RCAM Model for Turkish National Power Transmission System: *SF6 Circuit Breakers, Transmission Lines, Transformer Centers and Protection Relays*

H.Aysun KOKSAL
Department of Electrical Engineering
Istanbul Technical University
Istanbul, Turkey
hakoksal @itu.edu.tr

Aydogan OZDEMIR
Department of Electrical Engineering
Istanbul Technical University
Istanbul, Turkey
ozdemiraydo@itu.edu.tr

Abstract— **The reliability cost-worth conflict brought the necessity of improved management of the maintenance. RCM is continually improved together with proper asset management to meet this necessity. This study proposes an improved RCAM model to achieve cost-effective maintenance strategies for SF_6 circuit breakers, transmission lines, other components of the transformer centers and protection relays in 380 kV Turkish National Transmission System. Markov model of the existing maintenance procedure is constructed. Past outage data and current maintenance procedure details are used to calculate the model parameters. Some appropriate revisions validated by utility staff are made in inspection and test rates of the components. Finally, reliability indices and the costs are determined both for the existing maintenance procedure and for the improved one.**

Keywords- Reliability Centered Maintenance; Asset Manegement; Semi-Markov State Model.

I. INTRODUCTION

System reliability depends on overall system component conditions in addition to their configuration. In a competitive environment, old and unhealthy equipment may cause service interruptions, customer dissatisfaction, and loss of good and may eventually lead loss of customers. Therefore, improved quantitative risk evaluation, including the impacts of the maintenance interruptions and component deterioration process are required for a better decision making.

Reliability centered maintenance (RCM) is the systematic combination of several maintenance activities to achieve cost effective maintenance procedure, which implies a trade-off between corrective and preventive maintenances [1-3]. In conventional RCM scheduling, failure modes resulting in either partial or total loss of functioning of the components are identified, and then an effective maintenance method is realized thereby prioritizing these failure modes. In order to perform the tasks, critical components of the system/subsystem are first determined and prioritized. Then, a decision diagram is constructed to determine the appropriate maintenance action.

RCM experience has provided a basis for reliability centered asset management (RCAM) procedure. RCAM aims developing optimum maintenance processes providing the maximum reliability with minimized component costs [4, 5]. It has evolved throughout the years either removing the inadequacies of conventional RCM method or improving it to cover some additional tasks. Endrenyi and Anders stated that RCM could not compute the effects of projected maintenance programs on the reliability indices and used probabilistic Markov model including component deterioration process to quantify these effects [6].

Siqueira described an approach to optimize the frequency of maintenance tasks determined by RCM tasks [7]. Each RCM task and failure mode was simulated and a standard optimization model was built using a set of quality and productivity indices. Theil proposed a three-stage Markov model for outage and maintenance phases where the degradation process was represented by a chain of wear-out states [8].

Abeygunawardane proposed a new state diagram which represented the maintenance situation in the real world. The classical state diagram and the proposed state diagram were analyzed using Markov methods in a numerical example to compute performance measures [9]. Optimum preventive maintenance intervals were determined using time dependent 3-state Markov model with time-dependent failure rates in [10]. Ghavami and Kezunovic presented a probabilistic model to achieve cost-effective maintenance strategies [11]. They computed several reliability indices by Monte Carlo simulations and then used them to compute the total cost including inspection, maintenance and failure costs. Lindquist and Bertling presented a complete reliability assessment model for circuit breakers and estimated of their hazard rates [12].

Bertling claimed that RCAM was a reasonable method providing numerical measures of inspection or maintenance requirements of the components and suggested the methods for RCAM based cost analysis [13]. An RCAM study using the model constructed from past failure data and maintenance records of circuit breakers were presented in [14]. Tomasevicz and Asgarpoor used continuous-time semi-Markov process and determined optimal maintenance rate providing maximum availability for the equipment. They have later used semi-Markov decision process to determine whether maintenance should be performed at each deterioration state or not [15].

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An improved RCAM model to achieve cost-effective maintenance strategies for power transformers of Turkish National Power Transmission System was presented in [16]. Markov model of the existing maintenance procedure is constructed. Model solutions are then used to compute the reliability of the system and the total system costs.

This study is the continuation of [16] and presents RCAM based maintenance models of SF6 circuit breakers, transmission lines, transformer centers and protection relays in 380 kV Turkish National Power Transmission System. At first, Semi-Markov diagrams of existing maintenance procedures were constructed with respect to technical data provided by Turkish National Power Transmission Company (TEIAS). Model parameters were calculated using the past outage statistics. Then, reliability and cost of the components were improved by changing the controllable test periods. Finally, reliability indices and total costs were evaluated and were compared both for the existing and for the improved model. All the technical and the cost data of the components' and their maintenance procedures were from real applications provided by TEIAS.

II. Construction and Analyzing of RCAM Models of Current Maintenance Procedures

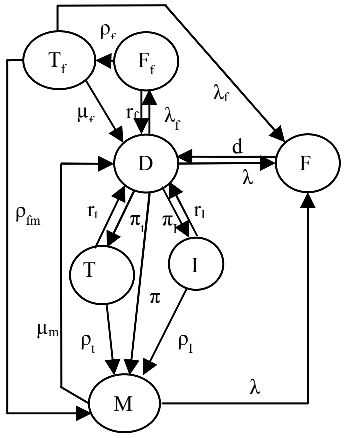
First, transmission system was divided into subsystems and subsystems were divided into main components. A decision-logic was then applied to the components and the resulting weighing coefficients were aggregated to calculate subsystem weighing coefficient those would be used for subsystem prioritizations. The decision table qualifying and quantifying the subsytem/component failures was constructed similar to TABLE's VIII-X in [3]. Consequently, predictive maintenance was found to be the best for SF6 circuit breakers and transformer centers, where the preventive maintenance was found to be the best for transmission lines and protection relays. After having determined the best maintenance policy for the sub-systems, we concentrated on constructing RCAM models and calculating the reliability and the cost of current maintenance procedure.

According to current maintenance procedure of TEIAS, predictive maintenance is performed with respect to periodical inspection and test results; preventive maintenance is applied at certain intervals and finally corrective maintenance is applied to repair failed components. Current maintenance procedures are summarized below.

A. *380 kV Circuit Breakers*

Corrective maintenance is applied following a failure and predictive maintenance is applied with respect to observations and measurements performed at constant time intervals. Those observations and measurements are daily controls with eyes, inspections with thermal cameras and tests with auxiliary equipment. Physical conditions, cleanness, electrical equipment problems etc. can be determined by daily controls. Overheated connections are determined by thermal camera inspections. The tests provide relevant information about the status of the circuit breaker as well as possible incident hazards. In addition to tests and inspections, most of the circuit breakers are equipped with SF6 gas pressure monitoring equipment. They provide real time measurements at certain time intervals. Circuit breakers are subjected to a maintenance procedure whenever the test results and gas pressure exceed specified threshold values.

Markov model of current maintenance tasks is given in Fig. 1. D represents the normal operating state of the breaker. I is the inspection state, F_f is the failure state where the failed breaker is repaired, T is the test state, T_f is the test/maintenance state following some serious failures, M is the predictive maintenance state and F is the final failure state where the circuit breaker is replaced with a new one. M includes the maintenance of leakproofness, insulation, contacts, electrical assets and connections, cleaning and similar maintenance activities.



λ_f: failure rate,
λ: deterioration rate,
π_t: test rate,
r_t: test return rate,
π_I: inspection rate,
r_I: inspection return rate,
π_w: warning rate,
ρ_t: periodic test-intensive maintenance transition rate,
ρ_I: periodic inspection-maintenance rate,
$1/\rho_f$: average maintenance duration following a random failure,
r_f: random failure return rate,
μ_m: repair rate following an intensive maintenance,
$1/\mu_f$: average test duration following a random failure,
$1/\mu_I$: average repair duration following an inspection,
$1/\rho_{fm}$: average maintenance duration following a random failure test
λ_m: deterioration rate determined by periodic test-maintenance process
λ_{ff}: deterioration rate determined by post-failure tests
d: replacement rate.

Fig. 1. Markov diagram representing the current maintenance tasks of 380 kV SF_6 circuit breakers.

Note that, in addition to periodical tests and maintenance tasks during its normal operational life, circuit breakers are subjected to similar tests and maintenance process following severe chance failures (state T_f). These tests and maintenances are for the verification of circuit breakers performance following a failure.

λ, μ, π, ρ, r and d are the transition rates between the states described above. λ is the deterioration rate identified from the expected lifetime of the circuit breaker. Inspection and test rates are utility defined parameters, where the remaining rates are determined from past operational data of the breakers. TABLE I illustrates the model parameters.

TABLE I. TRANSITION RATES OF THE CIRCUIT BREAKER MODEL

Parameter	Value (1/yr)
λ	1/12
d	360
π_I	12
π_t	1/3
λ_f	0,6
ρ_f	1200x0,4
r_f	1200x0,6
ρ_{fm}	360x0,4
μ_f	360x0,5
λ_{ff}	360x0,1
ρ_t	360x0,3
r_t	360x0,7
ρ_I	360x0,05
r_I	360x0,95
λ_m	360x0,4
μ_m	360x0,6
π_w	½

B. 380 kV Transmission Lines

Transmission lines are subjected to preventive maintenance procedure with respect to observations and measurements at constant intervals. Failures in transmission lines are perceived by distance relays. Transient failures are eliminated by reclosure type circuit breakers. Transmission lines are subjected to intensive maintenance and tests following some severe failures. All components of the transmission lines, such as poles, isolators, cables, connections etc. are inspected and controlled with eyes, thermal camera and other auxiliary equipment.

Markov Model of current maintenance procedure is illustrated in Fig. 2. D is the normal operating state, I is the inspection state, F_f is the failure state where the failed transmission line is repaired, M_f is the maintenance state following some severe failures, and M is the preventive maintenance state. F is the failure state due to deterioration and at least one part of the transmission line should be replaced with a new one. Maintenance requirements are determined by inspections. Note that, in addition to periodical maintenance tasks during its operational life, transmission lines are also subjected to similar maintenance processes following some severe failures. These tasks are represented by state M_f. Transition rates between the states are similar to those illustrated in Fig. 1. They are calculated from the data provided by TEIAS and are illustrated in TABLE II.

C. Transformer Centers

All the remaining components besides the power transformers, circuit breakers and protection relays are grouped and referred as transformer centers. They include measurement transformers, disconnectors, surge arresters, reactors, busbars etc. These components are subjected to corrective maintenance following a failure and are subjected to predictive maintenance with respect to inspections, observations and measurements at constant intervals. Similar tests are also applied following a severe failure. Markov Model of current maintenance tasks is given in Fig. 3. The states and the transition rates between the states are similar to previous ones. Their values are illustrated in TABLE III.

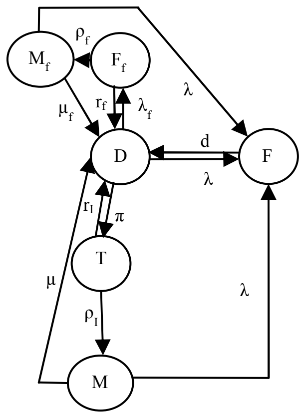
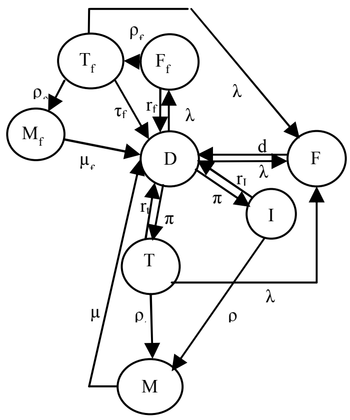


Fig. 2. Markov diagram representing the current maintenance tasks of 380 kV transmission lines

TABLE II. TRANSITION RATES OF THE TRANSMISSION LINE MODEL

Parameter	Value (1/yr)
λ	1/20
d	60
π_I	4
ρ_I	360x0,1
r_I	360x0,9
λ_f	8
ρ_f	1200x0,3
r_f	1200x0,7
λ_m	360x0,2
μ	360x0,8
λ_{ff}	360x0,2
μ_f	360x0,8



$1/\rho_{ft}$: average maintenance duration following a random failure test rate
τ_f: test return rate

Fig. 3. Markov diagram representing the current maintenance tasks of transformer centers.

TABLE III. TRANSITION RATES OF THE TRANSFORMER CENTER MODEL

Parameter	Value (1/yr)
λ	1/50
d	2,67
π_I	12
π_t	1/3
λ_f	8
ρ_f	1200x0,2
r_f	1200x0,8
ρ_I	360x0,05
r_I	360x0,95
ρ_{ft}	360x0,2
λ_{ff}	360x0,1
τ_f	360x0,7
μ	360
ρ_t	360x0,2
r_t	360x0,7
λ_t	360x0,1
μ_f	360

D. Protection Relays

Preventive maintenance is applied with respect to tests at constant intervals. However, they are not subjected to any post failure tests and intensive maintenance program. Model of current maintenance tasks is illustrated in Fig. 4. Model parameters derived from past data are given in TABLE IV.

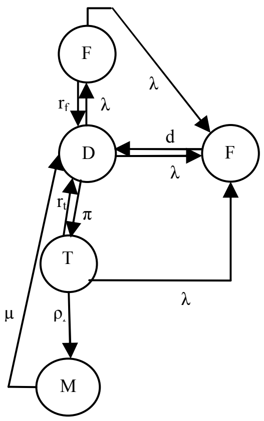


Fig. 4. Markov diagram representing the current maintenance tasks of protection relays.

TABLE IV. TRANSITION RATES OF THE PROTECTION RELAY MODEL

Parameter	Value (1/yr)
λ	1/20
d	720
π_t	1/2
λ_f	6
ρ_t	360x0,3
r_t	360x0,6
λ_t	360x0,1
μ	360
r_f	1200x0,8
λ_{ff}	1200x0,2

III. COST ANALYSIS

The second step of the study is devoted to cost analysis. Total cost of an item includes the maintenance and the failure costs. Maintenance cost is the cost of all maintenance tasks, tests, intensive maintenances and inspections. Failure cost includes the repair costs, post-failure maintenance costs, replacement costs, and interruption cost.

Maintenance cost is formulated as

$$C_m = k_t d_t + k_m d_m + k_I d_I \ USD/yr \tag{1}$$

where;

k_t is the test cost (USD/day),
d_t is the test duration (day/yr),
k_m is the intensive maintenance cost (USD/day),
d_m is the intensive maintenance duration (day/yr),
k_I is the inspection cost (USD/day),
d_I is the inspection duration (day/yr),

Failure cost is formulated as;

$$C_f = c_t + k_{ff} d_{ff} + k_f d_f + k_{mf} d_{mf} + L_a * CCD * d_{ff} * 24 \ \ USD/yr \tag{2}$$

where;

c_t is the annual cost of repairable parts,
k_{ff} is the repair cost (USD/day),
d_{ff} is the repair or interruption duration (day/yr),
k_f is the replacement cost (USD/yr),
d_f is the replacement duration (day/yr),
k_{mf} is post-failure maintenance and test cost,
d_{mf} is the post-failure maintenance and test duration,
L_a is the load shedding (kW),
CCD is Composite Customer Damage (the cost of provided energy to customer) (USD/kWh).

Cost parameters are given in TABLE V for circuit breakers, transmission lines, other transformer center components and protection relays.

TABLE V. COST PARAMETERS OF THE COMPONENTS

Parameter	Cost (x1000 $)			
	C.Breaker	***Tr.Line***	***Trf.center***	***P.Relay***
k_i	0.26	0.84	0.26	0.53
k_m	0.53	1.05	0.53	0.53
k_t	0.26		0.26	
k_f	0.26	0.63	0.53	0.53
k_{ff}	0.26	0.63	0.53	0.42
k_{tf}	0.26	0.63	0.26	
k_{mf}		0.79	0.58	
c_t	5.26	100.00	42.10	10,00
CCD	0.05	0.05	0.05	0.05

IV. IMPROVED MAINTENANCE PROCEDURES

The aim of this study is to achieve maximum reliability with minimum cost by improving the maintenance strategy of the components. At this first stage, some appropriate revisions are made in inspection and test rates. Basic motivation behind this idea was the uncertainty about the scientific and technical validation of those rates. All the revision ideas were discussed with TEIAS staff and their recommendations were taken into consideration.

The procedure was conducted at three steps. At first, existing test and inspection rates were increased in accordance with TEIAS staff's recommendations. It was clear that the improved test and inspection conditions would affect the other transition rates. Therefore, some of the remaining transition rates were revised according to expectations. Finally, total costs and the reliability indices (unavailability, failure frequency, and outage duration) were evaluated for the new set of parameters. The trade-off between increasing test and maintenance costs and reliability improvements were used to determine the optimal parameters. Note that, there were no transition rate records for those improved test and inspection rates. Computations were performed for expected variations, which should be validated by operational results in the future.

A. 380 kV Circuit Breakers

Circuit breakers test period is decreased to two years. It is expected that the failure rate and some other parameters will be improved due to this revisions. Existing and revised parameters are shown in TABLE VI together with corresponding reliability indices and the cost values. Note that unavailability, failure frequency, average outage duration per year and costs are represented by U, f, m and C, respectively. According to TABLE VI, this revision may improve the unavailability, average failure duration and total costs up to 2.8%, 3.5%, and 16.1 %, respectively.

TABLE VI. RESULTS FOR CIRCUIT BREAKERS

π_t	λ_f	ρ_f/r_f	ρ_t/r_t	U	f (1/yr)	m (day/yr)	C (x1000 USD/yr)	
							C_f	C_m
1/3	0.6	0.4/0.6	0.3/0.7	0.0071	2.03	2.57	26.00	3.59
1/2	0.54 (-10%)	0.36/0,64 (-10%)	0.27/0.73 (-10%)	0.0075	2.14	2.69	23.91	3.63
		0.32/ 0.68 (-20%)	0.24/0.76 (-20%)	0.0073	2.14	2.63	23.90	3.62
		0.24/0.76 (-40%)	0.18/0.82 (-40%)	0.0070	2.14	2.52	23.89	3.60
	0,48 (-20%)	0.36/ 0,64 (-10%)	0.27/0.73 (-10%)	0.0073	2.08	2.64	21.83	3.63
		0.32/0.68 (-20%)	0.24/0.76 (-20%)	0.0072	2.08	2.58	21.82	3.62
		0.24/0.76 (-40%)	0.18/0.82 (-40%)	0.0069	2.08	2.48	21.81	3.60

B. 380 kV Transmission Lines

Inspection rate and some dependent parameters are revised similarly. They are illustrated in TABLE VII with the reliability indices and the costs. It is clear that this revision improves the unavailability, failure frequency, average failure durations and failure cost by 38.7%, 19.6%, 38.5% and 12.2%, respectively.

C. Transformer Centers

Similarly, the revisions and the resulting values are illustrated in TABLE VIII for transformer centers. According to TABLE VIII, this revision decreases the unavailability, failure frequency, average failure durations and failure cost up to 31.6%, 13.2%, 31.6% and 12.0%, respectively.

TABLE VII. RESULTS FOR TRANSMISSION LINES

π_I	λ_f	ρ_f/r_f	ρ_I/r_I	U	f (1/yr)	m (day/yr)	C (x1000 USD/yr)	
							Cf	*Cm*
4	8	0.3/0.7	0.1/0.9	0.0238	8.16	8.55	251.88	3.66
5	7.2 (-10%)	0.27/0.73 (-10%)	0.09/0.91 (-10%)	0.0207	7.44	7.46	236.50	4.52
		0.24/0.76 (-20%)	0.08/0.92 (-20%)	0.0192	7.40	6.91	236.35	4.48
		0.18/0.82 (-40%)	0.06/0.94 (-40%)	0.0161	7.33	5.79	236.06	4.39
	6.4 (-20%)	0.27/0.73 (-10%)	0.09/0.91 (-10%)	0.0188	6.68	6.79	221.62	4.53
		0.24/0.76 (-20%)	0.08/0.92 (-20%)	0.0174	6.64	6.28	221.47	4.49
		0.18/0.82 (-40%)	0.06/0.94 (-40%)	0.0146	6.56	5.26	221.17	4.40

D. Protection Relays

Similarly, the revisions and the resulting values are illustrated in TABLE IX for protection relays. The revisions decrease the unavailability, failure frequency, average failure durations and failure cost up to 3.53%, 10.63%, 3.58% and 16.58%, respectively.

TABLE VIII. RESULTS FOR TRANSFORMER CENTERS

π_I	λ_f	ρ_f/r_f	$\rho_t/r_t/\lambda_t$	U	f (1/yr)	m (day/yr)	C (x1000 USD/yr)	
							Cf	*Cm*
1/3	8	0.2/0.8	0.2/0.7/0.1	0.0992	7.81	35.71	86.47	3.14
1/2	7.2 (-10%)	0.18/0.82 (-10%)	0.18/0.72/0.1 (-10%)	0.0913	7.32	32.88	82.53	3.21
		0.16/0.84 (-20%)	0.16/0.74/0.1 (-20%)	0.0852	7.37	30.67	81.56	3.23
		0.12/0.88 (-40%)	0.12/0.78/0.1 (-40%)	0.0727	7.47	26.16	79.59	3.26
	6.4 (-20%)	0.18/0.82 (-10%)	0.18/0.72/0.1 (-10%)	0.0847	6.66	30.48	78.79	3.24
		0.16/0.84 (-20%)	0.16/0.74/0.1 (-20%)	0.0791	6.70	28.49	77.90	3.25
		0.12/0.88 (-40%)	0.12/0.78/0.1 (-40%)	0.0679	6.78	24.44	76.10	3.28

TABLE IX. RESULTS FOR PROTECTION RELAYS

π_t	λ_f	λ_{ff}/r_f	$\rho_t/r_t/\lambda_t$	U	f (1/yr)	m (day/yr)	C (x1000 USD/yr)	
							Cf	*Cm*
1/2	6	0.2/0.8	0.3/0.6/0.1	0.0085	6.49	3.07	56.19	0.34
1	5.4 (-10%)	0.18/0.82 (-10%)	0.27/0.63/0.1 (-10%)	0.0095	6.39	3.42	51.51	0.66
		0.16/0.84 (-20%)	0.24/0.66/0.1 (-20%)	0.0093	6.39	3.34	51.49	0.65
		0.12/0.88 (-40%)	0.18/0.72/0.1 (-40%)	0.0088	6.39	3.17	51.45	0.62
	4.8 (-20%)	0.18/0.82 (-10%)	0.27/0.63/0.1 (-10%)	0.0089	5.80	3.19	46.92	0.66
		0.16/0.84 (-20%)	0.24/0.66/0.1 (-20%)	0.0086	5.80	3.11	46.91	0.65
		0.12/0.88 (-40%)	0.18/0.72/0.1 (-40%)	0.0082	5.80	2.96	46.87	0.62

The followings can easily be derived from Tables VI-IX.

- Decreasing test periods can improve the reliability of circuit breakers and protection relays if at least 15% of decreases are provided in the other transitions rates. However, it is more effective on total costs.

- Decreasing inspection/test periods improves both the reliability and the cost of transmission lines and transformer centers. Even small improvement of transition rates is effective on the results.

V. CONCLUSIONS

This study has presented RCAM based maintenance model for some components of 380 kV Turkish National Power Transmission System; namely, SF6 circuit breakers, transmission lines, transformer centers and protection relays. It is the continuation of RCAM of power transformers study presented in [16]. Technical and cost data of the components' and their maintenance procedures were provided by TEIAS.

First Semi-Markov state diagram of the current maintenance procedure is constructed for the components with respect to the information obtained from TEIAS. Then, model parameters were calculated using the past outage statistics. An improved maintenance procedure was derived by slight revisions in appropriate transition rates. Finally, reliability indices and the costs were evaluated both for the existing and for the improved model and the results are compared.

The results have shown that the reliability indices and cost could be improved by changing controllable maintenance parameters. However, there are still some questions regarding the new statistical parameters after the revision of inspection and test rates. Therefore, this study can be assumed as the initial phase of RCAM procedure for the system and will continue in the future to include the uncertainties because of the change in the statistics of parameters.

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REFERENCES

[1] Li, Wenyuan, "Risk Assessment of Power Systems Models, Methods and Applications", John Wiley & Sons, Inc., Publication, 2005.

[2] Bertling, L., "On Evaluation of RCM for Maintenance Management of Electric Power Systems", IEEE, 2005.

[3] Ozdemir,A., Kuldaşlı,E.D., "RCM Application for Turkish National Transmission System", 11'th lntemational Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Singapore, June 14-17, 2010.

[4] Lindquist,T.M., Hilber,P., Bertling,L., Eriksson,R., "Reliability Centered Asset Maintenance", IEEE Power Engineering Society General Meeting, IEEE, 2003.

[5] Zhang,X., Zhang,J., Gockenbach,E., "RCAM for MV Deteriorating Electrical Equipment Based on Germany Failure Statistics", IEEE Transactions on Power Systems, 2009, pp. 721-728.

[6] Endrenyi,J., Anders,G.J., Silva,L., "Probabilistic Evaluation of the effect of Maintenance on Reliability. An Application", IEEE Transactions on Power Systems, pp.576-583, 1998 .

[7] Siqueira, I.P., "Optimum Reliability-Centered Maintenance Task Frequencies for Power System Equipments", 8' lntemational Conference on Probabilistic Methods Applied to Power Systems, Iowa State University, Ames, Iowa, September 12-16,2004.

[8] Theil, G., "Parameter Evaluation for Extended Markov Models Applied to Condition and RCM Maintenance Plannin Strategies", 9th International Conference on Probabilistic Methods Applied to Power Systems KTH, Stockholm, Sweden - June 11-15, 2006

[9] Abeygunawardane,S.K., Jirutitijaroen, J., "A Realistic Maintenance Model Based on a New State Diagram", 11'th lntemational Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Singapore, June 14-17, 2010.

[10] Moon, J.F., Yoon, Y., "Reliability-Centered Maintenance Model to Managing Power System Equipment", Power Engineering Society General Meeting, IEEE, 2006.

[11] Ghavami, M, Kezunoviç, M., "Probabilistic Evaluation of The Effect of Maintenance Parameters on Reliability and Cost", 11'th lntemational Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Singapore, June 14-17, 2010.

[12] Lindquist, T.M., Bertling, L., "Circuit Breaker Failure Data and Reliability Modelling", IET Gener. Transm. Distrib., 2008, Vol. 2, No. 6, pp. 813–820.

[13] Bertling, L., "On Evaluation of RCM for Maintenance Management of Electric Power Systems", IEEE, 2005.

[14] Lindquist, T.M., Bertling, L., "A Feasibility Study for Probabilistic Modeling of Aging in Circuit Breakers for Maintenance Optimization", IEEE, 2004.

[15] Tomasevics, C., Asgarpoor, S., "Optimum Maintenance Policy Using Semi-Markov Decision Processes", 38th North American Power Symposium, 17-19 September 2006, pp.23-28.

[16] Ozdemir, A., Koksal, H.A., "Construction and Evaluation of RCAM Model for Power Transformers in Turkish National Power Transmission System", 12'Th lntemational Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Istanbul, June 10-14, 2012, pp.689-694.

[17] www.teias.gov.tr WEB site of Turkish National Power Transmission Company