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Auto Tuning PID Controller based on Improved Genetic Algorithm for Reverse Osmosis Plant

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and Hoon Heo

Abstract**—** An optimal control of Reverse Osmosis (RO) plant is studied in this paper utilizing the auto tuning concept in conjunction with PID controller. A control scheme composing an auto tuning stochastic technique based on an improved Genetic Algorithm (GA) is proposed. For better evaluation of the process in GA, objective function defined newly in sense of root mean square error has been used. Also in order to achieve better performance of GA, more pureness and longer period of random number generation in operation are sought. The main improvement is made by replacing the uniform distribution random number generator in conventional GA technique to newly designed hybrid random generator composed of Cauchy distribution and linear congruential generator, which provides independent and different random numbers at each individual steps in Genetic operation. The performance of newly proposed GA tuned controller is compared with those of conventional ones via simulation.

Keywords**—**Genetic Algorithm, Auto tuning, Hybrid random number generator, Reverse Osmosis, PID controller

I. INTRODUCTION

According to a report from UNESCO, by the middle of this century, at worst 7 billion people in sixty countries will be water scarce, at best 2 billion people in forty eight countries. This expectation makes necessary for humanity to look for new alternative ways of ensuring a dependable supply of drinking water. The significance of this problem is increasing in the underdeveloped countries as well as in industrialized regions.

Desalination of seawater and brackish water is one of the alternatives for ensuring a dependable supply of drinking water. In recent years the process of reverse osmosis (RO) has become a significant technical option to solve this problem through the desalination of seawater [1].

RO is a process used to clean brackish water or to desalt seawater. The process consists in recovering water from a saline solution pressurized by pumping it into a closed vessel to a point grater than the osmotic pressure of the solution. Thus, the solution is pressed against a membrane so that it is separated from the solutes (the dissolved material). The portion of water that passes through the membrane reducing strongly the solute concentration is called permeate. The remaining water (brine) is discharged with a high salt concentration.

In the last years, significant advances in the membrane technology have allowed an essential improvement in the filtering quality and simultaneously a general reduction of costs. Hence, RO plants have today lower energy consumption, investment cost, space requirements and maintenance than other desalination processes [2].

On the other hand, RO desalination plants are energy intensive and require fine tuned components. Therefore, a good control design is necessary to maintain water production costs at acceptable level and to elevate the plant availability, particularly in regions with high water scarcity. Therefore, an advanced control technique is required for more efficient operation of RO plant. In this paper new GA technique is implemented on RO system. [3].

Many PID tuning methods are introduced. The Ziegler Nichols method is an experimental one that is widely used, despite the requirement of a step input application with stopped process [4]. One of disadvantage on this method is the necessary of the prior knowledge regarding plant model. Once tuned the controller by Ziegler Nichols method a good but not optimum system response will be reached. The transient response can be even worse if the plant dynamics change. It must be noticed that a great amount of plants has time-varying dynamics due to external/environmental causes, e.g. temperature and pressure. To assure an environmentally independent good performance, the controller must be able to adapt the changes of plant dynamic characteristics [5].

For these reasons, it is highly desirable to increase the capabilities of PID controllers by adding new features. Many random search methods, such as genetic algorithm (GA) have recently received much interest for achieving high efficiency and searching global optimal solution in problem space [6]. Due to its high potential for global optimization, GA has received great attention in control systems such as the search of optimal PID controller parameters. Although GA has widely been applied to many control systems, its natural genetic operations would still result in enormous computational efforts [7].

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II. PID CONTROLLER

The PID controller is well known and widely used to improve the dynamic response as well as to reduce or eliminate the steady state error. The derivative controller adds a finite zero to the open loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady state error due to a step function to zero.

PID control consists of three types of control, Proportional, Integral, and Derivative control.

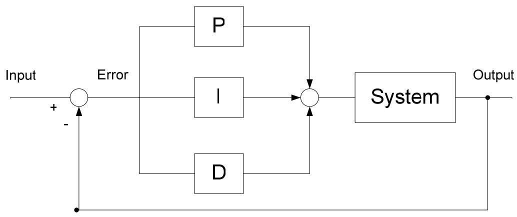

Fig.1 schematic of conventional PID controller

A. Proportional Control

The proportional controller output uses a ‘proportion’ of the system error to control the system. However, this introduces an offset error into the system.

$$P_{term} = K_P \times ERROR \tag{1}$$

B. Integral control

The integral controller output is proportional to the amount of time there is an error present in the system. The integral action removes the offset introduced by the proportional control but introduces a phase lag into the system.

$$I_{term} = K_I \times \int ERROR dt \tag{2}$$

C. Derivative control

The derivative controller output is proportional to the rate of change of the error. Derivative control is used to reduce/eliminate overshoot and introduces a phase lead action that removes the phase lag introduced by the integral action.

$$D_{term} = K_I \times \frac{d(ERROR)}{dt} \tag{3}$$

D. Continuous PID control

The three types of control are combined together to form a PID controller with the transfer function [8].

$$C_{PID}(s) = \frac{K_D s^2 + K_P s + K_I}{s} \tag{4}$$

III. GENETIC ALGORITHM

The basic principles of GA were first proposed by Holland. This technique was inspired by the mechanism of natural selection, a biological process in which stronger individual is likely to be the winners in a competing environment. GA uses a direct analogy of such natural evolution to do global optimization in order to solve highly complex problems [14]. It presumes that the potential solution of a problem is an individual and can be represented by a set of parameters. These parameters are regarded as the genes of a chromosome and can be structured by a string of concatenated values. The form of variables representation is defined by the encoding scheme. The variables can be represented by binary, real numbers, or other forms, depending on the application data. Its range, the search space, is usually defined by the problem.

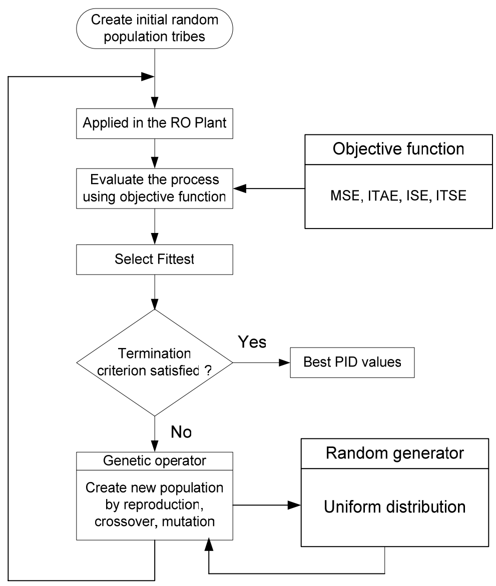

Fig. 2 flow chart of the general genetic algorithm

GA has been successfully applied to many different problems, such as: traveling salesman, graph partitioning problem, filters design, power electronics, etc. It has also been applied to machine learning, dynamic control system using learning rules and adaptive control. The combination of GA with other Artificial Intelligence techniques, like Fuzzy Sets and Artificial Neural Network, in hybrid system has been the solution for a great amount of problems. Success of GA solving high dimensional problem has been reported in the literature too. An illustrative flowchart of the GA algorithm implementation is presented in Figure 2. In the beginning an initial chromosome population is randomly generated. The chromosomes are candidate solutions to the problem. Than, the fitness values of all chromosomes are evaluated by calculating the objective function in a decoded form. So, based on the fitness of each individual, a group of the best chromosomes is selected through the selection process. The genetic operators, crossover and mutation, are applied to this "surviving" population in order to improve the next generation solution. Crossover is a recombination operator that combines subparts of two parent chromosomes to produce offspring. This operator extracts common features from different chromosomes in order to achieve even better solutions. Mutation is an operator that introduces variations into the chromosome. This operation occurs occasionally with a small probability. It randomly alters the value of a bit, in case of binary coding. In real coding it changes the entire value of a chromosome. Through the mutation operator the search space is explored by looking for better points. The process continues until the population converges to the global maximum or another stop criterion is reached [9].

IV. GENETIC OPERATOR

In each generation, the genetic operators are applied to selected individuals from the current population in order to create a new population. Generally, the three main genetic operators of reproduction, crossover and mutation are employed. By using different probabilities for applying these operators, the speed of convergence can be controlled. Crossover and mutation operators must be carefully designed, since their choice highly contributes to the performance of the whole genetic algorithm.

A. Reproduction

A part of the new population can be created by simply copying without change selected individuals from the present population. Also new population has the possibility of selection by already developed solutions.

There are a number of other selection methods available and it is up to the user to select the appropriate one for each process. All selection methods are based on the same principal i.e. giving fitter chromosomes a larger probability of selection. Four common methods for selection are:

1. Roulette Wheel selection
2. Stochastic Universal sampling
3. Normalized geometric selection
4. Tournament selection

And author uses Roulette Wheel selection.

B. Crossover

New individuals are generally created as offspring of two parents (i.e., crossover being a binary operator). One or more so called crossover points are selected (usually at random) within the chromosome of each parent, at the same place in each. The parts delimited by the crossover points are then interchanged between the parents. The individuals resulting in this way are the offspring. Beyond one point and multiple point crossover, there exist some crossover types. The so called arithmetic crossover generates an offspring as a component wise linear combination of the parents in later phases of evolution it is more desirable to keep individuals intact, so it is a good idea to use an adaptively changing crossover rate: higher rates in early phases and a lower rate at the end of the GA. Sometimes it is also helpful to use several different types of crossover at different stages of evolution

C. Mutation

A new individual is created by making modifications to one selected individual. The modifications can consist of changing one or more values in the representation or adding/deleting parts of the representation. In GA, mutation is a source of variability and too great a mutation rate results in less efficient evolution, except in the case of particularly simple problems. Hence, mutation should be used sparingly because it is a random search operator; otherwise, with high mutation rates, the algorithm will become little more than a random search. Moreover, at different stages, one may use different mutation operators. At the beginning, mutation operators resulting in bigger jumps in the search space might be preferred. Later on, when the solution is close by a mutation operator leading to slighter shifts in the search space could be favored [10][18].

V. EVALUATE THE PROCESS USING FITNESS FUNCTION

A. Objective function

The most crucial step in applying GA is to choose the objective functions that are used to evaluate fitness of each chromosome. Some works use performance indices as the objective functions. The objective functions are Mean of the Squared Error (MSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE)[8][11].

$$MSE=\frac{1}{t}\int_0^{\tau}(e(t))^2dt \quad ITAE=\int_0^{\tau}t|e(t)|dt$$
$$ISE=\int_0^{\tau}e(t)^2dt \quad ITSE=\int_0^{\tau}te(t)^2dt \tag{5}$$

B. The fitness values

The PID controller is used to minimize the error signals, or we can define more rigorously, in the term of error criteria: to minimize the value of performance indices mentioned above. And because the smaller the value of performance indices of the corresponding chromosomes the fitter the chromosomes will be, and vice versa, we define the fitness of the chromosomes as (6) [11][18].

$$Fitness\ \ value=\frac{1}{Performance\ \ index} \tag{6}$$

VI. PROPOSED NEW METHODS

This paper presents an advanced auto tuning PID controller for RO plant to search the optimal control gain parameters k_P, k_I, k_D with improved GA. The searching steps of the proposed optimal PID controller are shown as below. The improved GA has new random generator and objective function.

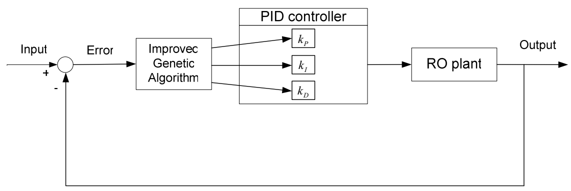

Fig. 3 schematic of auto tuning PID controller based on improved GA

A. New random generation

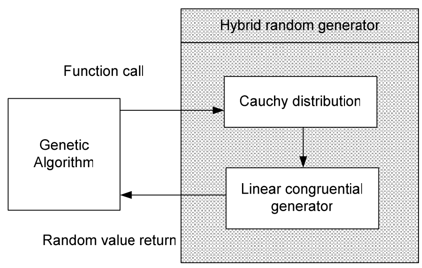

Fig. 4 schematic of proposed hybrid random generator

Fig 4 is the structure of new hybrid random generator.

Generally, GA is constructed on the basis of probability using random function. Conventional GA has used random function in the MATLAB or C language library. However more reliable random functions are required for better performance of GA.

This study proposes more pureness and longer period of random number generation for GA. The steps are listed below.

(Ⅰ) Call the random generator function to make random values during GA processing.

(Ⅱ) Get a first random number from Cauchy distribution function method, which is represented as (7).

$$F(p, x_0, \gamma) = x_0 + \gamma \tan[\pi(p - 0.5)] \tag{7}$$

p is random value between 0 and 1, x_0 is the location parameter, specifying the location of the peak of the distribution and γ is the scale parameter which specifies the half width at half maximum. Set as x_0=0, γ=1 generally and it is called 'standard Cauchy distribution' [15]. In this paper set these values as random from 0 to 1. So probability density function always changes when GA program is called for random generator function. The output from Cauchy distribution is the expanded value between 0 and 1 and the input of linear congruential generator.

(Ⅲ) The mechanism of linear congruential generator is represented as (8).

$$X_i = (aX_{i-1} + c) \bmod m \qquad ; i = 1,2,3\ldots$$
$$0 < m, \quad a < m, \quad c < m, \quad X_0 < m \tag{8}$$

Where X_0 the initial value that selected at random. Random value is that X_1 divided by m [16] [17]. This method can expand the period of random function effectively if the condition satisfies. As a result, the output value is improved random number.

(Ⅳ) Return the final value to GA.

The newly designed random number generator gives more reliable random generator than normally using conventionally one.

B. New objective function

In control engineering, Mean of the Squared Error (MSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE) are used as objective function of GA universally. However in the study use of new objective function is attempted for RO plant, which is Root Mean Square Error (RMSE) represented as in (9).

$$RMSE = \frac{1}{t}\int_0^{\tau} \sqrt{(e(t))^2}\, dt \tag{9}$$

Fig. 5 shows the schematic diagram of application of new hybrid random number generating method and objective

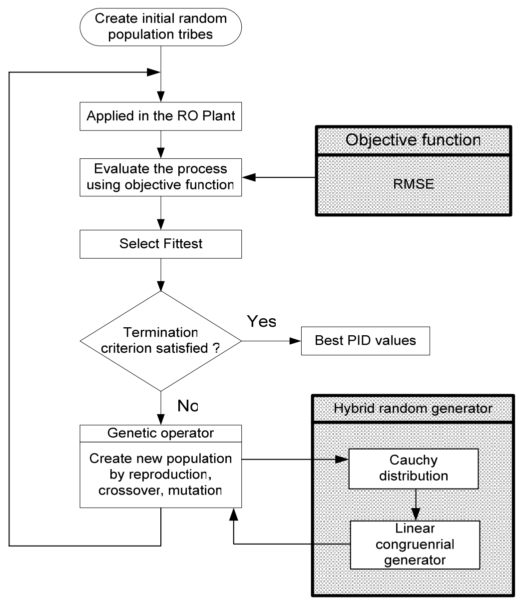

Fig. 5 flow chart of the improved Genetic Algorithm function for GA.

The improved GA work in this paper as follows.

(Ⅰ) The initial population tribes are filled with individuals that are generally created at random. Sometimes, the individuals in the initial population are the solutions found by some method determined by the problem domain. In this paper, we gave random values to these initial populations. But their ranges limited around the values. The ranges of PID values are rationally chosen by arbitrary and it is true that the limitation will influence the results of the GA search; it is intended to obtain more stable, efficient and accurate solutions.

(Ⅱ) Every generation is applied RO plant, which was described by PID parameters and produced a group of errors that calculated the RMSE value from transient to steady state.

(Ⅲ) Each individual in the current population is evaluated using the objective function.

(Ⅳ) If the termination standard [i.e., the generation number > preset number] is met, the best solution (i.e., PID gain parameters) is returned.

(Ⅴ) From the current population, individuals are selected based on the previously computed fitness values. A new population is formed by applying the genetic operators (i.e., reproduction, crossover, mutation using random generator) to these individuals.

(Ⅵ) Actions starting from step (Ⅱ) are repeated until the termination standard is satisfied, which is called a generation.[18]

VII. SIMULATION RESULTS

Recently the most widely used RO plant has its control system utilizing empirically determined parameters. The simulation concept is shown in Fig. 4, where the GA and PID

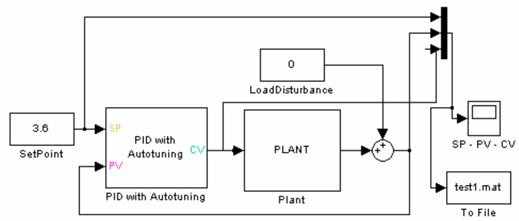

Fig. 6 simulink of auto tuning PID controller based on improved GA

control action are implemented in the MATLAB environment[12][13].

In this section, numerical simulation is conducted to confirm the effectiveness of the proposed method. Parameters are set for GAs in the study is as in Table1.

TABLE I
GAs PARAMETER SETTING

Parameter	Value
Selection method	Roulette wheel
Population size	80
Generation size	220
Crossover probability	65%
Mutation probability	0.1%
Ranges of PID gain values	-1000~1000

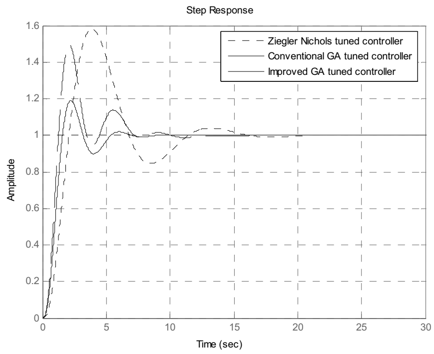

Fig. 7 step response of improved GA tuned controller vs. Ziegler Nichols tuned controller

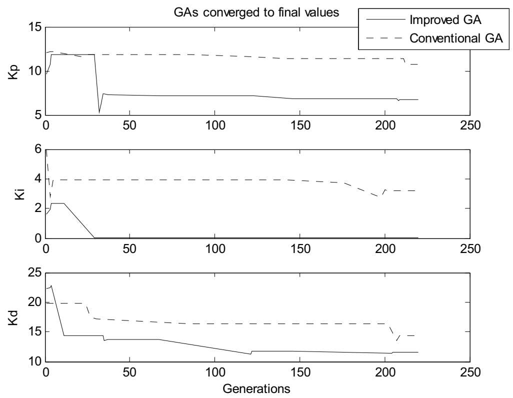

Fig. 8 response trends upon improved GA converging through generation

It can be seen that improved GA tuned PID controller reveals shorter settling time. Moreover the overshoot is considerably lower than the those obtained via the conventional GA tuned controller and Ziegler Nichols tuned controller. The comparison of the performances using improved GA based PID tuned controller, conventional GA based PID tuned controller and Ziegler Nichols method are made as shown in Table 2.

TABLE 2
PERFORMANCE COMPARISION

Item	Improved GA	GA	Ziegler Nichols
Peak amplitude	1.19	1.5	1.58
Overshoot (%)	19	49.9	58.1
Rising time (sec)	0.966	0.755	1.29
Settling time (sec)	5.12	6.92	14.9
Final value	1	1	1
P gain	6.71275	10.73984	6
I gain	0.0172	3.2230	1.91
D gain	11.48921	14.36576	4.74

VIII. Conclusion

This paper demonstrated how an improved GA can be used for the optimal control of RO plant via computer simulation. A new GA method based on hybrid concept of Cauchy distribution, linear congruential generator and simultaneous using of RMSE type objective function to design a controller for RO plant is presented. Much more improved performance of proposed GA tuned controller than the conventional ones has been revealed in terms of overshoot and settling time etc. Real time implementation of the proposed method is under way. Also at the same time implementation of micro controller based on the new method in commercially low cost is being sought. Although GA needs lot of computation, its real time realization of the idea will be performed via physical experiment.

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