ASSET MANAGEMENT INTO PRACTICE: A CASE STUDY OF A BRAZILIAN ELECTRICAL ENERGY UTILITY

J. C. M. Lúcio, J. L. T. Nuñez and R. C. G. Teive, Member, IEEE

Abstract **- Asset Management (AM) is one of the most important activities in the scope of the electric sector companies for allowing good readiness asset permanence, thus reducing risks of eventual failures. Literature distinguishes AM strategic character, as well as the need to define it as a multi criteria problem, also considering aspects concerning difficult quantification, such as those related to the environment. This study presents results of the application of a methodology for power transformer life cycle management with basis on the Fuzzy Logic and the Multi Criteria Decision Aim.**

Index Terms **- Asset Management, Maintenance, Power Transformers, Fuzzy Logic, Multi Criteria Decision Aim.**

I. INTRODUCTION

IN a deregulated environment, electrical utilities are under constant pressure for reducing operating costs, enhancing the equipment availability and improving service power and quality for customers. Electrical energy transmission utilities, particularly in Brazil, have to maintain high asset availability not only due to deregulation processes, but also to high demand growth, economic pressures, and profit constraints.

With regards to profit constraints, the Brazilian Electricity Regulatory Agency – ANEEL set forth the Normative Resolution 270/07, which defined economic penalties for lack of availability of transmission function (TF) assets.

As a result, transmission utilities are currently quite interested in improving maintenance policies as well as developing new techniques to estimate equipment conditions, considering mainly those having TF in the electrical system.

In relation to equipment that performs TF, power transformer is the most important since its management has gained remarkable recognition, involving technical and economic aspects. Its reliability and performance are still of great importance to these utilities.

In such a context it is necessary to develop methodologies to simulate transformer life cycle management strategies, which become increasingly important as transformer average age increases.

The evaluation of transformer condition influence on company performance and maintenance strategies is also important. In some cases residual life can be extended and maximum return on the investment can be achieved.

A well planned maintenance strategy can maximize a transformer's availability, resulting in capital investment minimization. Therefore, it is necessary to evaluate maintenance policies, associating technical aspects like reliability with costs and risks by utilizing the asset management philosophy.

Asset Management is a business philosophy designed to align corporate goals with asset-level spending decisions [1]. This study proposes a decision supporting system based on the asset management theory for simulating the performance of transmission equipment (in this case a power transformer), taking into account different maintenance strategies, costs, risk analysis and reliability indexes.

II. ASSET MANAGEMENT

AM may be defined as the process of maximizing equipment investment return by maximizing performance and minimizing cost over the entire equipment life cycle[2].

Typically, utilities adopt AM approach to either reduce expenses, manage risks more effectively, or drive corporate objectives throughout an organization [3]. Formerly, decisions related to asset utilization were mainly based on technical performance. However, in the last few years the ratio between technical performance and expenses became a relevant parameter in the decision process.

Currently it is also important to look at the effect asset utilization has on its environment [4]. Thus, AM is considered the art of balancing cost, performance and risk.

The social impact of a utility maintenance policy can be determined by a subjective factor, such as public image. The type of maintenance adopted by the company defines the failure profile (duration and frequency) and consequently the utility´s image. Thus, the maintenance policy has to be aligned to the corporate and strategic goals.

Figure 1 depicts the decision making process according to an asset management point of view. It is possible to observe some aspects usually considered in this approach, such as: equipment condition assessment, reliability management and risk analysis, taking into account the data and information flow from the component level up to the corporate level.

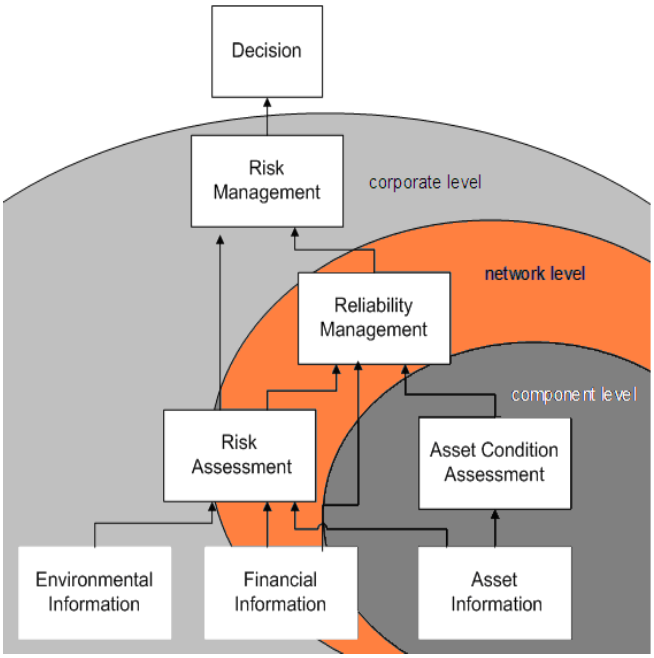

Fig. 1. Decision Making Process in an AM Approach.
Source: Cigre WG 23/19-14, 2002.

AM also provides an acceptable life time before a failure can occur or a criticality ranking among a group of transformer can be established [5].

Currently the transformer's residual life assesses which run-refurnish-replacement decision can be taken, playing a vital role for investment decision and failure planning of the entire power transmission system. A rational balance between risk and investment in aging assets has to be maintained [6].

III. PROPOSED MODEL

The model developed allows maintenance strategies simulation, taking into account both an ad-hoc approach based on technical and economic evaluation, as well as an asset management approach. It also considers corporate and strategic goals and asset utilization effect on its environment. Figure 2 shows the global view of this system, involving the implementation of the main aspects according to the asset management philosophy.

The whole model shown in Figure 2 will be described in detail in the following sections.

A. Technical Aspects

The maintenance strategies are modeled by using a Four-States Markov Chain, considering three deterioration stages and one terminal failure stage. The transformer aging is modeled by a decreasing exponential function. This model allows the simulation of several kinds of maintenance strategies, including different maintenance intervals, time for replacement and equipment maintenance operation up to failure.

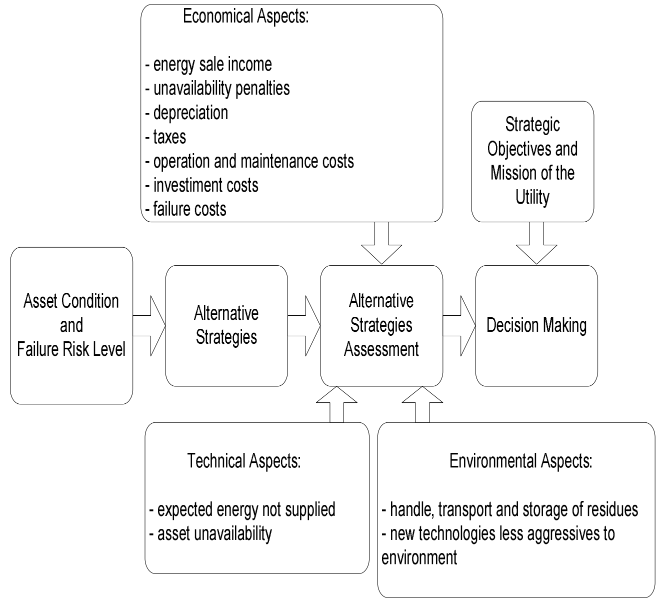

Fig. 2. Proposed model for the AM.

The equipment operation simulation is performed by Monte Carlo, associated with First Passage Times (FPT) concept [7], which defines the time needed to achieve final stage in Markov Chain, for the first time from an initial stage.

The FPT also allows inference as to the equipment's expected residual life time and curve, since the time span in each Markov Chain stage (aging process) is exponential with constant transition rates.

The model proposed in this study for simulating the equipment operation as well as the maintenance policies, involving the implementation of Markov Chains, Monte Carlo Simulation and FPT is based on [8].

B. Economical Aspects

The present value of the net cash flow method (PVNC) is used in this study for taking into account the economical aspects associated with the equipment life cycle.

The formulation of this method is presented in Frame I, calculated on a monthly basis. With regards to electrical energy transmission service, the income associated with the electrical energy sales must take into account the predicted penalties due to the lack of TF asset availability.

C. Environmental Aspects

The environment performance of the strategies is evaluated qualitatively by the following aspects: 1) waste toxicity generated for maintenance; 2) risk to handle, transport and store such wastes; 3) maintenance activity frequency; 4) use of new technologies less harmful to the environment.

FRAME I
PVNC FORMULATION

+ income with the electric energy sale
- unavailability penalty
- taxes on invoicing
= operational income

+ operational income
- operational costs
= monthly profit of the business management

+ monthly profit of the business management
- depreciation
= operational profit

+ operational profit
- income tax and social contribution
= net profit

+ net profit
+ depreciation
= operational net cash flow

+ operational net cash flow
- investment cost
= present value of the net cash flow

D. Equipment Condition Evaluation

The equipment condition is estimated by applying the Rogers method [9], combined with the Doernenburg method [10] and with the boundary values for the normal operation defined in [11] and [12], by means of an expert fuzzy system developed in Fuzzy Clips. The aim of this system is to detect incipient failures by dissolved gas-in-oil chromatography analysis. The failure diagnosis, involving thermal or electrical failure, depends on the number of relationships between gases and their thresholds.

E. Risk Level of Ultimate Failure Evaluation

The risk level of ultimate failure is defined from the expected time to failure, which is calculated by means of FPT theory and from the financial prejudices caused for this failure. The financial prejudices are determined by using the Net Present Value (NPV) of the failure cost, taking into account aspects such as: non supplied energy, acquisition of new equipments, severe injuries to people and environmental impacts. Afterwards, maintenance strategies can be simulated under these aspects.

The risk level of ultimate failure, which is classified as Very Low, Low, Tolerable, Big or Very Big, is obtained from the same expert fuzzy system which makes equipment diagnosis.

F. Strategies Evaluation and Decision Making Process

For the strategies evaluation and decision making, two approaches are adopted. The first being a mono criteria approach based only on the present value of the net cash flow method (PVNC) as described in sub-section B. The second, a multi criteria approach based on Fuzzy Logic and on fuzzy causal map inference process. This formulation is presented in [14].

The fuzzy causal map aim is to evaluate qualitatively the effect of each strategy on the fulfillment of the utility mission, considering technical, economical and environmental aspects. The causal inference process was also implemented by using an expert fuzzy system.

In this qualitative evaluation, every performance of strategy on each aspect of analysis is represented as an attribute-concept in the causal map. In the same way, the effect of each aspect on the fulfillment of the utility mission is represented as an end-concept, passing through intermediate concepts. These are characterized as fuzzy variables and evaluated by using the linguistic terms Very Weak (Vw), Weak (W), Moderate (M), Strong (S) and Very Strong (Vs), each term represented by a membership function, as shown in Figure 3.

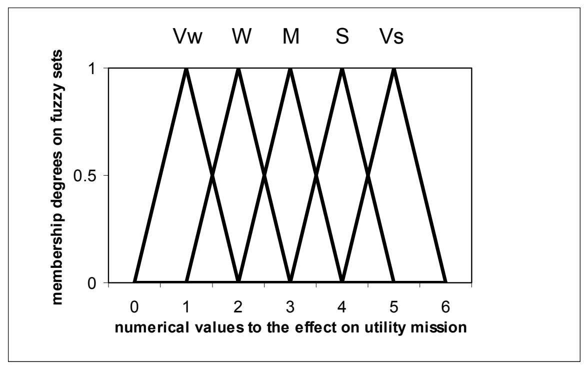

Fig. 3. Membership functions to the effect on utility mission.

Figure 9, shown in the Appendix, presents the fuzzy causal map used for the multi criteria evaluation. The highlighted concepts represent the attributes to be considered in the strategies evaluation (attribute-concepts) and are separated per area (economical, technical and environmental).

In order to compare and rank alternative strategies, the effects on the utility mission, initially evaluated qualitatively, are converted into numerical variables by defuzzifying the original linguistic variable. In this fuzzy inference process, the used membership functions are depicted in Figure 3. In this case, a value equal to 3 for instance, represents a Moderate effect on the utility mission. Similarly, a value equal to 1, a Very Weak effect. When it is a non-integer value, it means the effect evaluation on the utility mission is blurred (uncertain) thus belonging to more than one fuzzy set.

Finally, the multi criteria evaluation is performed based on the Pareto Optimal or Non-dominated solution concept [15], searching for the trade-off solution involving the evaluated strategies.

IV. A CASE STUDY

A. Initial Remarks

The proposed methodology was applied to the analysis of several alternative strategies for the management of a power transformer life cycle, 600 MVA, 525/230/13.8 kV during a one year operation span.

B. Incipient Failure Diagnosis and Ultimate Failure Risk Level Evaluation

For equipment condition evaluation, the following sample of gases were used: hydrogen (16 ppm), methane (5 ppm), acetylene (5 ppm), ethylene (2 ppm), ethane (2 ppm), carbon monoxide (121 ppm), carbon dioxide (749 ppm).

The gases analysis showed an operation without failure and the risk level of ultimate failure was evaluated as Very Low, having defined an expected time to failure of being approximately 35 years, with a profit of R$ 239,637.48, in present value with a 10% discount rate.

With basis on these results, the following alternative strategies for action were defined:

FRAME II
ALTERNATIVE STRATEGIES

Alternative Strategy 1 (traditionally adopted for the utility)
-Inspection every 3 months.
-Preventive maintenance every 6 years.
-Substitution of the equipment after the ultimate failure.

Alternative Strategy 2
-Inspection every 3 months.
-Preventive maintenance every 8 years.
-Substitution of the equipment after the ultimate failure.

C. Evaluation of the Strategies

Initially in Table I and Figure 4, the technical performances of the alternative strategies are presented.

TABLE I
TECHNICAL PERFORMANCES OF THE STRATEGIES

	Strategy 1	Strategy 2
Unavaliability (h/year)	67,25	62,28
Expected Not Supplied Energy (MWh/year)	36.987,83	34.255,21

Strategy 2 presents the best technical performance as shown in Figure 4. However, the mono criteria approach pointed to slightly different PVNC values in both strategies, as shown in Table II and so decision making becomes difficult.

TABLE II
ALTERNATIVE STRATEGY PVNC

	Strategy 1	Strategy 2
PVNC (R$)	50.150.068,59	50.180.283,74

Considering the multi criteria approach the best performance for strategy 2 was observed. Results are shown in Table III and Figure 5.

TABLE III
MULTICRITERIA RESULTS

Valuation Area	Strategy 1	Strategy 2
Technical	Strong (0.3) Very Strong (0.7)	Strong (0.3) Very Strong (0.7)
Economical	Strong (1.0)	Strong (0.2) Very Strong (0.8)
Environmental	Strong (1.0)	Very Strong (1.0)

The values in parenthesis in Table III represent the membership degrees, with which the utility mission effect is compatible with each fuzzy set presented in Figure 3.

The results presented reveal uncertainties associated with the cause-effect relationship intensity judgments, involving some concepts of the causal fuzzy map of Figure 9.

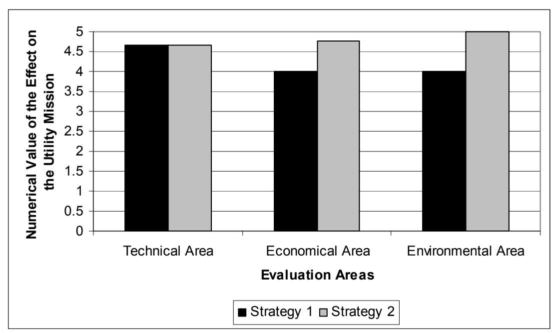

Fig. 5 – Numerical values of the effects on the utility mission.

The numerical values shown in Figure 5, obtained by means of performance defuzzyfication, initially obtained qualitatively are used in the multi criteria analyses of the alternatives, using the Non-dominated solution concept.

In this case, the dominance of strategy 2 over strategy 1 is observed. That means strategy 2 presents the best performance for utility mission fulfillment in the economical and environmental areas. Having had similar performance as strategy 1, in relation to the technical area, it suggests then, that for the analyzed equipment, the increase of the maintenance regularity is the trade-off solution.

Figures 6, 7 and 8, present the effect of defuzzyfication of strategy 2 on the utility mission, for each evaluation area, based on the causal inference results presented in Table III.

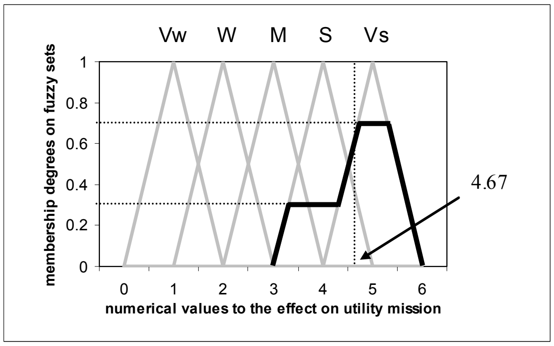

Fig. 6. Defuzzyfication of the effect on utility mission considering the technical area.

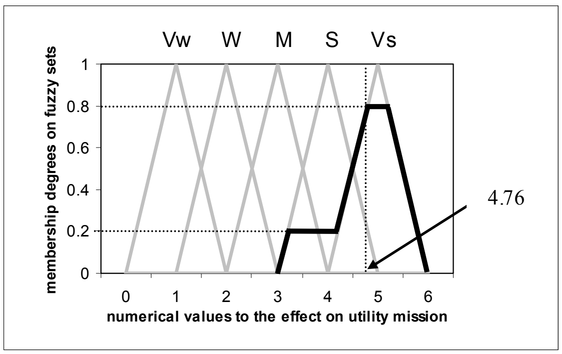

Fig. 7. Defuzzyfication of the effect on utility mission considering the economical area.

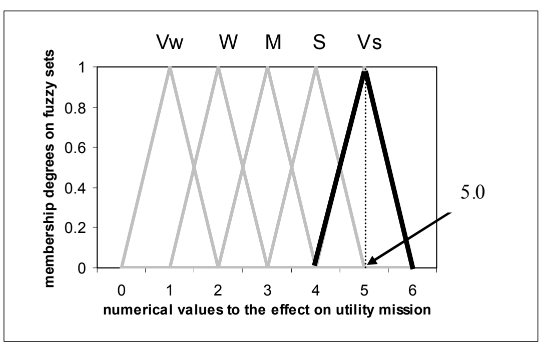

Fig. 8 – Defuzzyfication of the effect on utility mission considering the environmental area.

These figures reveal that a numerical value equal to 5 represents the maximization of the effect on utility mission, i.e. Very Strong effect, as in strategy 2, with regards to the environmental area. On the other hand, non integer values, as presented for this strategy in the technical and economical areas, reflect decision makers' judgement uncertainties, as shown in the fuzzy map in Figure 9. The effect on utility mission is evaluated qualitatively by two linguistic terms, with different membership degrees.

The numerical values obtained with the defuzzyfication procedure are used for forming a ranking of strategies, avoiding the indifference situations that can occur with the qualitative evaluation.

V. FINAL REMARKS

The Asset Management problem in the electric sector is characterized by the existence of evaluation conflicting objectives. In this case the need to define the importance of such objectives in the evaluation of alternative solutions seems rather evident.

The proposed methodology allows technical, economical and environmental aspects to be considered, without the need to aggregate these aspects into a mathematical function.

The hierarchical structure of causal maps permits the association of the evaluation aspects with the fulfillment of the utility mission. The transformation of this map into a fuzzy map allows the preferences of the decision makers to be expressed qualitatively.

Finally, it can be observed in the case study presented, that the multi criteria evaluation allows the comparison of alternative strategies, facilitating the decision making process. The case study shows that the mono criteria evaluation, based only on PVNC, can result in an indifference situation therefore enhancing the difficulty of the decision

APPENDIX

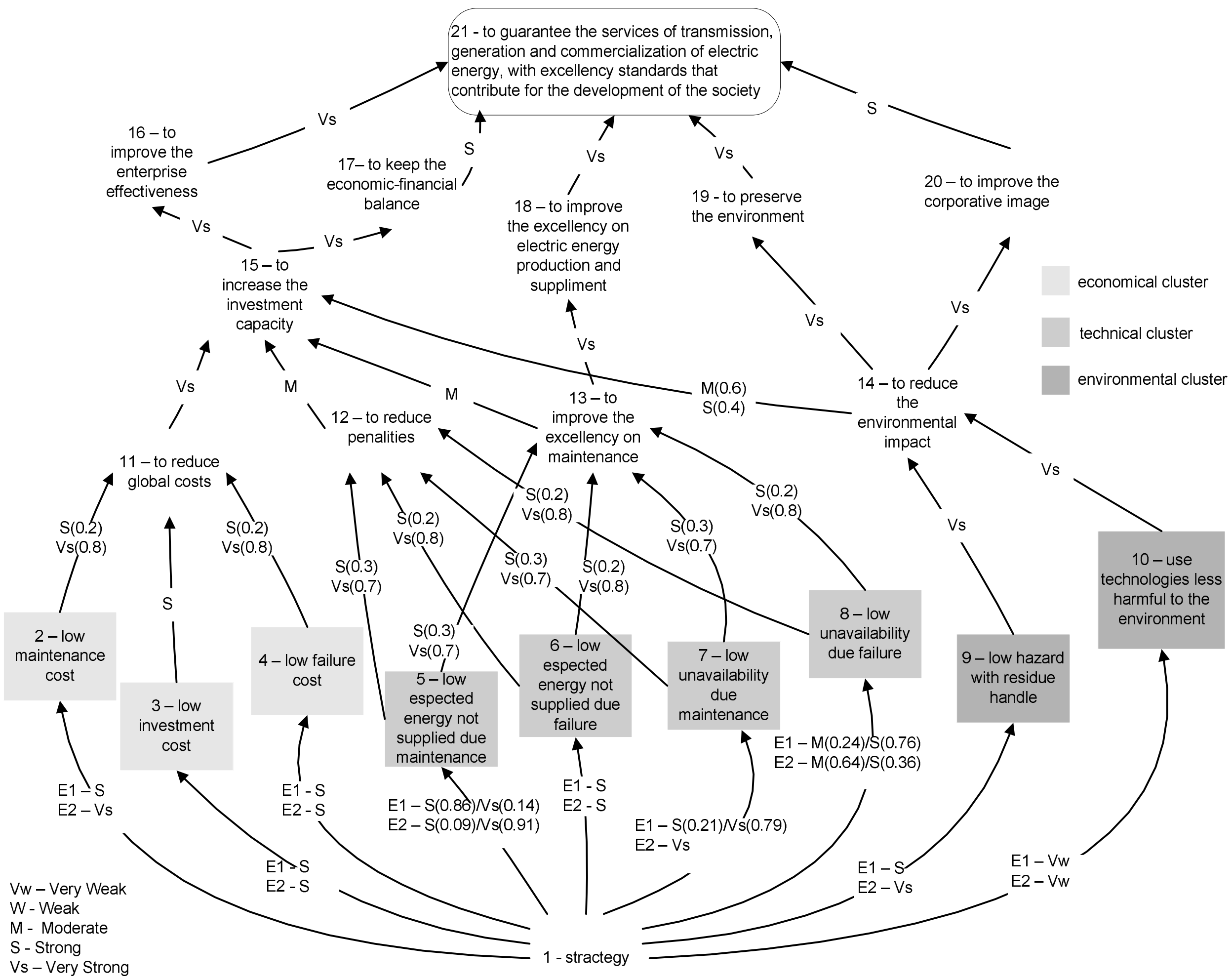

Fig. 9. Fuzzy causal map to causal inference.

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