MEASURING THE IMPACTS OF AN RCM PROGRAM ON POWER SYSTEM PERFORMANCE

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Abstract –Reliability Centered Maintenance (RCM) is the preferred maintenance policy among electric utilities, offering solid qualitative and empirical methods. Although probabilistic methods have been developed for choosing optimum RCM task frequencies, few cases describe their use on large power grids. This contribution reports on the application of such methods to more then 90 high-voltage stations operated by the largest generation and transmission company from Brazil. Several power system performance indexes and corporate results were modeled and measured from company operating and economic data, to validate the model, before and after its adoption. The work reports on the methods used to measure such impacts, availing the results for company owners and clients.

Keywords: RCM, Reliability-Centered Maintenance, Power System Performance

1 INTRODUCTION

The introduction of an RCM program usually results on changing (adding, modifying and deleting) maintenance activities, and their frequencies. To avail their impact on power system, changes on performance indexes must be correlated to these decisions. Correlation may be established by a model that simulates the activities, and their relation to measured indexes.

2 MODELING

Suitable models for RCM activities have been developed [1] that correlates these decisions to failure modes, and performance indexes. These models can be represented by a Markov chain as shown on Fig. 1, whose states model an equipment or system condition, and the state transitions model failure rates and maintenance events.

Maintenance optimization is achieved by fixing some controlled parameters on the Markov chain, such as task periodicity (T_{21}), Mean Time to Maintain (T_2), Mean Time to Correct (T_5) and Mean Time to Repair (T_3), which maximize or minimize an objective function. These parameters must also obey some restrictions, such as physical viabilities, available resources and security requirements. As T_2, T_3 and T_5 are limited by available technology, and assuming they are already at minimum values, the optimization must be sought by adjusting the maintenance frequency. The objective function to optimize must reflect the desired result, such as economy, risk, or quality of service, represented by some power system performance indexes.

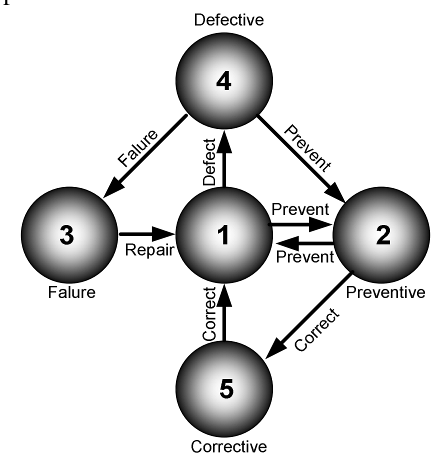

Fig 1 – RCM model

3 PERFORMANCE INDEXES

The performance of a stochastic process may be estimated by a scalar indicator that expresses the cost/benefit of state transition or visit in the system. Each transition/visit can be pondered by a return coefficient (*Ki*) that measure the gain/loss in the process for each maintenance event, assuming that the losses during a fault are included in the cost to repair. That is:

$$I = K_p F_p + K_r F_r + K_c F_c \qquad (1)$$

Where I = scalar indicator or objective function;
K_p = preventive return rate;
K_c = corrective return rate;
K_r = repair return rate;
F_p = preventive maintenance frequency;
F_c = corrective maintenance frequency;
F_r = repair frequency.

This general expression can be applied to many indicators in industry. The following are listed as examples, from power system practice, to which return rates can be derived by power flow, economic and contingency analysis [1]:

PSR	Protection system reliability
EFO	Equipment forced outage;

EFD	Equipment forced duration;
LPF	Loss of production frequency;
LPP	Loss of production probability;
DNS	Demand not supplied;
PNS	Production not supplied;
EOF	Equivalent outage frequency;
EOD	Equivalent outage duration;
PDI	Production discontinuity index;
EVC	Enterprise variable cost;
CVC	Client variable cost.

4 OPTIMIZING

The ideal maintenance frequency that optimizes any of these indicators, taken as an objective function *I*, can be determined by expanding F_p, F_c and F_r on expression (1), from the model equations in steady state. This allows us to build a canonical non-linear programming system, whose solution gives the optimum maintenance frequency. The process is shown on Fig. 2, valid for each index listed above.

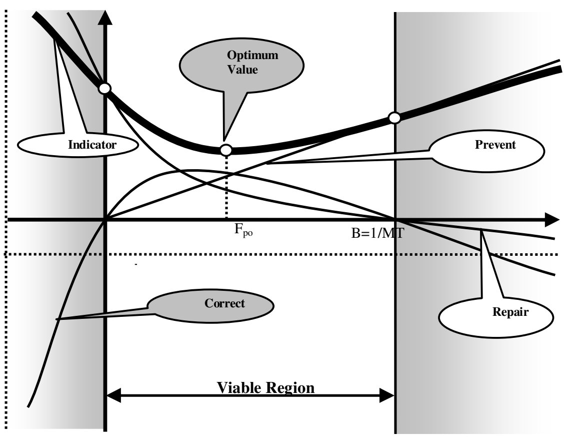

Fig. 2 - Performance Indexes

Its application to an extensible electrical transmission network, with more then 90 high voltage installations operated by CHESF, in Northeast of Brazil, has tested its validity. The test was preceded and followed by seminars and workshops where managers and specialists have analyzed the results and simulations, as a support tool to decision making. Statistics were determined from maintenance and operation records, covering 9 operating years. During this period, maintenance policy was held constant, assuring the steady state of equation (1). The models were parameterized to represent several partitions of the system, covering the protection of 1248 high voltage items.

5 MEASURING

After optimization of the maintenance interval for protection items, maintenance and operation records were compared to previous years, assuring optimum results for all quality indexes. Of special interest, all functional tests involving tripping of breakers from protection were cancelled since then, as the model recommended a negative frequency for this task! Other maintenance activities, such as relay checking, were optimized, resulting in annual gains superior to US$ 500,000.00/year (2).

To avail the reliability of protection systems after the RCM program, the following picture shows the evolution of this index, correlated to the demand for trip on all 90 CHESF stations, during 10 years (1982 to 1992) before and 4 years (1993 to 1996) after program start.

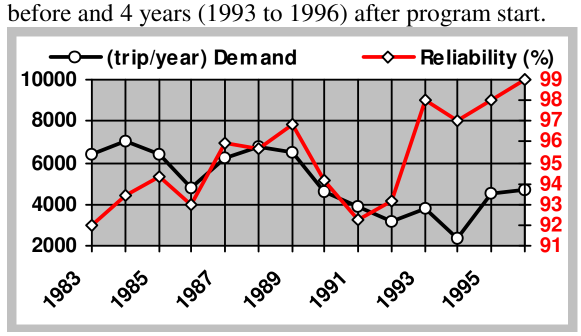

Fig 3 – *PSR* - Protection System Reliability

Prior to 1993, maintenance interval was held constant in 3 years. During this period, protection reliability varies according to demand, as expected from the model. After the RCM program in 1993 (January), a significant jump in protection reliability is measured, following again the demand changes in the next years.

Similar plots were obtained for many other indexes, like shown on Fig. 4, 5 and 6, for the months prior and after the adoption of the RCM program.

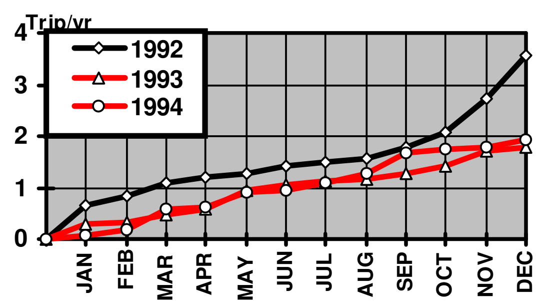

Figura 4– *EOF* -Equivalent Outage Frequency

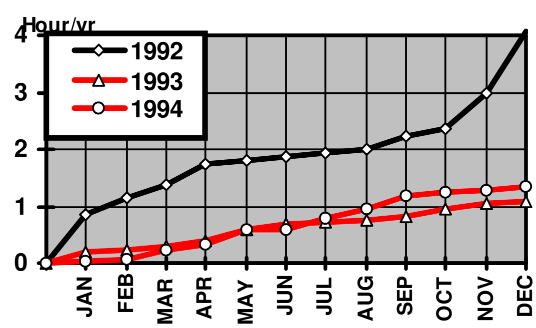

Figura 5 – *EOD* - Equivalent outage duration

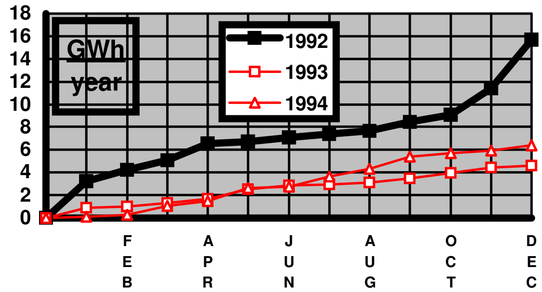

Fig. 6 – *PNS* - Production not supplied

These plots also show that the impacts on all indexes were immediate and permanent after the adoption of an RCM program.

6 CONCLUSION

Measuring the impact of an RCM program on power system performance must account for the long term effects of maintenance policies. Several years must be observed, prior and after the program adoption, in order to measure their adequacy. A stochastic model of equipment failures can be used in a Markovian decision process to optimize several power system indexes. Due to the general nature of the model, any kind of equipment and industrial activity can be modeled. Comparison among different families of equipment can be simulated by modeling their corresponding population, and referencing to benchmarks of the industrial sector. The uniform structure of the model, being independent from equipment type or failure mode, easies the interchange of experiences among companies, and adoption of uniform policies by industrial sectors.

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