	- examination, cleaning and lubrication of steel operating rod;	Not
Closing - opening mechanism (hydraulic piston)					
			x	- examination of the operating piston, cylinder, valves and ball limiters;	Not
x	x	x	x	- verification of the oil mechanism losses;	Yes
Oleo-pneumatic operating mechanism (MOP)					
		x	x	- operating at low voltage;	Not
		x	x	- verification of functioning signalling bottlenecks anti-pumping (O-C);	Not
x	x	x	x	- verification of oil losses from the system;	Yes
x	x	x	x	- verification of the tank oil level;	Not
		x	x	- verification of good tightening of connections;	Yes
x	x	x	x	- verification of the number of pump starts;	Yes
x	x	x	x	- verification of the nitrogen pre compression pressure;	Not
	x	x	x	- verification of good operation of heating;	Not
	x	x	x	- coupling control between motor and pump;	Not
		x	x	- engine lubrication;	Not
		x	x	- oil drain, clean and change oil filter ;	Not
		x	x	- verification of valves group and high pressure accumulator;	Not
		x	x	- oil filling;	Not
		x	x	- operation verification of check valve and safety device;	Not
Insulating medium of the electric arc					
			x	- SF6 emptying;	Not
		x	x	- SF6 filling;	Not
		x	x	- verification of gas humidity from circuit breaker;	Not
			x	- verification of working pressure compensated switch pressure;	Not
		x	x	- verification the SF6 losses on the overall circuit breaker;	Not
			x	- verification of SF6 losses in sealing system of driving rod from bottom.	Not

- data transmission to PC (through direct connection, GSM modem, SD card, etc.);

- data processing, with the help of adequate software, through comparison with the results of some similar records, and also with the limits before programmed, to filter and analyze data in order to better understanding and data interpretation;

- making decision about the maintenance activities (run, repair, refurbishment, replacement).

Implementation and operation of a maintenance program based on condition will provide a series of data, which analyzed can reduce the preventive maintenance cost, meaning that it will not be performed at predetermined intervals but at the right time.

The main role of a monitoring and diagnostic system of electrical equipment is to control the main functions of equipment and to compare measured values of certain parameters with prestabilised values, specifics of an equipment in good condition, or with anterior values of the same equipment. This comparison can be done continuous or after each operation in order to detect any possible deviation of parameters which could determinate an incident which could lead to an equipment failure.

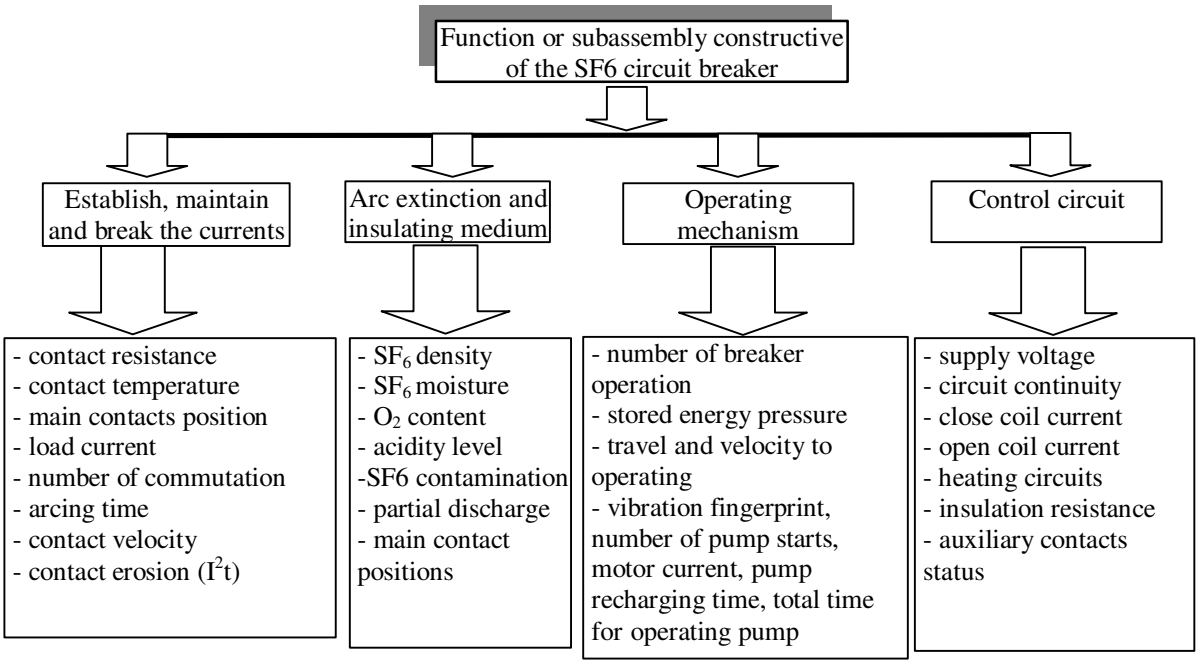

Fig.5 Monitoring parameters for an circuit breaker

The parameters and characteristics to be considered to perform the monitoring and diagnosis of the switching equipment technical condition are discussed on the function or subassembly. The parameters used currently and also the ones produced by the new development of diagnostic techniques are analyzed in terms of utility, known experience and technical and economic feasibility. In Fig. 5 are presented the parameters for monitoring the SF6 circuit breakers, [2], [6] and [10]. Embedding a large number of these parameters, it will allow a more accurate report of the real technical condition of equipment.

In operation of an equipment, it can be followed the value of various parameters and following an analysis, some decisions can be taken to influence the cost, as follows:

- if the system indicates an anomaly that do not present an immediate danger, the necessary measures can be taken for interrupting the power of the affected part to ensure the continuity of supply to consumers, and the action of the part will be made when the cost is minimal;

- if a fault occurs during the operation, the monitoring and diagnostic system allows to change the operating conditions, to limit the consequences and to reduce the fault detection time.

Application the monitoring and diagnostic systems can brings technical and economic benefits to users and manufacturers of the electrical equipment. Thus, by using the monitoring and diagnosis of the circuit breakers, the next benefits are obtained:

- increasing equipment availability;
- reducing failure rate;
- increasing system-operator safety;
- decreasing the lifetime cost;
- opportunities to increase the lifetime;
- improving equipment performance;
- improving maintenance activity.

The system also may have an influence on the cost by extending the time intervals of regular maintenance based on the real technical condition of equipment and it leads to a better use of operating personnel and equipment.

CONCLUSION

The paper presentes the evolution in time of the maintenance strategies, the classification of strategies maintenance by the criterion of fault occurrence and also the current trend through passing from time-based preventive maintenance (especially time criterion) to condition-based maintenance.

The research focused on circuit breaker maintenance because maintenance costs for this equipment represent a large percentage of maintenance budgets; failures adversely affect system reliability and monitoring technologies presently exist within substations.

The maintenance programs of HV circuit-breakers have been long performed by using the manufacture guidelines and operator experiences. Nevertheless, this strategy is no optimum in terms of performance and costs. The costs of these activities can become prohibitive if certain works are not necessary and other works performed improperly affects the technical condition of the electrical equipment.

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