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Proposed resolution of the IEA-R1 reactor recharge optimization problem using the particle swarm optimization method

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1. Introduction

The problem of optimizing the recharge of a nuclear reactor deals with finding a configuration for its core to maximize/minimize parameters that are convenient for the use of the reactor for a certain purpose, such as maximizing the fuel burn period or minimize peak power factor [1]. It is an extremely complex combinatorial problem, being of the NP-Complete type [2]. For many years, its resolution was through the manual operation of an expert, using their previous knowledge to find the best possible configuration.

After the advance of information technology, around the 80s, it was possible to develop methods aimed at replacing the specialist in the recharge optimization problem. One of these first methods used the Simulated Anneling (SA) technique [3]. A posteriori, several methods were created seeking a better solution for the problem in question.

The present work seeks to solve the recharging optimization problem of the IEA-R1 reactor, which is a research reactor located at the Institute of Energy and Nuclear Research – IPEN/CNEN-SP, at the University of São Paulo using the Particle Swarm Optimization (PSO) method.

2.The IEA-R1 reactor

It is the largest of the four existing research reactors in Brazil, this one with an open pool, with water as a moderator and a coolant. In 1995, IPEN/CNEN-SP decided to enable it to operate at 5 MW, its nominal design power. After that, it went through several renovations and modernizations that allowed it to increase the maximum operating power to 5MW [4].

As a research reactor, it has a considerably smaller core than power reactors. Even so, this doesn't make the optimization problem so much simpler that no computational method is needed to solve it. Figure 1 shows a configuration of this core.

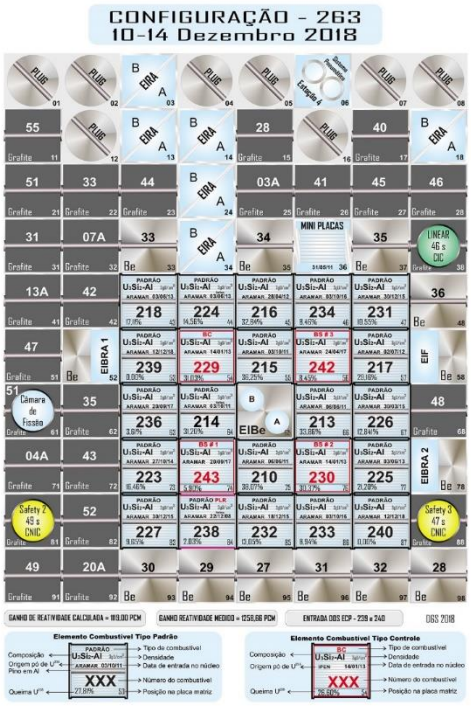

Figure 1: Number 263 IEA-R1 reactor core configuration.

A work automated, in a simple way, a good part of the codes that make up the neutron analysis of the IEA-R1[5]. Such work was of great value to the reactor calculation group, which obtained a reduction in the execution time of these analyses. Figure 2 shows a complete schematic of all neutronic and thermo-hydraulic calculations currently used in the IEA-R1 reactor.

The neutronic and thermohydraulic calculations in the work are done by the codes already used by the CERPQ (Research Reactor Center IEA-R1) calculation group: 2DB, which solves the neutron diffusion equation in two dimensions and several energy groups [6]. CITATION, solves problems involving the finite difference representation of the neutron diffusion equation, treating cases with up to three spatial dimensions, with arbitrary scattering between energy groups, xyz, θ-rz, hexagonal-z and trigonal-z geometries, in addition from static, evolution and fuel management problems to multiple cycle analysis [7]. COBRA, calculates the temperature distribution of the fuel element in radial direction as a function of power density and heat transfer, as well as enthalpy and pressure drop, in transient and permanent regimes, thus solving the mass and energy conservation equations and moment of fluid mechanics [8].

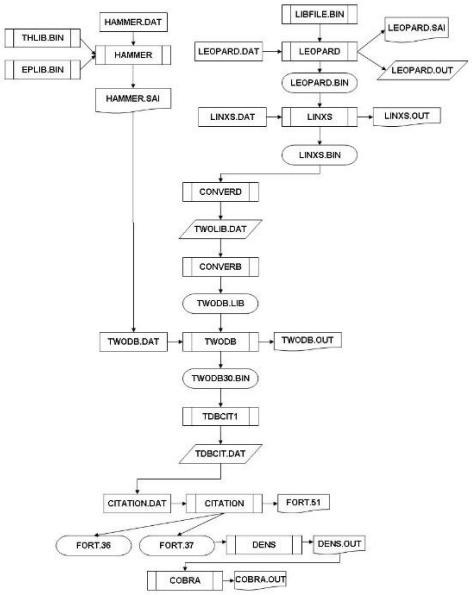

Figure 2: Diagram of neutronic and thermo-hydraulic calculations in the IEA-R1 reactor

3. PSO Method and the code

Particle Swarm Optimization (PSO) is a meta-heuristic created by Eberhart & Kennedy in 1995 based on observations of the social behavior of animals such as flocks of birds and schools of fish [9]. In this method, each individual or "particle" of a given population or "swarm", duly generated by the user, moves through the search space in successive iterations, cooperating and competing with other particles, moving, to always keep the best position of the search space you visited, (ie, the best objective function value) and towards the best individual in topological surroundings.

Considering the particle's movement in a plane or in a two-dimensional space and its location in this space characterized by its coordinates. Thus, we define $\left(x_k^i, y_k^i, \right)$ as the position of the particle k (k =1,2,...,n) in the iteration – or step – i (i = 1.2.. .,m), where m is the total number of iterations defined. From this definition, one can establish the best position of particle k and the best position of the swarm, shown here by $\left(x_k^{best}, y_k^{best}, \right)$ and $\left(x_{global}, y_{global}\right)$ respectively. The velocity of a particle k is defined by eq.1:

$$V_{y,k}^{i+1} = \omega^i V_{y,k}^i + c_1\eta\left[y_k^{best} - y_k^i\right] + c_2\varepsilon\left[y_{global} - y_k^i\right] \quad (1)$$

$$y_k^{i+1} = y_k^i + V_{y,k}^{i+1}$$

Where i = 0.1,2,… m-1. The values of λ, η, ε, μ are random and drawn at each step of the iterative process. The constants c_1 and c_2 are positive reals chosen by the user. Define the weight ω^i as configured in eq.2:

$$\omega^i = \omega_{inicial} + \left(\omega_{final} - \omega_{inicial}\right)\left(\frac{i}{m-1}\right) \quad (2)$$

Code uses the data provided by the three nuclear calculation programs mentioned above and with these it seeks the optimal configuration of the nucleus, each particle being one of these candidate solutions. For the case of this work, we sought to maximize the peak power factor (Fxy) but keeping the neutron flux distribution as stable as possible.

4. Conclusions

At the moment, the code is in the final stage of preparation, so the final version of this work will show the results thus obtained.

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