14 Genetic Algorithms Applied to Nuclear Reactor Design Optimization

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A genetic algorithm is a powerful search technique that simulates natural evolution in order to fit a population of computational structures to the solution of an optimization problem. This technique presents several advantages over classical ones such as linear programming based techniques, often used in nuclear engineering optimization problems. However, genetic algorithms demand some extra computational cost. Nowadays, due to the fast computers available, the use of genetic algorithms has increased and its practical application has become a reality.

In nuclear engineering there are many difficult optimization problems related to nuclear reactor design. Genetic algorithm is a suitable technique to face such kind of problems. This chapter presents applications of genetic algorithms for nuclear reactor core design optimization. A genetic algorithm has been designed to optimize the nuclear reactor cell parameters, such as array pitch, isotopic enrichment, dimensions and cells materials. Some advantages of this genetic algorithm implementation over a classical method based on linear programming are revealed through the application of both techniques to a simple optimization problem. In order to emphasize the suitability of genetic algorithms for design optimization, the technique was successfully applied to a more complex problem, where the classical method is not suitable. Results and comments about the applications are also presented.

1 Introduction

Nowadays, the most recent nuclear reactor design philosophies, such as the European Pressurized Reactor - EPR [Teichel, 1996, 1999], that embeds the safety and operation cost optimization concepts, as well as the new nuclear fuel concepts such as the Mixed Oxide - UO_2 - PuO_2 (MOX), have been motivating the nuclear reactor design techniques improvement.

The nuclear reactor core design involves a lot of constraints. During the design, a set of parameters must be adjusted in order to obtain a safe and economical reactor. Finding the best configuration in the design process includes

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a good representation of the phenomena related to the neutron interactions in the reactor core and an efficient optimization technique.

Due to their simplicity and low computational cost, gradient search has been used as the optimization methods. Most of them, such as the one described in Rozon (1992), use linear programming techniques. However, because of the nature of exploitation of these hill-climbing-like methods, their application to a multimodal search space can lead to a local optimum. The nuclear reactor core design optimization process includes non-linearities, discontinuities and multimodality, becoming a complex problem with large number of state parameters to be optimized subject to a large number of constraints.

In this chapter it is presented a global scope optimization approach for reactor core design based on genetic algorithms (GA) [Goldberg, 1989] in which it is considered the all-variable space and no prior knowledge to restrict the search is required. Global optimization has been explored by some researchers in the field of nuclear reactor design, such as Cacuci (1990). Genetic algorithms have been successfully applied to nuclear core reload optimization [DeChaine, 1995; Chapot, 1999], transient classification [Alvarenga, 1997; Pereira, 1998], some others specific problems in the nuclear field [Haibach, 1997; Omori, 1997], and, recently, in core designs [Pereira, 1999].

Here, results of the application of the method to a simple core configuration reveal some advantages when compared to a classical nonlinear optimization method based on linear programming. It is also shown the results of an application of the proposed method to a more complex problem to which the classical method mentioned above is not suitable.

2 The Genetic Algorithm Search Paradigm

The Holland's genetic algorithms [Holland, 1975], inspired on the species evolution theory [Darwin, 1859], manipulate a population of symbolic structures, that represent points in the search space, in order to evolve this population to its best adaptation, hence, the best solution of the problem. In GA [Goldberg, 1989; Davis, 1991; Michalewicz, 1994], the parameters to be varied in the optimization process are codified in a symbolic structure, metaphorically called genotype, that is formed by a set of genes that carry intrinsic characteristics of the symbolic individual. These characteristics dictate the adaptability of the individual in the environment, in which it may survive or die. The selection and evolution are made in such a way that stronger individuals have more chance to be selected, transferring theirs characteristics to the offsprings. This way, from generation to generation, the tendency is that strong individuals become stronger and more numerous while the weak individuals tend to be extinct.

The GA starts the adaptation process from a set of possible configurations, in other words, a random generated population of individuals. Evaluating independently each individual by an objective function, the GA assigns