Expert Systems with Applications 38 (2011) 11201–11208

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Soft computing technique for power control of Triga Mark-II reactor

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ARTICLE INFO

Keywords:
Fuzzy logic controller
Genetic algorithm
Soft computing
Triga reactor
Trajectory tracking

ABSTRACT

In this study, a trajectory tracking fuzzy genetic controller for Istanbul Technical University Triga Mark-II nuclear research reactor design approach is given. Power output of reactor is controlled along the predefined trajectory by fuzzy logic controller. Designed zero order Sugeno type fuzzy logic controller membership boundary value and rule weights are found by genetic algorithm. Non-chattering control with smooth control surface is also achieved using constrained fitness functions. Simulation results shows that reactor power successfully tracks the given trajectory under various working conditions and reaches the desired power level within the determined period within small tracking error.

1. Introduction

Soft computing (SC) advocate the integration of complementary methodologies such as fuzzy logic (FL), genetic algorithm (GA) and artificial neural network (ANN), each of which is adequate for its specific domain of problems and results in more powerful hybrid methods than using a single method exclusively. Many of the publications are concerned with the automatic design or optimization of fuzzy logic controller (FLC) either by adapting the fuzzy membership functions or by learning the fuzzy if then rules. The first method results in a self-tuning controller and is primarily useful in optimizing the performance of an already existing controller. The second approach is a self-organizing process that learns the appropriate relation between control input and output starting without any previous knowledge.

Intelligent technologies, including FL, ANNs, GA, and others provide additional tools that significantly enlarge the domain of problems that can be solved. Nuclear engineering is one of the areas with a large potential for applications of intelligent technologies (Ruan, 1998; Ulhirg & Tsoukalas, 1999). One such technique could be FLC, which can provide very desirable advantages over classical control, like robustness, adaptation and the capability to include human experience into the controller. Simple FLCs have been implemented for a few nuclear research reactors, among which the Massachusetts Institute of Technology (MIT) research reactor in 1988 and the first Belgian reactor (BR1) in 1998. Entzinger and Ruan were showed that adaptive FLC, GAs and ANNs are most promising strategies for further research and future application in nuclear reactor control (Entzinger & Ruan, 2006). Na and Upadhyaya were proposed a model predictive control method combined with fuzzy identification, which applied to the design of the thermoelectric (TE) power control in the SP-100 space reactor. In their work GA was used to optimize the fuzzy model predictive controller. They showed that the TE generator power level controlled by the proposed controller could track the target power level effectively, satisfying all control constraints (Na & Upadhyaya, 2006). Marseguerra et al. also proposed an approach, based on a GA optimization search, for determining the values of the parameters of an adaptive stable FLC suitable to drive a Chernick's model of a nuclear reactor to a desired reference trajectory (Marseguerra, Zio, & Cadini, 2005).

Numerous researches have been proposed a controller such as FLC, adaptive control and optimal control for the power control of ITU Triga Mark-II (Akbay, Can, & Baba, 2001; Baba, Can, Gok, & Akbay, 1996; Can, Baba, & Erdal, 1999; Can, 1992; Can, Yavuz, & Akbay, 1990; Erkan, Butun, & Can, 1998; Erkan & Can, 1996). Additionally, Coban and Can proposed a fuzzy controller for of ITU Triga Mark-II reactor (Coban & Can, 2009). They proposed a ANN model to find optimal trajectory values for required initial and target power with fixed FLC. Unlike the their models, in this work a reactor could be operated with any desired reference trajectory. To include the any reference trajectory in the cost function this could be easily achieved. The work presented here is a continuation of earlier research on FLC for this nuclear reactor. Lastly, Baba proposed a zero order Sugeno type trajectory tracking FLC to control the reactor power. In his approach, FLC parameters were determined by operators' experience and this has been difficulties for the designers to get an insight on how the fuzzy rule base affects the performance of the control system (Baba, 2004). Although this approach had superior results to comparing the classical FLC controllers, has difficulties for the designers to get

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doi:10.1016/j.eswa.2011.02.167

Nomenclature

PR_i	reactor initial power	ε	penalty value
PR_d	reactor desired power	¢	disturbance level
PT_i	trajectory initial power	T	total simulation time
PT_d	trajectory desired power	Γ	search space
$\alpha_3, \alpha_2, \alpha_1, \alpha_0$	trajectory coefficients	G	coding space
λ, β, δ	weight factor for each trajectory region	ρ	coding function
θ	trajectory slope	μ	population size
C_n	firing strength	I	initialization function
W_n	rule weight	S	selection type
J	cost function	Ω	genetic operators
u	control signal	ωm	mutation operator
δu	control signal deviation	ωc	crossover operator

an insight on how membership functions and fuzzy rule affects the system performance. In traditional methods, although this problem could be solved by doing many experiments, requires lot of time and energy. In addition, it is very hard to obtained the non chattering controller at this approach.

In this study, trajectory tracking fuzzy genetic controller (TTFGC) is designed and applied for the power control of ITU Triga Mark-II reactor for any given trajectory under various working conditions. In the proposed approach, predefined membership boundary values and action weights are optimized by GA. Additionally, constrained cost function is used to obtained non-chattering control surface. To demonstrate the effectiveness of proposed approach, a series of simulations are carried out on ITU Triga Mark-II reactor. The results demonstrated that reactor power perfectly tracks the predefined trajectory under various working conditions.

This paper is organized as follows. In Section 2 reactor model and defined trajectory are given. Designed TTFGC is explained in Section 3. In Section 4, experimental results are presented. Finally, conclusions can be found in Section 5.

2. Reactor physical model

ITU Triga Mark-II research reactor is use solid fuel which obtained by homogeneously mixed enriched uranium fuel and zirconium hydrate moderator. The reactor has steady state and pulse working mode. It is produces 250 kW powers at the steady state working mode and 1200 MW power at the pulse working mode for a instantaneous time. The reactor is an open tank type and cooled by light water. Because of reactor has negative heat coefficient, unexpected power increase is caused to decrease the fuel moderator heat and the reactivity. As a result, reactor power is automatically decreased. Only Triga type reactor has this special characteristic. Reactor has shock rod, safety rods and control rods which safety and control rods are controlled by electro mechanic mechanism. In this work, to simulate the neutronic–thermal-hydraulic behaviors of reactor, YavCan code is used [6] where reactor model could be given as follows:

$$\frac{dX(t)}{dt} = \mathbf{A}X(t) + \mathbf{B}, \tag{1}$$

where X is (10×1) dimension vector and represents the neutron density, precursor concentration, fuel temperature, coolant temperature, and coolant velocity. $\mathbf{A}$ is a coefficient matrices and has (10×10) dimension. $\mathbf{B}$ is (10×1) dimension input vector. Detailed reactor model can be found in Can (1992) and Coban and Can (2009).

In order to define control signal, it is necessary to determine the trajectory function that has to be tracked by the reactor power. The trajectory has three regions which given as follows:

$$PT = \alpha_0 + \alpha_1(t_1 - t_0)^3 + \alpha_2(t_2 - t_1)^2 + \alpha_3(t_3 - t_2), \tag{2}$$

where PT is power trajectory, t is time, α_3, α_2, α_1, α_0 are trajectory coefficients and can be calculated from the initial, required power and trajectory slope (θ) (Baba 2004). There are 14 unknown coefficients in the above equations.

3. Genetic algorithm based trajectory tracking fuzzy logic controller design

Several studies have shown that FLC to be an appropriate method for the control of complex or partially identified processes, many of which cannot easily be modeled in a mathematical way. Unlike a conventional controller, no rigorous mathematical model is required to design a FLC and in many cases they can be implemented easily. However, this simplicity also presents a bottleneck in their design. FLC rely on heuristic knowledge that is subject to designer's interpretation and choice. The traditional approach to FLC design is laborious, time consuming and in most cases specific to each application. These difficulties can be eliminated by using GA to find optimal FLC parameters (Herrera, Lozano, & Verdegay, 1994; Linkens & Nyongesa, 1995).

GAs are stochastic global search and optimization methods that mimic the metaphor of natural biological evolution. GAs operate on a population of potential solutions applying the principle of survival of the fittest to produce successively better approximations to a solution. At each generation of a GA, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and reproducing them using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals from which they were created, just as in natural adaptation. A Simple GA (SGA) procedure could be defined by 11 parameters given as below

Table 1
Obtained SGA operator values.

SGA parameters	Value
Population size (μ)	30
Mutation operator (ω_m)	Bit mutation
Crossover operator (ω_c)	One point
Mutation probability ($P\omega_m$)	0.01
Crossover probability ($P\omega_c$)	0.9
Selection operator (S)	Tournament