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Control of the reactor core power in PWR using optimized PID controller with the real-coded GA

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ABSTRACT

Load following is an importance topic in the Nuclear Power Plants (NPPs). One of the conventional and simplest ways is the use of Proportional-Integral-Derivative (PID) controller. The reactor power is simulated based on the point kinetic model. PID gains of a nonlinear time-varying system (a PWR NPP) are optimized and scheduled using real-coded genetic algorithm (GA). To this end, the objective function of the decision variables, include the overshoot, settling time and stabilization time (based on the Lyapunov approach) of the system is minimized. The presented control system track demand power level change within a wide range of time. The simulation results demonstrate good stability of this method and show high performance of the optimized PID gains to adapt any changes in the output power.

1. Introduction

Development of load following topics has always been interested in the Nuclear Power Plants (NPPs) (Andrade, 1978; Zhengyao, 1998; Chen et al., 2010). The dynamic of NPPs is nonlinear which most of its parameters depend on the output power. Therefore, it is important to use an appropriate controller with optimal design.

One of the conventional and simplest controller that used in industries, such as nuclear facility, is Proportional-Integral-Deriva tive (PID) controller (Bennett, 2001; Araki, 2009). Up to now, various methods of PID gains tuning have been considered by researchers (Zhao et al., 1993; Åström and Hägglund, 1995; Ho et al., 1995; Åström et al., 2001; Ang et al., 2005; Åström and Hägglund, 2006). Also, use of the fuzzy logic and the intelligent algorithms has a special place in researches. Ota and Omatu (1996) tuned PID gains using the Genetic Algorithm (GA) to control the desired plant. They compared the real number string GA with the bit string GA; and results showed the first is better.

The multi-objective optimization and GA method were used to design the robust control for a certain linear system, considering the rise time, maximum overshoot and steady-state error (Lin et al., 2003). The second and third order control systems were taken to account using GA for self-tuning of the PID gains; and performance was improved compared to Ziegler Nichols and fuzzy methods (Fan and Joo, 2009). Particle Swarm Optimization (PSO) algorithm was used for the PID gains tuning in the certain system; and its accuracy was proved compared to the Ziegler Nichols theory (Solihin et al., 2011). Also, GA was employed for offline optimization of the PID gains in nonlinear systems (Chang, 2007). Results showed good effectiveness of the real-coded GA. Visioli (2001), used the fuzzy logic method to set the PID gains. He compared different methods base on fuzzy logic, and demonstrated that the fuzzy set-point weighting methodology was better than other methods. The fuzzy, PID and advanced fuzzy controls were used and compared in the reactor simulations by LI and Ruan (2000). The results showed that the advanced fuzzy control could dynamically adjust the rule base.

Liu et al. (2009) designed and optimized the fuzzy-PID controller with the used of GA, for the nuclear reactor power control. In this control strategy, GA was improved the precision through quadratic optimization for the membership function of the fuzzy logic controller. The results showed the high performance of the fuzzy-PID controller. Luan et al. (2011), designed the Takagi-Sugeno (T-S) fuzzy control system for NPP load following. In this method, the stability analysis was considered by means of linear matrix inequality approach.

All population-based metaheuristic algorithms have the potential to reach the optimal solution; without requiring a system physical information and transfer function. Unlike some other methods, as Ziegler-Nichols, these algorithms do not require any linearization, which reduces the output performance of a nonlinear system. Also, they have a better performance, especially on nonlin-

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ear issues. Other benefits include: intuitiveness, ease of implementation, ramp mode input, and the ability to effectively solve highly nonlinear mixed integer optimization problems (Hassan et al., 2005). In general, real-coded GA is more suitable and comfortable to deal with most practical complex engineering issues (Chang, 2007).

In this paper, the gains of PID controller are optimized (tuned) and scheduled directly based on any changes in the output power level (power demand), using the real-coded GA. The tuning is performed by minimizing an objective function of the decision variables include overshoot, settling time and stabilization time (along time intervals as measure of stability, using the Lyapunov analysis). Also, compared to other intelligent algorithms, the stability condition is considered in objective function.

2. Materials and methods

2.1. Problem description

The reactor power model is implemented based on the point kinetic equations with three groups of delayed neutrons; and the reactivity feedback, that caused by changes in the fuel and coolant temperatures and neutron poisons (Hetrick, 1993; Ramaswamy et al., 1993). The equations of a PWR-type nuclear reactor core are shown as follows:

2.1.1. Relative power kinetic model of the point reactor

$$\frac{dP_r}{dt} = \frac{\rho_t - \beta}{\Lambda} P_r + \sum_{i=1}^{3} \frac{\beta_i}{\Lambda} c_{ri} \tag{1}$$

Table 1
The typical PWR parameters at BOC, in 100% of nominal power.

Parameter	Value
Thermal Power	3000 MW
Core height	400 cm
Core radius	200 cm
Mean velocity of thermal neutron	220000 cm/s
Microscopic absorption cross section of xenon (σ_x)	3.5×10^{-18}cm^2
Effective microscopic fission cross section (Σ_f)	0.3358 s^{-1}
Fission yield of xenon (γ_X)	0.003
Fission yield of iodine (γ_I)	0.059
Decay constant of xenon (λ_X)	2.1×10^{-5}s^{-1}
Decay constant of iodine (λ_I)	2.9×10^{-5}s^{-1}
Prompt neutron lifetime (Λ)	10^{-4}s^{-1}
Delayed neutron fraction (β)	0.0065
Delayed neutron fraction of 1st group neutron precursor (β_1)	0.00021
Delayed neutron fraction of 2nd group neutron precursor (β_2)	0.00225
Delayed neutron fraction of 3rd group neutron precursor (β_3)	0.00404
Decay constant of 1st group neutron precursor (λ_1)	0.0124 s^{-1}
Decay constant of 2nd group neutron precursor (λ_2)	0.0369 s^{-1}
Decay constant of 3rd group neutron precursor (λ_3)	0.632 s^{-1}
Total reactivity worth of control rod (G_r)	14.5×10^{-3} δK/K
Heat capacity of the fuel (μ_f)	26.3 MW·s/°C
Fraction of reactor power deposited in the fuel (f_f)	0.92

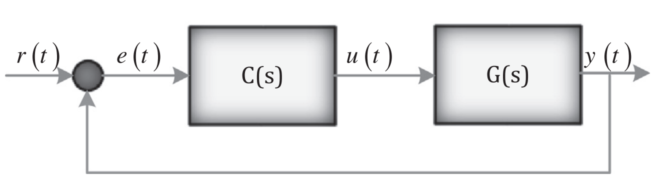

Fig. 1. Classical PID system, $C(s)$: Controller, $G(s)$: Plant.

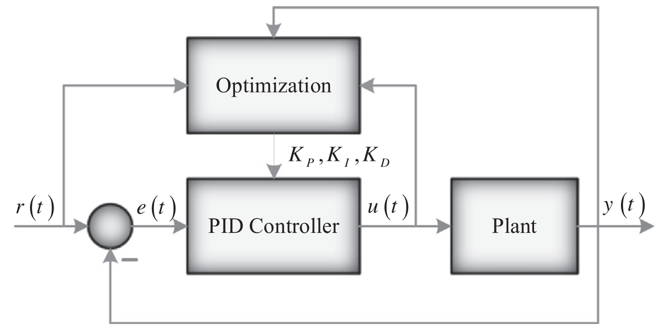

Fig. 2. Diagram of proposed GA-PID controller. $r(t)$: desired signal (relative power); $y(t)$: output signal; $e(t)$: error between input and output signal; $u(t) = Z_r$: control signal.

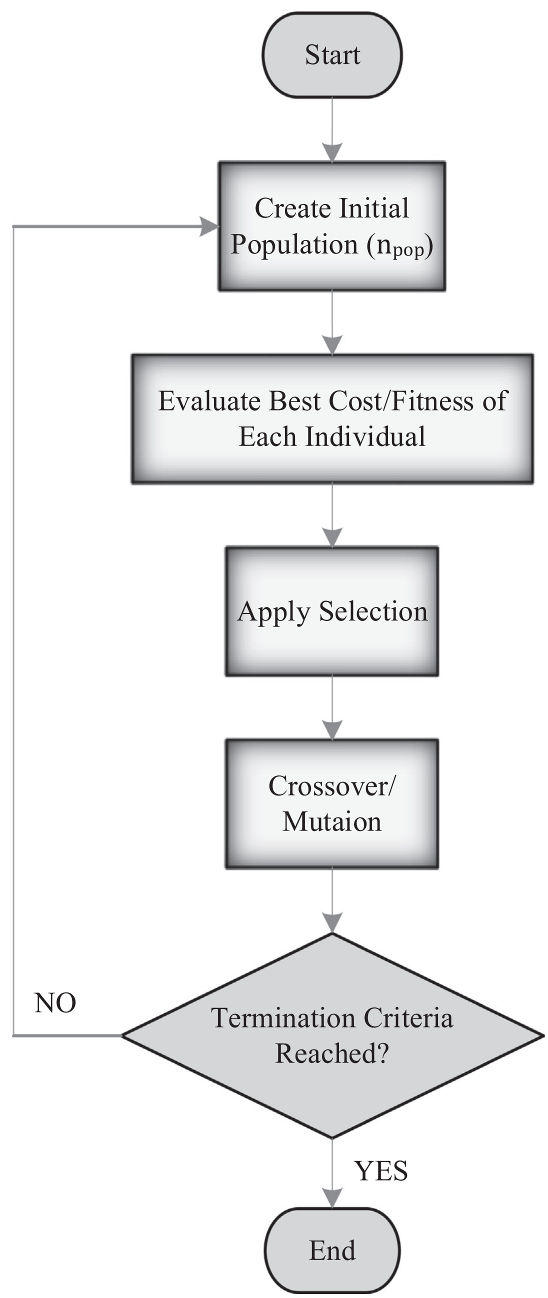

Fig. 3. GA scheme.