Application of Differential Evolution to Parameter Identification of Bhumibol Hydro Power Plant in Thailand

N. Punarai, S. Khumkaew, J. Kluabwang, *Member, IAENG*

Abstract—**This article shows an application of differential evolution (DE) technique for solving parameters identification of an mathematical model of Bhumibol hydro power plant. The mathematic model is in quadratic form which its two input arguments are the water stored in reservoir and water discharge, the only one output argument is electric output power. The model also consists of six parameters to be solved. To find the optimal values of those parameters, efficient identification technique and sufficient data are necessary all 24 hour a day. The data will be divided into two parts, first 60% part for parameter identification and the second 40% part for model validation. The obtained results from randomly 20 trials are satisfied. To confirm by validation results, all four errors of validated data set are less than 0.67%. In addition, the convergence property of DE over the parameter identification is also elaborated.**

***Index Terms*—parameter identification, mathematical model, differential evolution technique**

I. Introduction

In the last decades, world electrical energy consumption has significantly increased with a share that has reached 17.7% in 2010 and is predicted to double by 2025 [1].

A modern power system consists of a large number of thermal and hydro plants connected at various load centers through a transmission network. An important objective in the operation of such a power system is to generate and transmit power to meet the system load demand at minimum fuel cost by an optimal mix of various types of plants. However, the hydro resources being limited, thus the worth of water is greatly increased. Therefore, an optimal operation of a hydrothermal system will lead to a huge saving in fuel cost of thermal power plants [2]. This paper presents an alternative method for solving parameter identification of a hydro power plant by an efficient search techniques, namely differential evolution (DE) to identify parameter.

This paper consists of five parts, introduction, problem description, differential evolution technique, experimental results and conclusion.

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N. Punarai is with Operating and maintenance Department, Bhumibol hydroelectric power plant, Yan Ree, Sam Ngao, Tak 63150 THAILAND (e-mail:nathapong.p@egat.co.th).

S. Khumkaew, and J. Kluabwang are with Electrical Engineering Department, Rajamangala University of Technology Lanna, Muang, Tak 63000 THAILAND (e-mail: sunthon262009@hotmail.com and jukkrit_k@rmutl.ac.th).

II. Problem description

A. Mathematical model of the Bhumibol dam

Bhumibol hydroelectric power plant located in Tak province of northern Thailand. As shown in Fig. 1, Bhumibol dam is a concrete arch gravity dam constructed across the Ping River and its storage capacity is 13,462 million cubic meters (MCM). There are eight electric power generating units with total installed capacity 779.2 MW [3].

Fig. 1. Bhumibol dam and its hydroelectric power plant.

The dam has played an important role in irrigation, electricity, flood control, fishery and also tourism sector from 1964 [4].

Bhumibol hydroelectric power plant is connected to a large grid power system which other thermal plants and hydro plants are also connected too. Optimal operation planning technique is required to scheduling each generating unit successfully [2].

Mathematical model of a hydro power plant frequently used in the short-term hydro thermal generation scheduling problem [5]-[7] is in quadratic form as shown in (1)

$$P_i = c_1 V_i^2(t) + c_2 Q_i^2(t) + c_3 V_i(t) Q_i(t) + c_4 V_i(t) + c_5 Q_i(t) + c_6 \qquad (1)$$

Where P_i is output power (MW) of generating unit, V_i is storage volume (MCM) of a dam. Q_i is water discharge (MCM). Subscript i refer to time interval i and c_1 to c_6 are coefficients of the hydro unit.

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To find these coefficients by an efficient heuristic search technique, namely Differential Evolution (DE) [8] is an interestingly alternative method proposed in this paper.

III. Differential Evolution Techniques

DE is an evolutionary technique similar to classic genetic algorithms (GAs) that is useful for the solution of global optimization problems. DE has been proposed by Storn and Price in 1997 [8]. With the advantages of simplicity, fast convergence and less parameter, DE has been used in many areas, such as chemical process optimization [9], path planning [10], electric power control [11], scheduling [12] and so on [13]-[14].

A. Basic concept

DE follows the general procedure of an evolutionary algorithm: an initial population of individuals is created by random selection and evaluated; then the algorithm enters a loop of generating offspring, evaluating offspring, and selection to create the next generation, till a stop condition is met. Generating offspring consists of two operations: differential mutation and differential crossover. The mutation operation creates a new individual v_i called the mutant by adding the weighted difference between two individuals (vectors) chosen randomly from the population to a third one, also chosen randomly, as shown in (2).

$$v_i = x_{i1} + F \cdot (x_{i2} - x_{i3}) \tag{2}$$

Where i, $i1$, $i2$, $i3 \in \{1, \ldots, \mathrm{NP}\}$ are mutually different indices, NP is the size of population, and F is a real positive scaling factor of the difference $d_i = x_{i2} - x_{i3}$.

The crossover operator implements a discrete recombination of the mutant, v_i, and the parent vector, x_i, to produce the offspring u_i. This operator is formulated as shown in (3)

$$u_i(j) = \begin{cases} v_i(j), \ if \ U_j(0,1) \le CR \ or \ j = k, \\ x_i(j), \qquad\qquad otherwise \end{cases} \tag{3}$$

Where: $U_j(0, 1)$ is a random number in the interval [0,1], $CR \in [0, 1]$ is the crossover rate, and $k \in \{1, 2, \ldots, d\}$ is a random parameter index, chosen once for each individual i to be sure that at least one parameter is always selected from the mutant.

B. Objective function

This study monitors process of searching all six seeking coefficients in (1) by DE through the error between measured and simulated powers. The error considered here is mean absolute error as shown in (4)

$$E = \frac{1}{n}\sum_{i=1}^{n} \left| P_{mea} - P_{sim} \right| \tag{4}$$

Where P_{mea} is measured power, P_{sim} is measured power, and n is number of data recorded from each hour all a day. Electricity Generating Authority of Thailand (EGAT) who owns the Bhumibol dam, provided valuable data (recorded in October, 2013 the same time of flood in Bangkok) including, output power, storage volume, and water discharge, according to (1). From ten prepared data sets, six sets are used to identify and then return E_{i1} to E_{i6} and the rest four sets will be treated to validation procedure in order to obtain E_{v7} to E_{v10}. All obtained errors will be formulated in linear function to create an objective function with their weighting functions as in (5)

$$\begin{aligned} J = {} & a_1E_{i1} + a_2E_{i2} + a_3E_{i3} + a_4E_{i4} + a_5E_{i5} \\ & + a_6E_{i6} + a_7E_{v7} + a_8E_{v8} + a_9E_{i9} + a_{10}E_{v10} \end{aligned} \tag{5}$$

Where J is the objective function of DE and all weighting functions, a_1 to a_{10}, are defined as 0.1 alike. The objective function will minimized by the efficient iterative search technique, DE, to obtain the proper value of those coefficients, c_1 to c_6, in (1).

C. Parameters setting

To learn how does the DE work, the useful document, and its code may be required and available in [8]. This research has applied DE to solve the parameter identification of Bhumibol hydroelectric power plant in northern Thailand. The parameter of DE can be summarized as follows,

- number of input arguments, D = 6
- termination criteria, VTR = 0.390855
- maximum iteration, Iter_max = 50,000
- crossover ratio, CR = 0.75
- mutation factor, F= 0.85
- population, NP = 100
- strategy = 3 (DE/best/1 with jitter)

IV. Experiments and Results

DE and its objective function are coded in MATLAB®. All codes for identification process operated on Intel® Pentium® CPU B940 2 GHz, RAM 4 GByte, HDD 400 GByte and Window® 7 operating system. To confirm obtained results, 20 trials were performed with randomly initial solutions.

A. Computational results

Table I shows performance of DE on parameter identification of Bhumibol dam in used iterations and time spent from 20 trials. All trials are success. The maximum number of iteration till stop searching (J<0.390855) is 821 with its J = 3.90854607 within 23.96184 seconds and another minimum number of iteration till stop searching is 663 with J = 3.90854634 within 19.27394 seconds. The maximum searching time of 24.50318 seconds occurred when the trial stop searching at the 813th iteration. The average searching iterations and searching are 757.95 iteration and 22.27772 seconds. We can conduct the

TABLE I
ITERATIONS AND TIME SPENT FROM 20 TRIALS

	Iterations	Searching Time (seconds)
Maximum	821	24.50318
Mean	757.95	22.27772
Minimum	663	19.27394
Standard Deviation	42.10	1.28070

TABLE II
FINAL SOLUTIONS FROM 20 TRIALS

	Minimum	Maximum
Objective function	0.3908543	0.3908549
c_1	-3.1372	-3.1374
c_2 (x10^7)	-6.3441	-6.3442
c_3 (x10^4)	1.2884	1.2891
c_4 (x10^4)	8.1833	8.1819
c_5 (x10^8)	4.2632	4.2632
c_6 (x10^8)	-8.8512	-8.8493

behavior of DE on the problem throughout this results that more time spent may not spend more iteration.

Table II illustrates two samples of final solution, the minimum one with J = 0.3908543 has c_1=-3.1372, c_2=-6.3441x10^7, c_3=1.2884x10^4, c_4=8.1833x10^4, c_5=4.2632x10^8 and c_6=-8.8512x10^8. The other one with J = 0.3908549 has

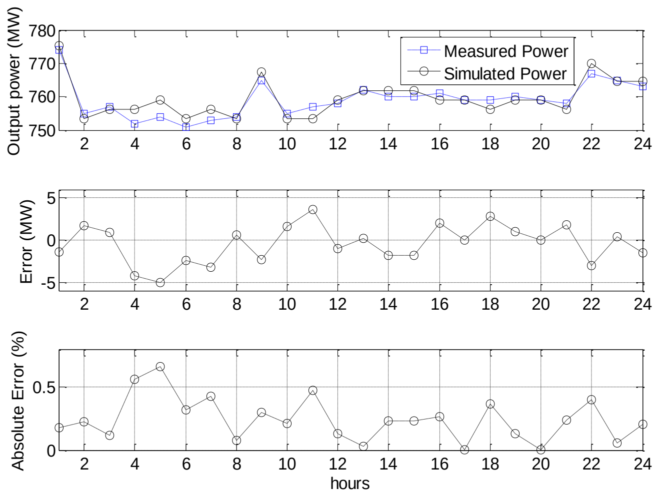

Fig. 2. Parameters validation of the best result (J=0.3908543)

the same value of c_5 and other coefficients are a little bit different.

Graph on the top of Fig. 2 is comparative demonstration between measured and simulated output powers generated by the obtained coefficients through (1). Both lines are very close together, we can consider in the lower graph. The errors are bounded in ± 5 MW that it is very tiny with respect to the actual output power 760 MW. The absolute error in percent according to (2) are shown on the bottom graph of Fig. 2, the peak absolute error happens at hour 5 with value 0.6631% and there are two near zero errors (0.000034%) located at hour 17 and 20 respectively.

B. Convergence characteristics

In practice, after 20 trials have been performed successfully, all of them converge to the same termination criteria (J= 0.390855). We are satisfied these convergence property of DE on the parameter identification problem.

Fig. 3 shows a convergence curve of DE which begin at J=28.09 and continuously improve solution until J is less than TC. The searching is end at 751th iteration within 22.55 seconds

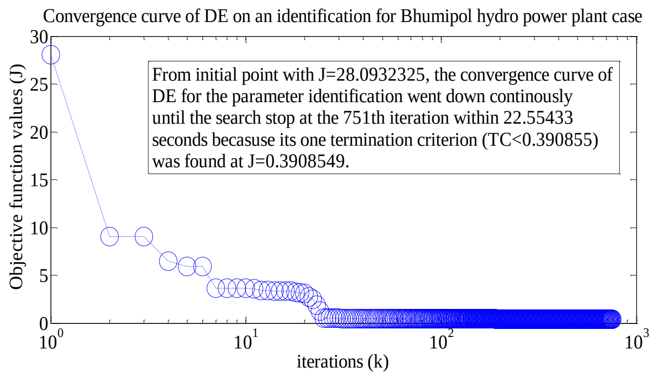

Fig. 3. Convergence curve of DE.

V. CONCLUSION

Application of the classic DE on solving parameter identification for Bhumibol hydro power plant is presented in this paper. Because quadratic function are frequently used to represent mathematical model of the hydro power plant in hydrothermal power generation scheduling problem, to obtain their coefficients by efficient search techniques, DE, has been proposed here. Experiment repeated independently 20 trials, and obtained results guaranteed convergence property and good quality solution bounded error less than 0.67%.

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