RELIABILITY OPTIMIZATION OF THE POWER SYSTEM NODES CONSIDERING THE SWITCHING COMPONENTS

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***Abstract* – This paper focuses on a nodal reliability optimization method for power systems. Usually, system reliability optimization is based on components reliability and on system architecture. Most papers assume that input reliability data are deterministic, and certainly known. Taking into account the reliability of a component includes some uncertainties it is only an estimation. Following a review of available different methodologies for system reliability optimization which explicitly consider uncertainty, the authors are dealing with a specific method using scenarios' theory based on parametric sets of values of involved variables. The optimization criterion is related to cost-reliability function considering the redundancy degree focusing on the switching components reliability. The failure probabilities vector Q = f(q_0, q_1, ….. q_i, ….. q_n) of the sub-system is the optimization subject while the used algorithms is targeting the number of vector components as well as their reliability parameters. The study case is based on usual simplified nodal architecture of the power systems and practical values of reliability parameters. The calculations demonstrated that a large number of back-up components are not economically and even more, the back-up switching components are negatively influencing the system nodal reliability and the total investment, operating and maintenance costs.**

Keywords: *power systems, nodal reliability, optimization*

1. INTRODUCTION

Generally, reliability optimization of power systems relates to different criteria like:

A) Optimal system reliability indices
B) Optimal system architecture and reliability indices defined in A) and restrictions about cost, volume, etc.
C) Life operating time, maintenance strategies and costs.

One of the problems for system reliability optimization is the components reliability which includes some uncertainty even the source is a prescription [1], a standard or the industrial practice. To make a decision usually a higher reliability estimate but also lower uncertainty is preferred.

For reliability maximization, a technique is the redundancy allocation to maximize a lower percentile of the MTTF distribution for the system [2]. Another method is based on the multi-objective optimization function solved to maximize the system reliability and minimize the variance of the estimate using the weighted objective method to obtain Pareto optimal set by iteratively changing weights [3].

Classical optimization methods for power systems based on conditional successive increasing process, Lagrange multiplier, dynamic programming or on introducing the reliability indices in the complex cost function to be minimized [4].

Power systems and specially their nodal architecture have specific initial conditions form reliability point of view due to the presence and importance of the switching components.

In the followings, the uncertainty of the input reliability data is covered by their values parameterization. Consequently, different scenarios based on realistic, but uncertain data, are used for quantitative and qualitative analysis of the results.

2. NODES STRUCTURE OPTIMIZATION CONSIDERING THE REDUNDANCY OF SWITCHING COMPONENTS

2.1. Unreliability cost calculation

The minimum total actual costs or maximum reliability with risk restriction are the optimization criteria. Investment costs (I) are directly influenced by the number and the quality (reliability) of the components. Operating costs are divided in that related to investment costs in which they can be included, annual losses costs and unreliability costs or damages following supply interruptions (D) depending on the number of interruptions and their duration.

The system components are ranked by failure probability q. System reliability optimization means optimal reliability for Q = f(q_i), i=1,2,…,i,…, n. Finally, we'll know optimal value of vector Q which means knowing the unique element characteristics or the number of identical elements of the system.

First, q is considered a continuously variable having an optimal value after optimization. Dependence between I and q in the case of more different components, is a result of the cost and reliability index or of the reliability calculations.

If the component subsystems are connected in parallel, we can write:

$$I = n \cdot I_0 \tag{1}$$

$$q = q_0^n \tag{2}$$

where I and q are related to a subsystem and I_0 and q_0 to the parallel connected components of it.
From (2) and (1) we can write:

$$\ln q = n \ln q_0 \tag{3}$$

$$I = I_0 \cdot \frac{\ln q}{\ln q_0} \tag{4}$$

A similar relation is for operating costs C having two components:

$$C_i = k_c \cdot I + k_p \cdot P \tag{5}$$

where k_c and k_p are parameters and P, power losses.

$$P = n \cdot P_u + \frac{P_k}{n} \tag{6}$$

In eq. (6), P_u and P_k are power losses for the unloaded and short-circuit states of the element respectively.
Using eq. (3), eq. (6) becomes:

$$P = P_u \frac{\ln q}{\ln q_0} + P_k \frac{\ln q_0}{\ln q} \tag{7}$$

The unreliability cost (D) can be expressed as:

$$\begin{aligned} D &= q \cdot T \cdot d_t + n_i \cdot d_i = q \cdot T \cdot d_t + n \cdot n_{0i} \cdot d_i = \\ &= q \cdot T \cdot d_t + n_{0i} \cdot d_i \frac{\ln q}{\ln q_0} \end{aligned} \tag{8}$$

It was noted: T – reference time; d_t – specific damage (money) per time unit; n_t – average interruption duration; n_{0i} – number of interruptions following increasing from n_i to n_i+1 the number of elements of the subsystem i.

2.2. Cost-reliability relationship considering the switching components

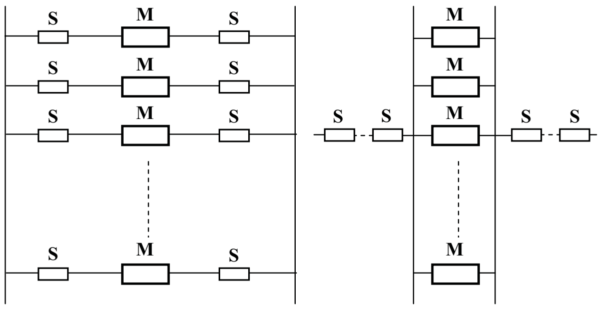
Quantifying the cost-reliability relationship is not an easy task due to different adopted solutions for reliability improvement: dimensional redundancy or structural redundancy. The first one is more difficult to model while the second can be fulfilled based on reliability theory of redundant systems [5].
The reliability of a redundant system with n elements having the unit cost I_0 and reliability p_0 is given by:

$$p_s = 1 - q_s = 1 - q_0^n \tag{9}$$

where $q_s = q_0^n$, $\ln q_s = n \cdot \ln q_0$, $n = \ln q / \ln q_0$ and the cost:

$$I_s = nI_0 = I_0 \frac{\ln q}{\ln q_0} = I_0 \frac{\ln(1-p_s)}{\ln q_0} \tag{10}$$

For $p_s=1$, $I_s \to \infty$. Increasing reliability cost is as much as its reliability is greater. The above mentioned relations are not considering the main (M) switching elements (circuit breakers), usually included in the power systems nodes structure. Every main switching element is surrounded by two secondary (S) switching elements (isolators) as presented in fig.1



a) b)

Figure 1: Subsystem with switching elements: a) technical diagram; b) reliability structural equivalent model

Equation (9) becomes:

$$p_s = [1 - (1 - p_0)^n] p_k^{2n} \tag{11}$$

where p_k is the reliability switching element S and equation (10) can be written as:

$$I_s = n(I_0 + 2I_k) \tag{12}$$

Taking I_0 as the reference value and $I_s^{"} = \frac{I_s}{I_0}$ and $I_k^{"} = \frac{I_k}{I_0}$ the system reliability is

$$p_s = [1 - (1 - p_0)^{\frac{I_s^*}{1+2I_k^*}}] p_k^{\frac{2I_s^*}{1+2I_k^*}} \tag{12}$$

Results of a parametric analysis are shown in figures 2 – 7 containing qualitative and quantitative information concerning the cost-reliability relationship of redundant systems for plausible combination between components reliability: $p_0 = 0.9 \div 0.9999$; $p_k = 0.9 \div 0.9999$; $I_k^{"} = 0.1 \div 0.5$; $I_{s\max} = 10$.
Obviously, every time the interest is focused on the zones where $\partial p_s / \partial I_s \geq 0$. The diagrams allows for some interesting results:

- fig. 3, fig. 4 and fig. 5 shows the strong influence of the switching element reliability on system reliability;
- for greater values of p_k, increasing the system redundancy has not an important positive

influence on system reliability over a given maximum value of p_s as shown in fig. 2 and fig. 3;

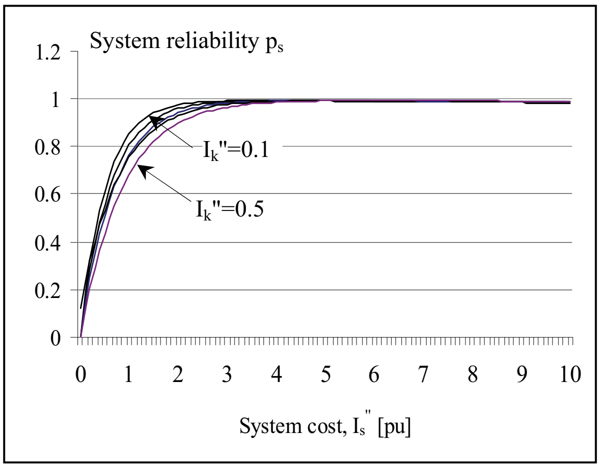


Figure 2: System cost-reliability relationship: p_0=0.9; p_k=0.999

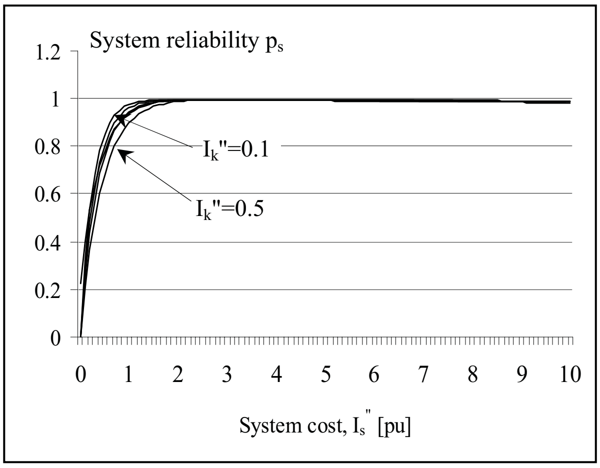


Figure 3: System cost-reliability relationship: p_0=0.99; p_k=0.999

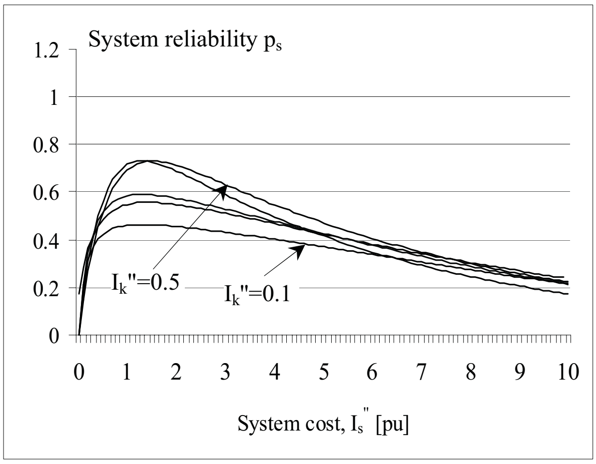


Figure 4: System cost-reliability relationship: p_0=0.9; p_k=0.9

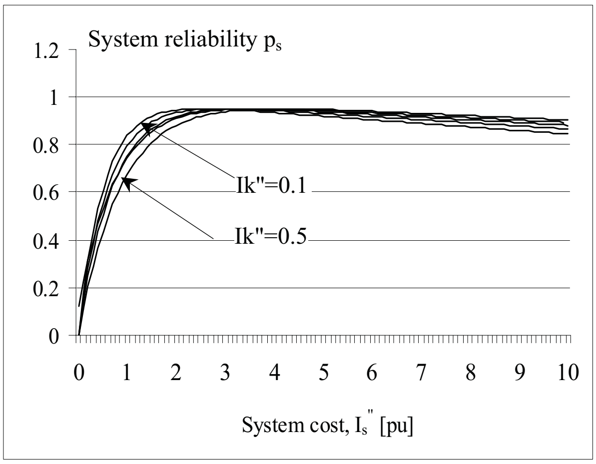


Figure 5: System cost-reliability relationship: p_0=0.9; p_k=0.99

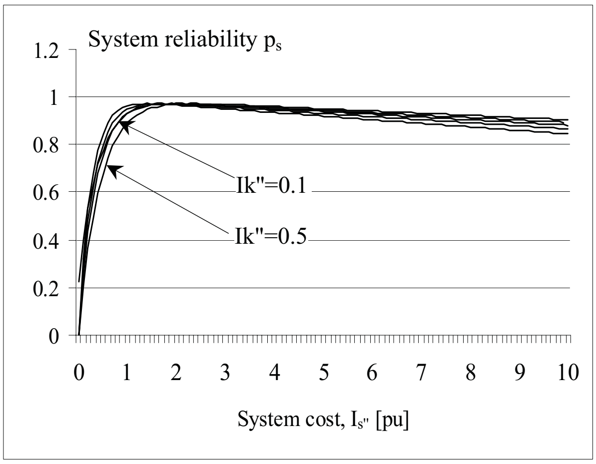


Figure 6: System cost-reliability relationship: p_0=0.99; p_k=0.99

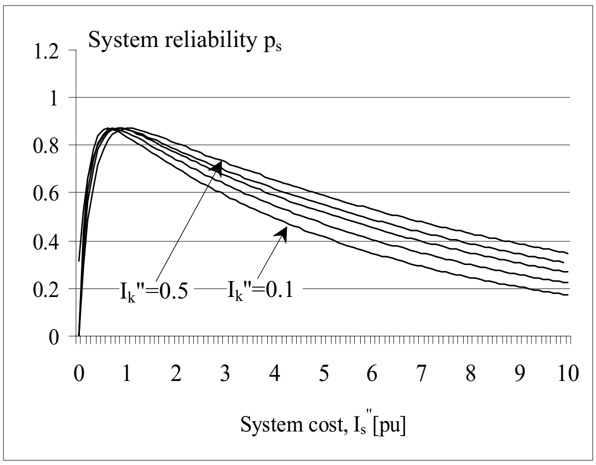


Figure 7: System cost-reliability relationship: p_0=0.999; p_k=0.9

In every situation depicted in figures 2 – 7, the maximum of p_s is the same, independently of I_k''. Consequently, if the cost is not so important for global decision makers (strategic, military, aerospace systems, etc.), the maximum system reliability is depending exclusively on its components reliability.
Concerning the optimization of the reliability of the redundant system structure, establishing the optimum number of parallel elements, n_{opt}, means using the characteristics in fig. 8 calculated using figures 2- 7 from which the maxim value for p_s was extracted.

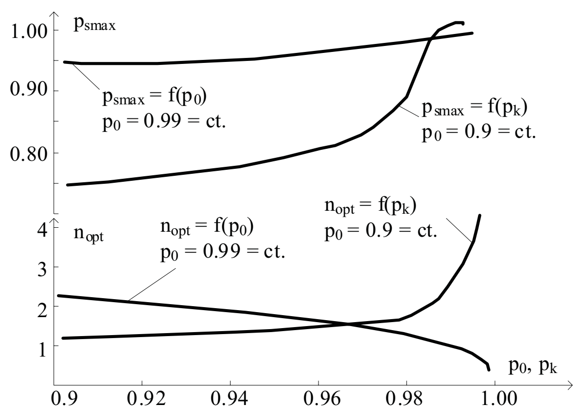


Figure 8: Optimal structure of redundant systems and their maximum reliability as a function of component elements reliability

Fig. 8 demonstrates that, for real cases for which $p_k \prec 0.9999$ (0.999899 for circuit-breakers and 0.999605 for mechanisms) the number of parallel switching elements is economically limited at 2 or 3.

4. CONCLUSIONS

The usual structure of power network nodes includes switching elements connected in parallel. There is some times a tendency to use a redundant structure with a view to increase the node reliability and, consequently, quality of supply.

Based on the cost - system reliability relationship and the reliability of components the authors' demonstrated that:

- excepting some kind of systems where the cost is not important, the redundancy degree has a lower necessary value;
- the presence of switching elements, for a given combination of reliability indices, has a negative influence on the resultant system reliability.

The examples included in this paper, based on realistic values of input data – per unit investment, losses and operating costs, allow for a good interpretation of the simple theory related to the nodes structure.

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