TECHNICAL CONDITION AND THE IMPORTANCE OF ELECTRICAL EQUIPMENT FROM A TRANSFORMER ELECTRIC SUBSTATION ON THEIR MAINTENANCE ORDER

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REZUMAT. Societăţile electrice au un număr mare de echipamente electrice (întrerupătoare, separatoare, transformatoare etc.) care trebuie să fie administrat. Lucrarea prezintă informaţii privind managementul (tipuri şi componente) aparatelor şi echipamentelor electrice, respectiv aspecte privind un sistem de management al acestora. Este prezentat un studiu de caz privind infuenţa stării tehnice şi a importanţei echipamentelor electrice dintr-o staţie electrică de transformare de 400/110 kV asupra ordinii mentenanţei acestora.

Cuvinte cheie: staţie electrică, starea tehnică şi importanţa echipamentelor electrice, management şi mentenenţă

ABSTRACT. The electrical utilities have a lot of electrical equipment (circuit-breakers, separators, transformers, etc.) which must to be managed. The paper presents the information about the management (types and components) of the electrical apparatus and equipment, respective aspects regarding an asset management system. It's made a case study concerning the influence of technical condition and the importance of the electrical equipment from a 400/110 kV transformer electric substation on their maintenance order.

Keywords: electric substation, technical condition and importance of electrical equipment, management and maintenance

1. INTRODUCTION

The production, transport and distribution of the electrical energy regarded as a business has suffered important changes in the last time because of the increasing of wide competition and of the market deregulation for the electrical energy.

The electrical utilities have various electrical equipment (circuit-breakers, separators, transformers etc.) which must to be managed. In this context, for the return on investment maximising is necessary the cost minimisation of the equipment install, exploitation and maintenance and an increasing of the security with the maintaining of a high level reliability of its. The problem's solution is to uses an asset management (AM) system based on information technology (IT) applications.

The asset management, in the case of the physical assets, can be: the means set (methods, disciplines, and procedures) used for the optimising, during all business life, of the cost, of the performance and risk exposition of the business, [1],[2],[3]. Thus, the asset management system allows to be realising equilibrium between costs, risk and availability on the principle of the best value of investment.

2. TYPES AND COMPONENTS OF THE ELECTRICAL EQUIPMENT MANAGEMENT

The management of the electrical equipment can be of two types: tactical, respective strategic management, [4],[5],[6].

The tactical management of the electrical equipment. This is defined through the specific maintenance programs for each type of equipment, programs which generates norms and maintenance. For example, the circuit-breakers have maintenance programs which help to establish the technical state of its, respective of the maintenance activities which must to be done. These programs consists in inspections, on-line and off-line monitoring, diagnostics etc.

The strategic management of the equipment. There are two essential strategies to maintain the performances in the management of the electrical equipment:

- life duration optimisation of the equipment on a long term, respective short term;
- reliability optimisation of the equipment. The optimum level of reliability is established through the minimisation of maintenance activities of the equipment with the maintaining of a required availability, [7].

Specific for a electrical utility is that both types of asset management must be combined to identify all processes which determinate the financial base for the management, operating and maintenance of physical assets from utility, [5].

AM system of an electrical utility should to include the following components, [2],[3],[4]:

- asset register – this can includes from a simple code list of the equipment (e.g. circuit breakers, transformers etc.) from the systems of generation, transport and distribution of electrical power, till a sophisticated technical database: technical specifications, GIS diagrams (Geospatial Information Systems);
- planning and control systems – represents the centre of the work management system and it permits us to realise the opportune operation, in optimal time, with corresponding materials and with responsible departments;
- monitoring and diagnostic – represents an essential AM activity, which help us to realise the electrical equipment operations.

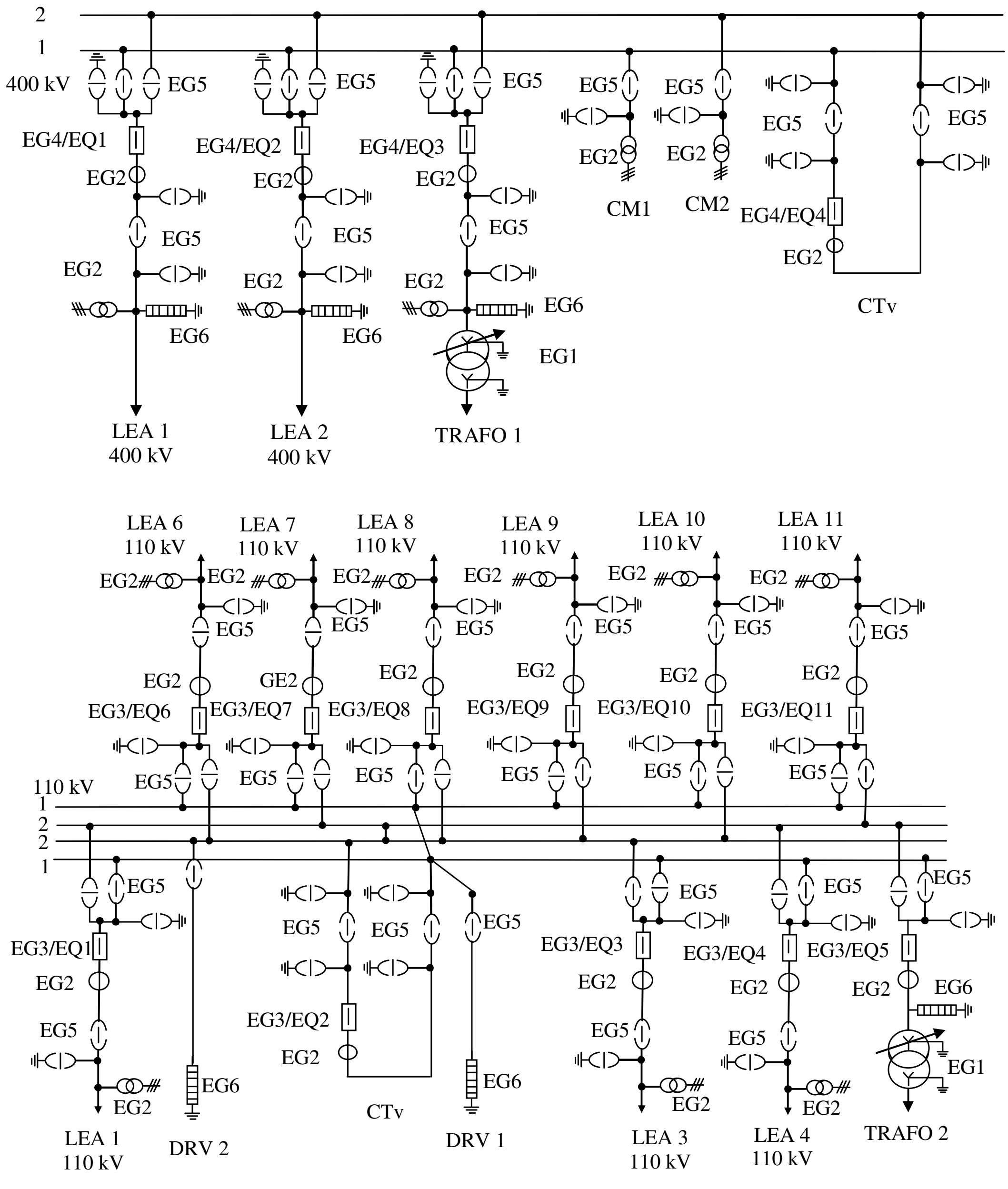

Fig. 1. Electrical equipment groups from a transformer electric substation.

The inspection, the monitoring and diagnostic systems must to lead the maintenance and the decisions of re-technology and renewal. The equipment must to be leaded not only from physical point of view but and financial;

- historical database and in real time-through the creation of some database, the analysing and communication go its allows us an increasing performances and life time of the power system, a decreasing maintenance cost and a methods optimisation for the realising of the maintenance. Without the access at historical database and in real time of the equipment, all the information before presented cannot be realised.

Additional at the before information it can enumerate and the following applications, more important, which deliver dates about assets and which can be used to realise an AM system: supervisory control and data acquisition (SCADA), financial management, resource management, project management etc.

3. MANAGEMENT SYSTEM OF THE ELECTRICAL EQUIPMENT

In [1] and [8] it's presented a management system of the electrical equipment from an electrical substation, Figure 1, which follows to quantify the technical condition of electrical equipment on the base of history and on-line database and also to establish a hierarchy of the maintenance activities.

The stages for implementation of an asset management system are, [1],[2],[8],[9]:

- distribution on subensembles (SE), ensembles (EN), equipment (EQ) and equipment groups (EG) of all assets from a power station (PS); for example the electrical groups from the power station taken as a study are: EG1 - power transformers; EG2 - measuring transformers, EG3- 110 kV circuit breakers, EG4 - 400 kV circuit breakers, EG5 - switchgears, EG6 - surge arresters. The EG3 equipment group consists of 11 high voltage circuit breakers, which are consist of ensembles and subensembles, as follows: EN1 - current path is composed of SE1 - connection terminal, SE2 - mobile contacts, SE3 - fixed contacts, SE4 - conductive parts; EN2 - isolation system that is composed of SE1 - insulation between contacts (insulating oil), ES2 - insulation between phases and ground, ES3 - insulation between phases; EN3 -mechanical mounting system consisting of ES1 - concrete foundation and pole; EN4 - operating mechanism composed of ES1 - energy accumulator element, ES2 - opening and closing electromagnets, ES3 - motor and pump, ES4 - control, signalling and heating circuits;
- failure mechanisms knowledge of the equipment;
- knowledge of the initial state without fault for all equipment and of the whole substation with the aid of some technical condition indexes (*TCI*);
- supervision of the different parameters (e.g. current, pressure, temperature, motion etc.) of the equipment and state diagnose of those;
- generate of the state report for the chosen moment;
- realisation of the electrical equipment repartition from the substation in co-ordinates plan: the importance index (*II*) and the technical condition deterioration index (*TCDI*) for given equipment and at the considered moment;
- establish of maintenance activities order, with the aid of the priority diagrams.

The knowledge of the technical condition deterioration index (*TCDI*) for different subensembles, ensembles, equipment and groups of equipment from power station, suppose, for the beginning, to determinates the importance for each component of the substation. The finding of the importance is done for each level of hierarchy, hierarchy which has been established in the first step of application. Thus, for example, in Table 1 is shown an extract from a card that leads us to determinate the values of the importance for the hierarchic level-circuit-breakers.

To determination of the importance it goes from the criteria that allow to make a difference between the elements of the same hierarchic level, [1]. The importance of the components depends on objective and subjective criteria. Each criterion has associated an evaluation scale and each step of the scale is noted with a number from 1 to 10. The maximum note is given for the most favourable step. Also, for each criterion is attached a certain weight in reference with all criteria.

Once established the value of importance for each component of the hierarchical level it can determinates the values of the technical condition index in initial state without fault and also, at "*t*" given moment.

In Table 2 is shown a part of a card that leads us to determinate the values of the technical condition index for a "*k*" circuit-breaker from group of equipment named – circuit-breakers.

The parameters from Table 2 are on component type and allow to be establishing the evolution of technical condition of equipment going from the initial state, without fault. In this case the technical condition index $TCI_{0(k)}$ having the shape:

$$TCI_{0(k)} = I_{(k)} \cdot 100, \quad [\%]. \tag{1}$$

Table 1

Card for determination of the importance for circuit-breakers (extract)

No.	Criterion	Scale/evaluation factor		Weight	Criterion evaluation of circuit-breakers ($CEV_{(k)}$)			
					1	2	…	n
1	Circuit-breaker type	SF_6	10	1				
		vacuum	10					
		oil	7					
		air blast	3					
2	Cost apparatus	> x euro	10	2				
		⋮	⋮					
		<y euro	1					
3	Damages because of un-operating	> u euro	10	1				
		⋮	⋮					
		<v euro	1					
4	Maintenance costs	> s euro	10	2				
		⋮	⋮					
		<t euro	1					
5	Voltage level	400 kV	10	3				
		220 kV	8					
		110 kV	6					
		20 kV	2					
⋮	⋮	⋮	⋮					
Criterion evaluation: $CEV_{(k)} = ES_j \cdot W_j$ Total evaluation of *k* circuit breaker: $TEV_{cb(k)} = \sum_j CEV_{j(k)}$ where: ES_j is the value of the evaluation scale, W_j is the weight of criterion, *j=1, 2, 3, …* is the number of the criterion and *k=1, 2, 3, …, n* is the circuit breaker number.								
Importance of *k* circuit breaker: $I_{cb(k)} = \frac{TEV_{cb(k)}}{\sum_{i=1}^{n} TEV_{cb(i)}}$ where: *i=1, 2, 3, …, n* is the element number.								

Table 2

Card for determination of the technical condition index for *k* circuit-breaker (extract)

No.	Parameter	Scale/evaluation factor		Weight	Parameter evaluation ($PEV_{j(k)}$)
1	Electroerosion	<50%	10	3	
		50-70%	7		
		71-90%	5		
		91-99%	1		
2	Deviations of the cinematic characteristics	<5%	10	2	
		6%-10%	7		
		11%-20%	5		
		21%-30%	3		
		>30%	1		

Table 2 (continued)

3	Age	<1 year	4	1	
		1-15 years	10		
		16-24 years	7		
		25-30 years	4		
		>30 years	1		
4	Deviations of some monitoring parameters	<5%	10	3	
		⋮			
		>25%	1		
⋮	⋮				
Parameter evaluation: $PEV_{j(k)} = ES_j \cdot W_j$ Technical condition at the moment "*t*": $TC_{t(k)} = \sum_j PEV_{j(k)}$ where: ES_j is the value of the evaluation scale, W_j is the weight of criterion, *j=1, 2, 3, …* is the number of the evaluation parameter and *k=1, 2, 3, …, n* is the circuit breaker number.					
The importance of *k* circuit breaker, $I_{cb(k)}$					
Technical condition index at "*t*": $TCI_{t(k)} = I_{cb(k)} \frac{TC_{t(k)}}{TC_{0(k)}} 100$					

The values of the technical condition indexes in the initial state, without fault help us to realise a state report corresponding to this state. In Figure 2 are presented the values of the technical condition indexes TCI_0 in the initial state without fault for the various equipment, ensembles and subensembles of the electric substation, [8]. The value of the technical condition index for the electric substation is 100%.

The monitoring and diagnostic system allows to know the step of each criterion from the evaluation scale where is placed the equipment at a desired moment and, in this way, it can know the value of the technical condition index at that moment. The values of the technical condition indexes at a given moment going from the base of established hierarchy allows to generates a new state report which takes in consideration all existing problems in the assets of analysed system.

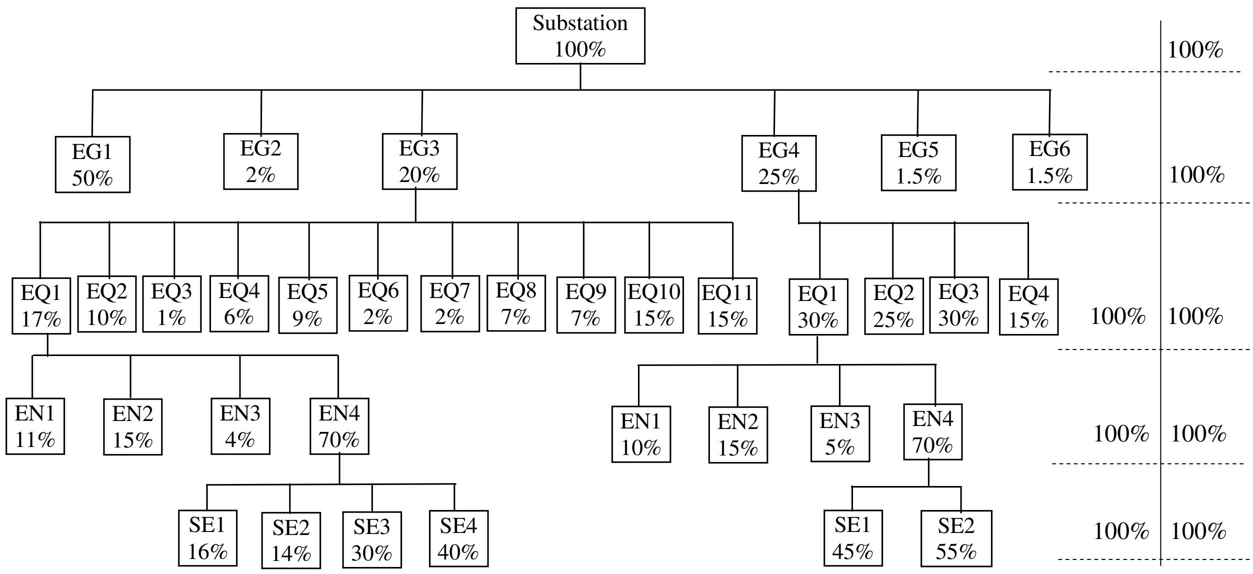

Fig. 2. The values of the technical condition indexes TCI_0 in the initial state without fault.

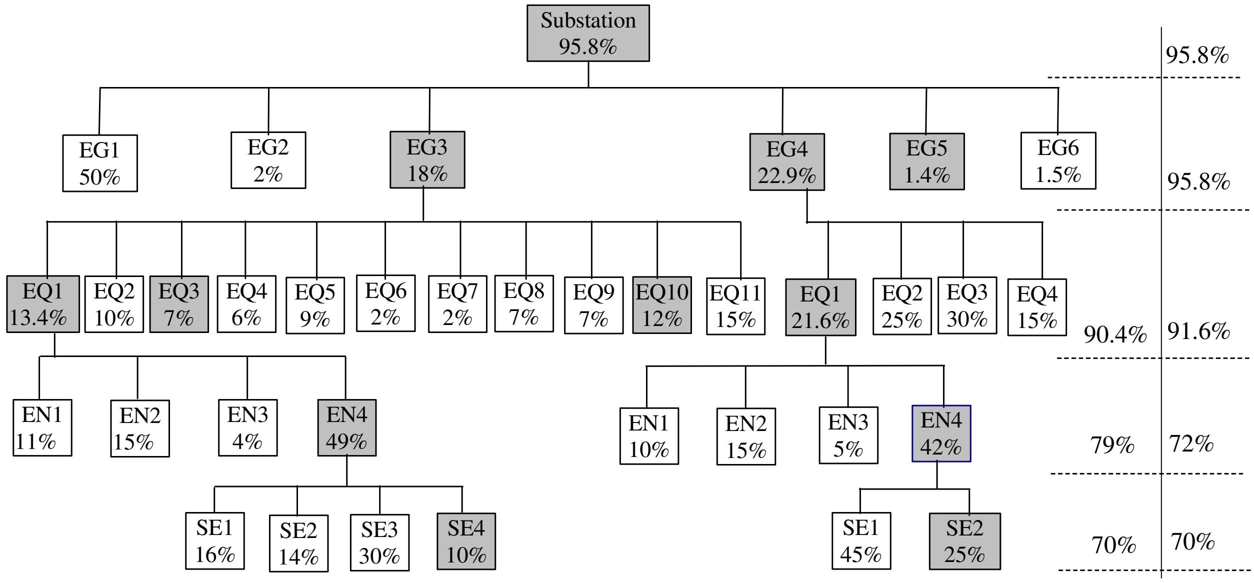

Fig. 3. The values of the technical condition indexes TCI_t for a chosen moment.

In the electric substation taken in the study is recorded a fault in the EQ1 circuit breaker from EG3 to SE4/EN4. Also, it is considered a fault occurs in EQ3 and EQ10 of the same group of equipment. Also, at the 110 kV switchgear from EG5 group of equipment a fault occurs to SE3/EN2. And to the EQ1 circuit breaker of 400 kV from EG4 group of equipment a fault occurs to SE2/EN4.

In Figure 3 are presented the values of the technical condition indexes in the actual state TCI_t with fault for various equipment, ensembles and subensembles of the electric substation. The value of the technical condition index for the substation is now 95.5%.

Both state reports lead to the realisation of the repartition of electrical equipment from substation in the plane of co-ordinates (*II*) and (*TCDI*), for the equipment considered with problems.

The importance index is an indicator that shows the influence which an equipment has of the equipment group where is included, and is calculated with the equation [2],[3],[4],[8]:

$$II_{(EQk)} = I_{(EGj)} \cdot (n \cdot \frac{TCI_{0(EQk)}}{100}), \qquad (2)$$

where: $II_{(EQk)}$ representing the importance index of the "EQk" equipment that are included in "EGj" equipment group, k=1, 2,…n; *n* is the number of the equipment included in "j" equipment group; $TCI_{0(EQk)}$ representing the technical condition index of the "EQk " equipment in the initial state without fault; $I_{(EGj)}$ representing the importance of "EGj" equipment group ($I_{(EGj)}= TCI_{0(EGj)}$) and $TCI_{0(EGj)}$ representing the technical condition index of the "EGj" equipment group in the initial state without fault.

The technical condition deterioration index (*TCDI*) for an equipment at a given moment is calculated with the equation:

$$TCDI_{(EQk)} = (1 - \frac{TCI_{t(EQk)}}{TCI_{0(EQk)}}) \cdot 100, \qquad (3)$$

where: $TCI_{0(EQk)}$, $TCI_{t(EQk)}$ representing the technical condition indexes of the "EQk" equipment of the in initial state without fault, at a "*t*" given moment.

In Table 3 were calculated the importance indexes (*II*) and the technical condition deterioration indexes (*TCDI*) for the equipment considered with fault.

Table 3

The values of the importance indexes (*II*) and of the technical condition deterioration index relative (*TCDI*)

Equipment group / equipment EG_j/EQ_k	*n*	$I_{(EGj)}$ [%]	$TCI_{0(EQk)}$ [%]	$TCI_{t(EQk)}$ [%]	$II_{(EQk)}$ [%]	$TCDI_{(EQk)}$ [%]	*d* ($\alpha=45^0$) [%]
EG3/EQ1	11	20	17	13.4	36.4	21	40.18
EG3/EQ3	11	20	10	7	22	30	36.4
EG3/EQ10	11	20	15	12	33	20	37.1
EG4/EQ1	4	25	30	21.6	30	28	40.6
EG5/EQ1	33	1.5	0.8	0.6	0.39	25	17.77

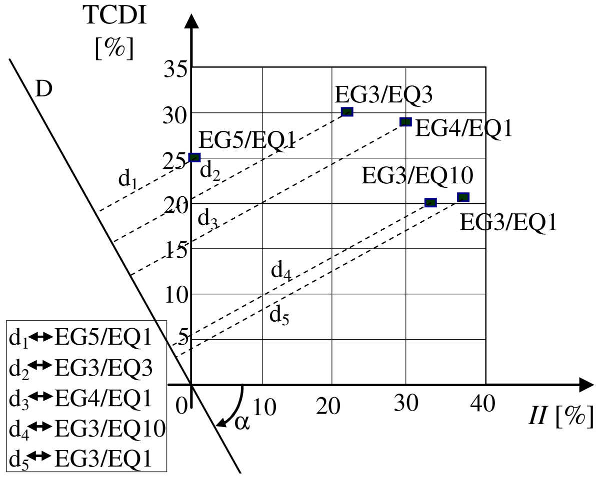

Fig. 4. The repartition of electrical equipment with problems from substation.

In Figure 4 is presented the repartition of electrical equipment from substation in the plane of co-ordinates the importance index (*II*) and the technical condition deterioration index (*TCDI*), for the equipment considered with problems.

4. THE INFLUENCE OF TECHNICAL CONDITION DETERIORATION INDEX AND THE IMPORTANCE INDEX OF THE ELECTRICAL EQUIPMENT ON THEIR MAINTENANCE ORDER

Using the results (numerical values) of the technical condition deterioration index of electrical equipment and its importance index, it can be established an order of maintenance activities which must be scheduled in the near future, at a desired moment.

Considering only the influence of technical condition deterioration index (α=0°) for prioritization of maintenance activities the maintenance order of the electrical equipment with problems is in descending order of *TDCI* values.

Considering only the influence of the importance index (α=90°) for prioritization of maintenance activities the maintenance order of the electrical equipment with problems is in descending order of *II* values.

In practice both criteria (technical condition deterioration index and importance index), are expected to have the influence on the prioritization of maintenance activities. Establishing the order of maintenance activities is performed by comparing the lengths of straight segments d_1, d_2, ... (named vectors of maintenance order). Straight segments are obtained by lowering perpendiculars through points from the plane (*II*, *TCDI*) on axis "*D*". Axis "*D*" is a straight line drawn in only two and four quadrants of the plan mentioned above. The numerical values of straight segments can be calculated analytically using:

$$d_{(EGj/EQk)} = II_{(EQk)} \cdot \sin\alpha + TCDI_{(EQk)} \cdot \cos\alpha, \quad (4)$$

where α is the angle between the axes (*II*) and (*D*).

The electrical equipment which have the segments of straight with biggest lengths will have the priority to maintenance. The angle α has the influence on the lengths of straight segments.

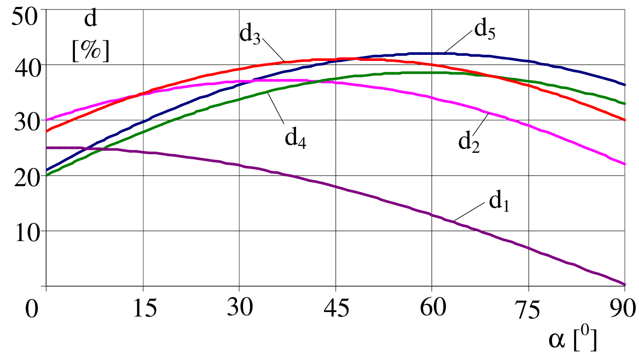

Fig. 5. The evolutions of the lengths of straight segments for the equipment considered with fault from substation.

In Figure 5 are presented the evolutions of the lengths of straight segments depending on the angle α, for the equipment considered with faults.

The degree of influence of technical condition deterioration and importance indexes can be set by the angle α. If the indexes have the same influence on the prioritization of maintenance activities then the angle α must be equal to 45°. The maintenance order of the electrical equipment, in this case, is in descending order of the vectors *d*, Table 3.

In Table 4 are presented the maintenance order of the electrical equipment with faults in according to the angle α. It can observe eight possible orders of maintenance in according to the angle α, thus the first electrical equipment which has priority at maintenance is EG3/EQ3 - for $\alpha \in [0^0, 32^0)$, or EG4/EQ1 - for $\alpha \in [32^0, 48^0)$, respectively EG3/EQ1 - for $\alpha \in [48^0, 90^0]$.

The influence of the indexes of technical condition deterioration and importance makes that the place of electrical equipment on the priority scale of maintenance to be changed. For example, for the equipment EG3/EQ1 taking in consideration the importance indexes of equipment, this equipment from four position (to zero influence of *II*) of five reaches on first position (to maximum influence of *II*). Also, for the equipment EG3/EQ3 taking in consideration the technical condition deterioration indexes of equipment, this equipment from the first position (to maximum influence of *TCDI*) arrived on four position (to zero influence of *TCDI*) of five. When, the degree of influence of indexes is the same ($\alpha=45^0$) it can establish the following order of priorities in the maintenance activities: EG4/EQ1 - the circuit breaker of LEA1, 400 kV; EG3/EQ1 - the circuit breaker of LEA1, 110 kV; EG3/EQ10 - the circuit breaker of LEA 10, 110 kV; EG3/EQ3 - the circuit breaker of LEA 3, 110 kV; EG5/EQ1 - the switchgear of TRAFO 2, 110 kV.

Table 4

The maintenance order of the electrical equipment

	α [^{0}]							
Order of maintenance	[0^0…6^0)	[6^0…9^0)	[9^0…14^0)	[14^0…32^0)	[32^0…42^0)	[42^0…48^0)	[48^0…69^0)	[69^0…90^0]
	d_2	**d_2**	**d_2**	**d_3**	**d_3**	**d_3**	**d_5**	**d_5**
	d_3	d_3	d_3	d_2	d_5	d_5	d_3	d_4
	d_1	d_5	d_5	d_5	d_2	d_4	d_4	d_3
	d_5	d_1	d_4	d_4	d_4	d_2	d_2	d_2
	d_4	d_4	d_1	d_1	d_1	d_1	d_1	d_1

5. CONCLUSIONS

The management of the electrical equipment is a combination between the tactical management based on maintenance programs and strategic management oriented to optimisation of life duration or of their reliability. An asset management system contains more components as: asset register, planning and control systems, monitoring and diagnostic system; historical database etc.

The asset management system allows to be realising equilibrium between costs, risk and availability on the principle of the best value of investment.

The management system of electrical equipment from an electrical substation allows: to quantify the technical state of electrical equipment based on historical database and in real time; the supervision of the state parameters and the generating of an alarm and warning at the pass of the some threshold values; the selection and dates storage; the diagram generating and state reports; the establishing of a hierarchy for maintenance activities of the electrical equipment.

The order of maintenance activities is influenced of the technical condition deterioration indexes and importance indexes of the electrical equipment from substation. The degree of influence of these indexes can be set with the help of the angle α. If the indexes have the same influence on the prioritization of maintenance activities then the angle α must be equal to 45°.

Establishing the order of maintenance activities is performed by comparing the vectors of maintenance order.

Implementing an electrical equipment management system in an electric company, it will be a necessity in the near future because of the AM main activities such as monitoring and diagnosis of the equipment condition, chosen maintenance strategy and the assessment of the risks involved, should find the optimal solution on the assets managed, in real time, for the economical goals pursued by the company, as increasing profitability.

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