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An Effective Oriented Genetic Algorithm for solving redundancy allocation problem in multi-state power systems

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Abstract

The main goal in the design of industrial systems is to improve their reliability. This can be achieved by reducing the complexity of the system by increasing the reliability of its components (reliability allocation) or hardware redundancy (redundancy allocation) or a combination of these two approaches. In this paper, we are interested in solving the redundancy allocation problems RAP in serial-parallel multi-state systems MSS. Our contribution is the Effective Oriented Genetic Algorithm (EOGA) which aims to improve the genetic algorithm by introducing a new parameter which is the degree of relevance of the component, thus allowing a more oriented search in the generation of the initial population, and also the use of specific operators and fitness function, giving better results. In the following, we will cite some errors in the calculations encountered in previous work. Our goal is to improve the redundancy of the system to satisfy a required demand under the constraint of maximizing the reliability of the system and minimizing its cost. To evaluate the reliability, we will hybridize our algorithm with the universal generating function UGF. A comparison with the literature will be discussed at the end of this work showing the effectiveness of our approach, and the significant gap between our results and previous work.

Keywords : Redundancy allocation problem (RAP); Reliability; Multi-State Systems (MSS); Universal Generating Function (UGF); Genetic algorithm (GA); Effective Oriented Genetic Algorithm (EOGA).

1. Introduction

A parallel serial multi-state system (MSS) usually consists of several subsystems connected in series and each subsystem consists of several components in parallel. This structure acquires a certain level of redundancy from the system which enables it to be available in the event of failure of one or other components. The system and its components then have a performance level ranging from nominal operation to total failure. These components are

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chosen from a list on the market and are characterized by their performance G, availability A and cost C [1]. The redundancy allocation problem (RAP) consists to reduce the complexity of the system by increasing hardware redundancy in order to achieve an optimal topology. The system thus constituted must satisfy a demand threshold W_0 under the constraint of maximizing its reliability and of minimizing its cost [2]. The reliability of a system represents the probability that a system is operational in a time interval [0, t]. As for availability, it represents the probability that a system is operational at a given time t. This very broad definition, and generalizing the notion of reliability, leads us to take an interest in the notion of availability of systems. In general, the evaluation methods of the latter are based on four different approaches: the structure function approach, the Markov stochastic process, the Monte-Carlo simulation technique and the universal generator function (UGF) approach.

The RAP is a complex combinatorial optimization problem and the exhaustive examination of the huge number of possible solutions is not simple enough given the time limitation. Solving this problem leads to solutions that are in the form of possible configurations. The calculation within its configurations must give results respecting the constraints which are defined by mathematical equations. However, several errors are encountered in the literature affecting the cost function and reflect the incompatibility of the configuration with the cost of the components.

In [3], a comparison between these four approaches emphasizes that the UGF approach is fast enough to be used in optimization problems in the case where the search space is important.

However, several errors are encountered in the literature affecting the cost function and reflect the incompatibility of the configuration with the cost of the corresponding components. These errors will be cited in detail in Section 3. Our contribution is to remedy this problem and improve the results found. We will show improvements, and more relevant results through the use of a new algorithm, EOGA.

Our work will be organized as follow: A formulation of the problem and UGF technique in section 2. Quotation of some errors encountered in the literature in 3. Introduce and apply our approach in 4. In section 5, we will test our algorithm while showing its efficiency through the errors cited in 3 and at the end a conclusion and our perspectives.

2. Problem formulation and Universal Generating Function technique

Redundancy is a technique used to improve the reliability of systems. Optimization of the latter plays a key role in system design engineering. In this section we will try to mathematically model our problem after formulating it.

Nomenclature:

Let $\otimes_f$ be a multiplicative operator, this operator acts differently on the function $u_i(z)$; on one hand, it performs a multiplication of the components of the vector p_i, on the other hand, the function f acts on the components of the vector x_i. The function $u_i(z)$ checks the following strong properties:

i $\otimes (pZ^a) = pZ^a$

ii $\otimes_f (pZ^a, qZ^b) = pqZ^{f(a,b)}$ where f is defined depending on the nature of the MSS

iii $\otimes \{u_1(z), \dots, u_k(z), u_{k+1}(z), \dots, u_n(z)\} = \psi\{\psi[u_1(z), \dots, u_k(z)]; \psi[u_{k+1}(z), \dots, u_n(z)]\}, \forall k.$

iv $\otimes \{u_1(z), \dots, u_k(z), u_{k+1}(z), \dots, u_n(z)\} = \psi\{u_1(z), \dots, u_k(z), u_{k+1}(z), \dots, u_n(z)\}, \forall k.$

2.1 *Mathematical formulation of the problem*

Let us consider a MSS that consists of n subsystems. Those subsystems are in series and each subsystem i $(1 \le i \le n)$ contains k_i components in parallel, each, with a version V_i[4, 5]. For each version v (1≤ v ≤ V_i), the component is characterized by its availability A_{iv}, performance G_{iv} and cost C_{iv}. The structure of each subsystem i is defined by the number of parallel components k_{iv} for each version [6, 7], as shown below in Figure 1.

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