MAINTENANCE OPTIMIZATION OF EQUIPMENT POWER DISTRIBUTION SYSTEMS USING LIFE CYCLE COST ANALYSIS

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ABSTRACT. *Economic pressures, the rapid evolution of technology and rapid population growth make it imperative to maximize asset reliability at the optimum cost. Life-cycle cost analysis begins with the design and selection of new or replacement assets. Procurement takes place only after the initial stages (asset strategy, plan, evaluate and design) are completed. This is followed by the cost of operating, maintaining and sometimes modifying the asset before its eventual disposal. This paper presents brief history and a state of the art study of Life Cycle Cost Analysis (LCCA), in particular LCC analysis in Power Distribution Systems, based on a detailed literature assessment and interviews with experts. Life cycle costs Analysis (LCCA) are support to serious costs summarized as an economic model of evaluating alternatives for equipment's and projects. A main objective of the LCC analysis is to quantify the total cost of ownership of a system throughout its full life cycle, which includes research and development, construction, operation and maintenance, and disposal. LCC calculates the total cost for Power Distribution System during its lifetime. The total cost includes planning, operation, equipment's purchase, and maintenance and power cut. The predicted LCC is useful information for decision in optimizing design, in scheduling maintenance, or in planning revamping.*
  In this article we present a LCC procedure consisting of six steps, which are "Problems definition in introduction", "System modelling", "Cost elements definition", "Data collection", "Cost profile development", and "Evaluation".

KEYWORDS: *Optimization, Asset Management, Modelling, Power Distribution Systems, life cycle cost Analysis model LCCA.*

1. Introduction

The analysis of life cycle costs (LCCA) is a method to estimate the total cost of ownership of electrical networks. It takes into account all costs of acquisition, possession, maintenance, operation, and to have a management model to optimize the maintenance of electrical equipment. (LCCA) is especially useful when project alternatives that fulfil the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings [1], [2].
The Asset management is the systematic and coordinated activities and practices to optimally manage their assets, and their associated performance, risks and expenditures over their life cycle attaining their organizational strategic plan [3, 4]. However, utility's portfolio comprise of a very large and diversified group of assets resulting in difficulty to manage their assets systematically. Therefore, effective asset management is inevitable to the utility from both financial and technical aspects. in this study, the electrical line, power transformer and circuit breaker are selected because they are regarded as those of the critical and expensive asset in power system operation. This is because sudden failures may cause disruption in power supply resulting in higher costs, revenue losses, environmental and collateral damage. This leads to significant investment each year [5, 6]. For example the Transformer works in a more humid area and operated at peak load affects the hot spot temperature of transformer as a result of reducing insulation life [7]. Moreover, life cycle management of power transformer, electrical line and the circuit breaker becomes more important due to economic and engineering values. So, the decisions become infeasible from the financial perspective. Consequently, the assets have not been fully utilized over their life cycle. In this context, this paper is aimed to provide alternative methodology, comprising both a financial and a knowledge based model, for an assessment of effective life cycle of the power transformer, the electrical line and the circuit breaker in order to maximize their use during its life cycle. This paper has mainly focused on the financial model. This methodology can systematically assess the life cycle of the power transformer, electrical line and

the circuit breaker satisfying both the financial and engineering requirements with the utilization of hidden knowledge [8, 9, 10].

2. Methodology for the life cycle cost analysis model, LCCA

The methodology for the life cycle model used in this study followed the international standards, ISO 14040, ISO 14041, and ISO 14042 methods (ISO, 1997; ISO, 22 1998; ISO, 2000).[11] The complete integrated (LCA-LCCA) model framework, including modules which make up the model, the project execution flowchart is shown in Figure 1. The initial step was model development were all identifiable cost elements are addressed and existing models in literature were incorporated into single more detailed (LCCA) model.[12] A case study was conducted to test model functionality and result is compared with the base system. After successful result has been achieved, the software development stage began using MS Excel. The developed Excel model is based on the cost elements developed in the analytical models retrieved from literature. And now they often use probability and statistics software's such as bridgeLCC20, LCC-lmtd, Minitab 15, ReliSoft ….. that have proved useful in this area. The life cycle modelling of electrical system represents a unique analytical technique for assessing reliability indicators, including the total availability of electricity through end of life management. Life cycle cost analysis (LCCA) is the conscious use of engineering process technology to increase system performance and reduce costs as far as possible, while satisfying, and often exceeding, customer requirements.

LCC requires designing both the product and the product delivery process (i.e., the asset's constructability and maintainability) for simplicity [12]. In this research, life cycle modelling refers to both life cycle assessment (LCA) and life cycle cost analysis (LCCA). (LCA) evaluates the potential environmental impacts of a system at each life cycle stage. (LCA) provides metrics that can be used to measure progress toward power electrical grid sustainability. Life cycle cost analysis is a complementary framework to life cycle assessment. The project execution flow chart is proposed and shown in Figure1.
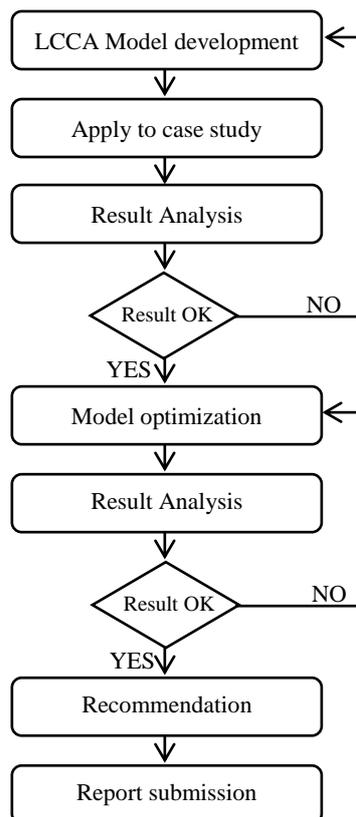

Fig. 1 analytical models of LCCA

2.1. Maintenance cost

The power distribution systems in the region of RELIZANE northwest of ALGERIA spend around 15.10^5 DA on maintenance per year including all components overhead costs of maintenance, out of which 38% is spent on power transformer maintenance, 31% on electrical line maintenance, 20% on circuit breaker maintenance, 10% on bus bar maintenance and 1% on switch maintenance. If one recognises that maintenance is essentially the management of failure then it is clear that this expenditure is primarily the result of poor quality and unreliability. However, since it is impossible to produce a system which will never fail if operated for long enough, we must consider ways in which the costs of maintenance can be kept to a minimum whilst ensuring system. We have already seen that there are many factors which can affect the costs of maintaining a system. Whilst the original design will be a major influencing factor on these costs, the operators and maintainers of the system can, nonetheless, do much to minimize the cost of ownership by adopting the most suitable maintenance policies for the conditions prevailing reliability, availability, safety and integrity. [13, 16-19]

2.2. Cost of maintenance task

The cost of the maintenance task is the cost associated with each corrective or preventive task, whether time-based or condition-based. The expected corrective maintenance cost is the total cost of maintenance resources needed to repair or replace failed items. Similarly, the expected preventive maintenance cost is the total cost of maintenance resources needed to inspect and/or examine an item before failure takes place and to replace any items rejected. Thus, the total maintenance cost throughout the life of systems/product is the sum of the corrective and preventive maintenance costs and the overhead costs, which consist of all costs other than direct material, labour and system equipment. [13, 16-19] The LCC of maintenance task can be divided into two categories:

2.1.1. Direct cost of maintenance task

The direct cost associated with each maintenance task, DCM, is related to the cost of maintenance resources, CMR of power distribution system. This is the cost of the maintenance resources directly used during the execution of the maintenance task, which is proposed as follows:

$$DCM = Cm + Cf + Cs + Cu + Cp + Cd \qquad (1)$$

Where:
Cm= cost of material, Cf = cost of facilities, Cs = cost of spare parts, Cu = unavailability cost, Cp = cost of personnel, and Cd = cost of technical data.

2.1.2. Indirect cost of maintenance task

Indirect costs (ICM) includes both management and administration staff needed for the successful completion of the task and the cost of the consequences of not having the system available which is related to a complete or partial loss of production. It also includes the overhead costs, i.e. salaries of employees, air conditioning, insurance, taxes, telephone, IT, training and similar which are incurred while the item is in state of failure (and, of course, not included in the direct costs). These costs should not be neglected, because they could be even higher than the other elements cost.

The cost of production loss, CLP, is directly proportional to the product ,the length of the time which the system spends in the state of failure (down time) and the hourly rate income, IHR (α), which is the money, the system would earn whilst in operation. Thus, the cost of production loss could be determined through the following expression:

$$ICM = \alpha.CLP \qquad (2)$$

2.1.3. Total cost of maintenance task

The total cost of maintenance task LCC is the sum cost of direct and indirect costs, thus:

$$LCC = DCM + ICM \tag{3}$$

2.3. Life cycle cost analysis LCCA for all equipment of power distribution network

In general, the LCCA model uses those following inputs typical of those generated by the functional departments such as (research and development, production and construction, operation and maintenance, retirement and disposal). By pressing the discount rate, the assumption can be made based on the cost estimates and relevant to the problem at hand. The discount rate refers to the rate of change of true value of money over time, considering fluctuations in both investment interest rates and the rate of inflation. Individual cost projections for each alternative must be discounted to the present value. LCCA is determined using the basic multi-year discounting formula as follows:

$$PV = \left(\frac{1}{1+r}\right)^n . C \tag{4}$$

Where,
PV = present value at time zero (base year), r = discount rate n= (number of year), C = the present value of one outlay

Then, The Life cycle costs analysis LCCA of maintenance is the sum of the costs for each year LCC is calculated and multiplied with the present value factor PV. This gives the present value for the sum of costs LCC, PV*LCC for each year which then is summarized over the years into the total sum of present value for the cost LCC, PV*LCC.

$$LCCA = LCC + \sum_{i=1}^{n} PV_i * LCC_i \tag{5}$$

2.3.1. Life cycle cost of transformers

For distribution transformers, often bought in large batches, the process is undertaken once every few years. This yields an optimum transformer design, which is then retained for several years less so nowadays because of the volatility of metal prices until energy prices and load profiles have changed significantly. There are many different models, which have been developed for determining the cost life cycle analysis (LCCA) of transformers. In this paper, the proposed model is:

$$\boldsymbol{LCCA = LCC + \sum_{i=1}^{n} PV_i * LCC_i + [CA * P_0 + CB * P_C]} \tag{6}$$

Where:
CA = represents the assigned cost of no load losses per watt; Po = the rated no load loss; CB = the assigned cost of load losses per watt; Pc = the rated load loss.

Po and Pc are transformer rated losses. CA and CB values depend on the expected loading of the transformer and energy prices. The choice of the factors CA and CB is difficult since they depend on the expected loading of the transformer, which is often unknown, and energy prices, that are volatile, as well as interest rate and the anticipated economic lifetime. If the load grows over time, the growth rate must be known or estimated and the applicable energy price over the lifetime must be forecast [14, 16-19]. Typically, the value of CA ranges from less than 10 to 500 DA / Watt and CB is between 5 and 300 DA / Watt.

The method used to determine the factors of CA and CB for distribution transformers is as follows:
No load loss capitalisation

$$CA = \frac{(1+i)^n - 1}{i.(1+i)^n} . C. 8760 \tag{7}$$

Load loss capitalisation

$$CB = CA. \left(\frac{I_l}{I_r}\right)^2 \tag{8}$$

Where:
i = interest rate [%/year]; n = life time [years]; C = kWh price [EUR/kWh]; 8760 = number of hours in a year [h/year]; Il = loading current [A]; Ir = rated current [A].

3. Case studies: application to the power distribution systems

In order to illustrate our view in this work, we will give a general description of the electrical distribution station located in the region of RELIZANE northwest of ALGERIA. The suggested alternative for the Power Distribution Systems can be schematized as follows (Fig. 2):
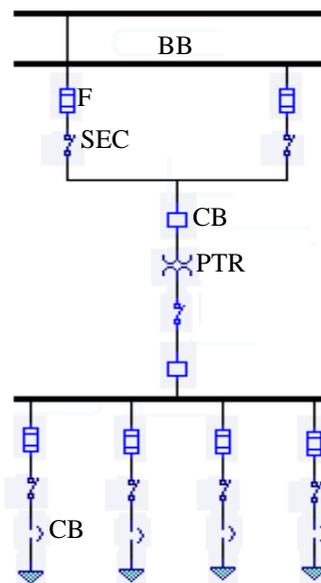

Fig. 2 Standard diagram of the EFS structure

Where:
1. Electrical Line (EL); 2. Circuit breaker (CB);
3. Bus bar (BB); 4. Power Transformer (PTR); Fuse (F);
5. Sectionalizer (SW). EFS: Electric Feeder System

3.1. Classification of failures and estimated replacement cost for major components

The failures of the various elements are at the base of the failures of the EFS, however the reliability of the complex systems as the EFS depend primarily on their structure of the type of connection of the elements and the dependability of operation of the elements. It is known that from elements of no high level of reliability, the design of the reliable system can be obtained on the basis of optimal redundant structure, however in no case we can expect to assure a great effectiveness of these systems   . In order to locate the weak link of the EFS and its elements, we should highlight the best means of improvement of their reliability and to determine the source data to ensure the requirements for the reliability of these systems, the first stage to be realized at the time of the study of the reliability of the EFS is the determination and the analysis the reliability of the various elements of these systems. [15, 16-19] The information collected on a sample of several power distribution system, located in the north west of Algeria allowed us to represent the cost curve and distribution of the failures of the various elements of these EFS, Table 1,   the denominator is indicated the distribution of the failures in per cent and estimated replacement cost for major equipment's of the EFS in the north west of ALGERIA.

Table1
Classification of failures and estimated replacement cost for major components of the EFS in the north west of ALGERIA

Electric components	Number of analyzed Failures	Number of failures of elements		Costs (DA / 3years)
Transmission Lines (EL)	143	Electric drivers	11/7.7	218500
		insulators	132/92.3	
Transformers (PTR)	96	insulators	53/55.2	745000
		terminals	31/32.3	
		switch	12/12.5	
Circuit breakers of line (CB)	105	Insulators	27/25.7	141400
		control drive	58/55.3	
		system of drive	21/19.0	
Bus bars (BB)	39	Contact with apparatuses	39/100	68500

DA: Algerian dinars

The average time of repair of the elements of the EFS is estimated by the following relation:

$$Tr = \frac{1}{n}\sum_1^n Ti \tag{9}$$

$$\mu = \frac{1}{Tr} \tag{10}$$

Where:
Ti: duration of repair after appearance of failure, μ: rate of repair.
The failure rate and the average repair time of the elements of the EFS determined with a probability of confidence α = 0.95 are represented on the Table 2.

Table 2
Data of reliability of the elements of the EFS in north of ALGERIA between 2007 and 2010

Elements of EFS	high voltage (KV)	Failure rate (1/year)			Average time of repair(h)
		λ min	λ	λ max	
Electric lines on100km	30	1.80	2.50	3.37	12
	60	1.20	2.20	3.12	5.6
Transformers	30	0.012	0.023	0.038	70
	60	0.009	0.018	0.030	90
Circuit breaker of line	30	0.003	0.005	0.007	10
	60	0.002	0.005	0.012	10
Bus bars	30	0.003	0.010	0.020	4
	60	0.16	0.030	0.062	4

3.2. Results and discussion

The determination of the LCCA results before and after the adoption and implementation of a preventive maintenance plan and implementation of an optimization model for all components of the electrical distribution system. And after calculating the present value of all charges and determination of factors CA and CB for the power transformer, the search result can be presented in the following figures.

3.2.1. Calculation of the present value

The present value is a summary of all the charges and cost resulting in a fixed period of time reduces for example the first years of installation. The following data are used for determining results of optimization:
    Interest rate 6.8%
    Inflation rate 1, 5 %
    Useful lives ranging from 10 to 30 years depending   on each component
    Costs of failure and maintenance costs are used in Table1
    Calculation time 15 years

3.2.2. Determination of factors CA

For the power transformer, this case illustrates that, for a price of electricity 4179 DA / MWh, an interest rate of 7% and a funding period of 15 years, the cost of the loss will be 330.877 DA / Watt, deduced from Figure 3 below.
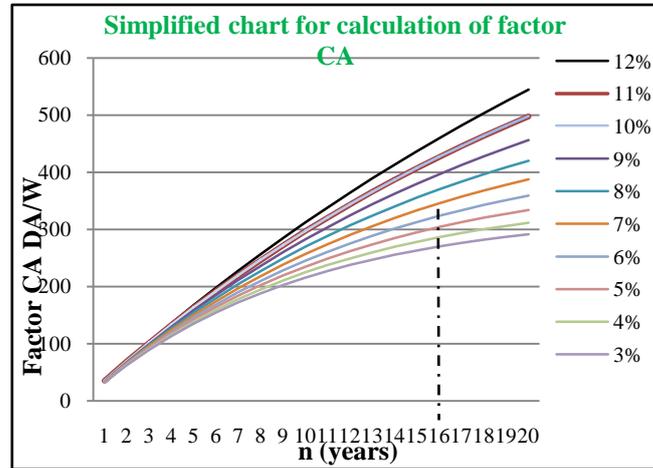

Fig3. Simplified chart for calculation of factor A

3.2.3. LCCA *of equipment before optimisation*

Figures 4, 5 and 6, we show the evolution and distribution of charges for the equipment of the power distribution system and the percentage of the cost of maintenance taken by each element before adoption and implementation of an optimized maintenance plan. So we see clearly that the majority of maintenance costs are taken by the power transformer and power lines. Moreover, an improved life cycle cost of materials of electricity distribution network is an essential task for the reliability, availability and safety of the electrical system.
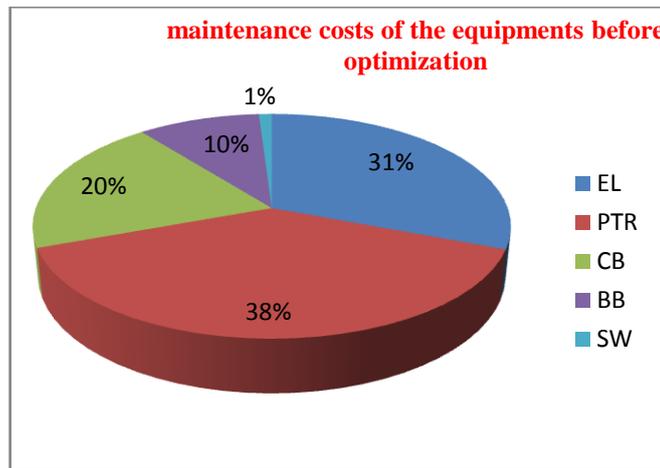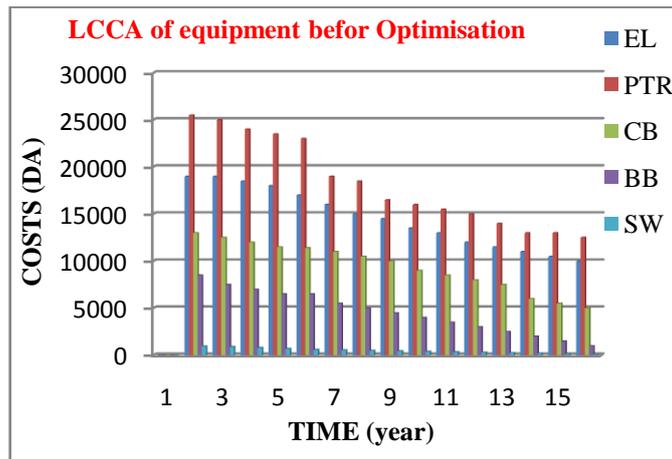

Fig4. LCCA of equipment befor Optimisation

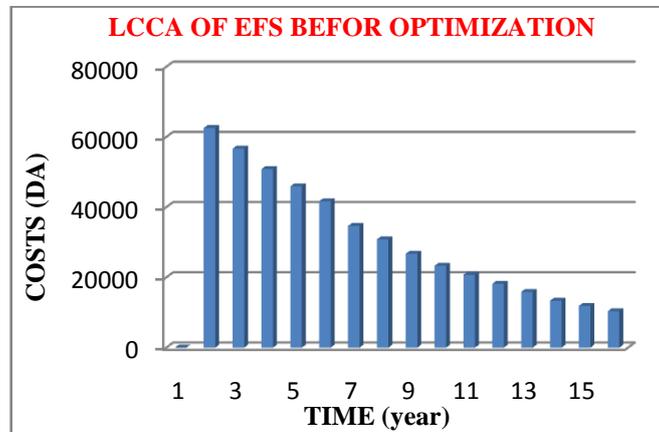**Fig5. Maintenance costs of the equipment before optimization**

Fig6. LCCA of the EFS before optimization

3.2.4. *LCCA of equipment after optimisation*

After the adoption and implementation of an optimized maintenance plan, we could achieve this result interesting, which is shown at Figures 6, 7 and 8 below. This figure shows the impact of the introduction of the LCCA model on the optimization of maintenance costs, compared to the previous state of the electrical distribution system.
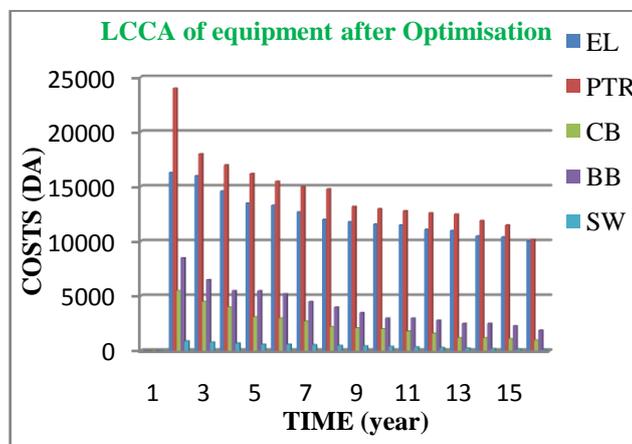
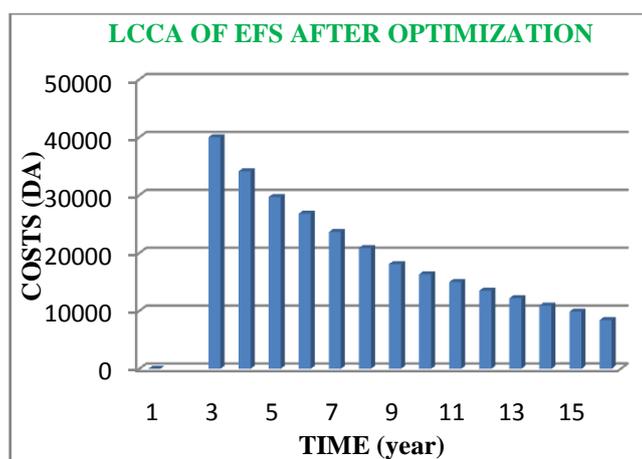**Fig7. LCCA of equipment after Optimisation**

Fig8. LCCA of EFS after Optimisation

And therefore, we step on the optimization of maintenance to increase reliability and reduce cost. The difference is summarized in the following table.

Table 3
Reduction of equipment costs

Electric components	Reduction costs (%)
Transmission Lines (EL)	8.48 - 14.73
Transformers(PTR)	15.65 - 21.45
Circuit breakers of line (CB)	6.32 - 10.65
Bus bars(BB)	2.35 - 9.45
Sectionalizer (SW)	7.65 - 12.69

Moreover, as in the case of further examination, it becomes clear that the present value of the electrical line and the power transformer have the most influence on the current value of the entire network (68%). They must be specified for a remote maintenance continued and therefore their costs are not taken into account in calculating the present value because the inside of the station power transformer provides the largest quota, while other components have a minor influence on the result.

4. conclusion

This paper demonstrates a systematic methodology using the LCCA model to quantitatively determine the savings that can be achieved by keeping the power transformers, power line and the circuit breaker in service longer than current practice. Finally it can be summarized, that the Life-Cycle-Cost Analysis is a useful instrument to identify the main cost drivers of an electrical network and to take up there appropriate actions of maintenance, to increase availability and reduce the costs. Because it is possible to examine the present value of each component these set screws still can be refined. The calculation of the outage costs plays a crucial part, if the system operator intends to change the maintenance strategy. The final recommendation for the particular case studied here was to delay replacement by 15 years for power transformer, 12 years for circuit breaker and 10 years for electrical line. This was considered to be a judicious choice since the loss of life and hot spot temperature for all equipment's both start to increase exponentially and the 'savings' curve starts to flatten out.

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