Estimation of Fuel Cost Function Characteristics Using Cuckoo Search

M. R. AlRashidi, K. M. El-Naggar, and M. F. AlHajri

Abstract— The fuel cost function describes the electric power generation-cost relationship in thermal plants, hence, it sheds light on economical aspects of power industry. Different models have been proposed to describe this relationship with the quadratic function model being the most popular one. Parameters of second order fuel cost function are estimated in this paper using cuckoo search algorithm. It is a new population based meta-heuristic optimization technique that has been used in this study primarily as an accurate estimation tool. Its main features are flexibility, simplicity, and effectiveness when compared to other estimation techniques. The parameter estimation problem is formulated as an optimization one with the goal being minimizing the error associated with the estimated parameters. A case study is considered in this paper to illustrate cuckoo search promising potential as a valuable estimation and optimization technique.

Keywords— Cuckoo Search, Parameters estimation, Fuel cost function, Economic dispatch.

I. INTRODUCTION

THE overall modeling simulation accuracy depends on many factors like system modeling and its parameters and simulation data as well as the technique or tool proposed for solving the targeted problem. Many factors such as ambient operating temperature and aging of generating units greatly affect the heat curve (or alternatively fuel cost curve) characteristics of generating units. Thus, to achieve better overall operational and economical practices, frequent estimation of generating units characteristics is highly recommended [1]. Many utilities are using obsolete data to describe the input-output relationship of generating units [2]. One of the most critical issues in solving the economic dispatch problem is to have an accurate estimate of the thermal unit input-output curve coefficients. Therefore, it is very important to use precise and reliable estimation technique for estimating the input-output curve coefficients. Different mathematical models are proposed to represent the fuel cost function. However, the most commonly one is the second order model which is very popular due its sufficient accuracy and simplicity.

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Various parameter estimation techniques have been proposed to solve estimation problems in power systems. Some of these techniques are based on static estimation techniques such as least error square (LES) and least absolute value, others are based on dynamic estimation techniques such as Kalman filter. While the LES technique has been the most famous static estimation technique and in use for a long time as the preferred technique for optimum estimation in general, some limitation and disadvantages are associated with this approach. For example, when the data set is contaminated with bad measurements, the estimates may be inaccurate unless a large number of data points are used [3;4].

Dynamic Kalman filtering algorithm is another powerful approach commonly used in state estimation. Unlike static approaches, where the entire data is used to obtain the optimal solution, dynamic filters are recursive algorithms. In recursive filters, the estimates are updated using each new measurement. Dynamic filters are well suited to on-line digital processing as data are processed recursively. They are used extensively in estimation problems for dynamic systems [5].

Bio-inspired and artificial intelligence based techniques such as artificial neural networks (ANN), expert systems, particle swarm optimization (PSO), genetic algorithms (GA) have been also used in power system state estimation. In general, artificial neural networks are superior when the process model is not well defined mathematically. However, ANN based methods have some disadvantages. One of the drawbacks of such techniques is the huge amount of data required for network training which may not be feasible in some cases [6-8].

This paper presents a new application of parameter estimation technique based on Cuckoo search algorithm (CS) .It is a relatively new member of the family of evolutionary computation methods that have been gaining added popularity due to their robustness and ease of use.

II. FUEL COST MODELING

The fuel cost curve for thermal generating unit (*i*) can be modeled by a second order polynomial function that relates its fuel cost to its real power output as:

$$F_i\left(P_{ti}\right) = a_{oi} + a_{1i}P_{ti} + a_{2i}P_{ti}^{\ 2} + r_i \qquad (1)$$

Where

F_i is the fuel cost function of the i[th] generating unit
P_{ti} is the power generated by the i[th] thermal generating unit
a_{oi}, a_{1i}, and a_{2i} are the curve constants of the i[th] generating unit.
r_i is the error associated with the i[th] equation

This model can be clearly classified as a convex and smooth curve. Now, the objective function is to find an estimate for the parameters that minimizes the error vector for a given set of data. The fuel cost function may be either in terms of heat energy requirements (GJ/hr), i.e. heat curve, or in terms of total cost per hour ($/hr), i.e. fuel cost. The output is normally the net electrical power output of the unit (MW).

III. Cuckoo Search

CS is a new member of naturally inspired optimization algorithm that was first introduced by Yang and Deb in 2009 [9]. This meta-heuristic combines two basic concepts: the breeding behavior of some cuckoo species as they lay their eggs in the nests of other hosting birds and characteristics of Lévy flights of some birds and fruit flies. Cuckoos are famous for their intruding nature in their reproduction process as they lay their eggs in other species nests. It is even more interesting to know that some types of female cuckoo species like Tapera are able to mimic other species eggs in color and pattern in order to increase the probability of their eggs survival. This aggressive instinct is also presented in cuckoo chicks as they usually hatch earlier than other host eggs and their first "innocent" action is evict competitor eggs away from the nest in order to have exclusive feeding privileges [10].

CS is a general population-based optimization algorithm with promising potential to compete with other well established biologically and naturally inspired optimization methods such as ANN , GA, PSO, simulated annealing (SA), and differential evolution (DE). It can be generally described as follows:

1. There is a fixed number of nests with hosting eggs and each cuckoo lays one egg (new possible solution) in a randomly chosen nest at each iteration.
2. The nests with high quality of eggs (better objective function values) will survive to the next generation, i.e. the cuckoo egg will replace original eggs with worse objective function values.
3. Hosting birds will discover intruding eggs with a probability $P_a \in (0,1)$ and cuckoo eggs will be eliminated from the current population or nests are abandon.

Randomness is included in this meta-heuristic approach by introducing Lévy flight operator when generating a new set of solutions as follows:

$$x_i^{k+1} = x_i^k + \alpha \oplus Levy(\lambda) \quad (2)$$

where
k is the iteration index
x is a solution candidate
α is a step size related to the problem search space
$\oplus$ is entry wise multiplication operator
The Lévy flight is basically a random walk with a random step length being drawn from Levy distribution:

$$Levy \sim u = k^{-\lambda}, \lambda \in]1,3] \quad (3)$$

IV. Simulation Results

A practical data published in the literature is used to validate and test the proposed CS approach [11]. The field data are used to estimate the parameters of the second order model described in Equation (1). These measurements are for three thermal plants using different fuels (coal, oil and gas) and each plant is rated at 50 MW.

TABLE I
CS PARAMETERS ESTIMATION

Type	P (MW)	Estimated Parameters based on CS	
Unit 1 (Coal)	10.0		
	20.0	a_0	96.540
	30.0	a_1	7.575
	40.0	a_2	0.042
	50.0		
Unit 2 (Oil)	10.0		
	20.0	a_0	100.887
	30.0	a_1	7.890
	40.0	a_2	0.045
	50.0		
Unit 3 (Gas)	10.0		
	20.0	a_0	99.239
	30.0	a_1	8.138
	40.0	a_2	0.045
	50.0		

Figures 1-3 shows the estimated fuel cost function along with the actual cost based on CS estimated parameters for three kinds of generating units. It is clear that CS was able to accurately estimate the second order model parameters.

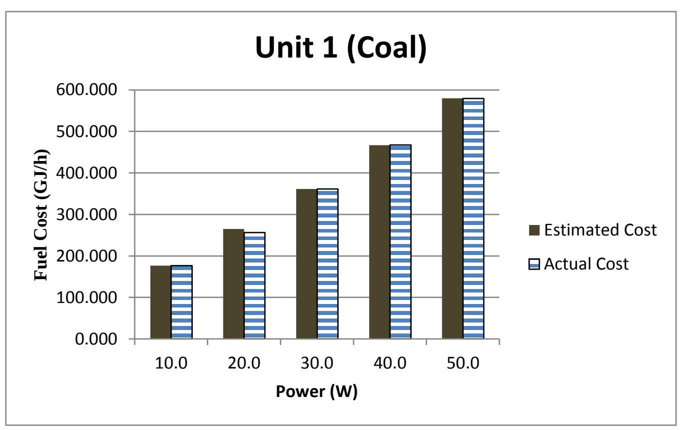

Fig. 1 Estimated and actual costs for Unit 1

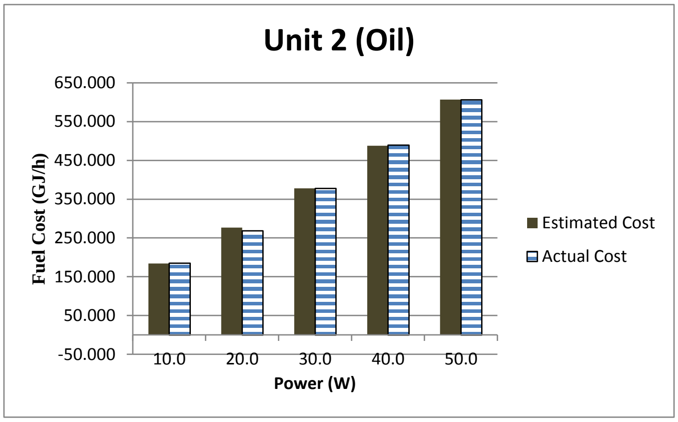

Fig. 2 Estimated and actual costs for Unit 2.

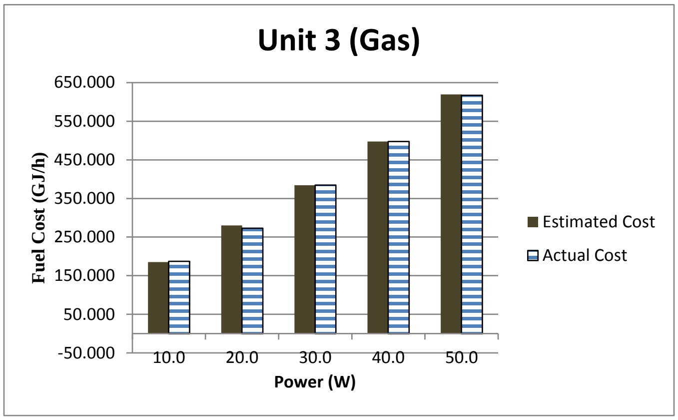

Fig. 3 Estimated and actual costs for Unit 3.

V. Conclusion

CS technique is presented in this paper for estimating the parameters of input-output curve of thermal units. The formulated estimation problem is presented in state space form. The objective is to minimize the total estimation error. Therefore the problem is handled and viewed as an optimization problem rather than an estimation one. The developed CS technique is used to solve the formulated optimization problem. The proposed CS method is tested successfully using second order model. Different units are used to test the robustness of the developed approach. CS performance is steady and precise in all test cases. The very accurate results obtained show that the proposed method can be used as a very precise tool for estimating the fuel cost curve parameters.

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