ISSN 1746-7659, England, UK
Journal of Information and Computing Science
Vol. 6, No. 1, 2011, *pp*. 064-072

Simulated Annealing Algorithm for Environmental/Economic Dispatch Problem

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(*Received September 29, 2009, accepted November 2, 2009*)

Abstract. This paper presents a Simulated Annealing (SA) algorithm for solving the Environmental/Economic Dispatch Problem (EED). This problem is formulated as a multi-objective one with two competing functions, namely economic cost and emission functions, subject to different constraints. The inequality constraints considered are maximum and minimum limits of power generation while the equality constraint is demand-generation balance. The results are obtained for a simple power 3-generator system. The advantage of the SA algorithm is its robustness to find the global for our problem.

Keywords: Environmental/Economic Dispatch, Simulated Annealing Algorithm, Multi-objective optimization, Combinatorial optimization

1. Introduction

Major part of the power generation is due to fossil fuel power plants and their emission is a source of pollution for the environment [1].

Many countries around the globe have recently scheduled strategies for the reduction of the amount of the pollutants from fossil fuel power generation units.

Apart from particular pollutants, there are three different types of particular matter such as carbon di-oxide (CO_2), nitrogen oxides (NO_x) and sulphur oxides (SO_x) emitted from fossil fuel power plants. These pollutants have, mainly, ill effects to the human body.

This paper focuses on SO_2 and NO_x because their control is important at global level.

The Environmental/Economic Dispatch Problem (EED), is a multi-objective problem with conflicting objective because the minimum cost of power generation is conflicting with pollution minimization.

Many researches addressed the environmental and the economical objectives simultaneously by combining them linearly to form a single objective function [2]. King et al [3] suggested a Hopfield neural network for finding the optimal EED of thermal generation units. J. Nanda et al [4] solved th.e EED Problem using linear and non-linear goal programming techniques. Song et al [5] used a fuzzy logic controlled genetic algorithm for solving the EED Problem. Yalcinoz and Altum [6] solve the EED Problem via genetic algorithm with arithmetic crossover. Srinivasan and Tettamanzi [7] used a Heuristic-guided Evolutionary Approach to multi-objective Generation Scheduling suggesting a feasible solution.

The paper is organized as follows: Section 2 is an overview of the SA algorithm is presented. Section 3 formulates the SA algorithm for EED Problem. Section 5 presents the case study. Finally, Section 6 presents the conclusions.

2. Simulated Annealing Method

Simulated Annealing (SA) is a stochastic optimization technique which is based on the principles of statistical engineering. The search for a global minimum of a multidimensional cost function is a quite complex problem especially when a big number of local minimums correspond to the respective function. The main purpose of the optimization is to prevent hemming about to local minimums. The originality of the

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SA method lies in the application of a mechanism that guarantees the avoidance of local minimums.

Following its introduction from Kirkpatrick et al [8], simulated annealing is mainly applied to large-scale combinatorial optimization problems.

2.1. The process of annealing in Thermodynamics

At high temperatures, the metal is in liquid phase. The molecules of liquidated metal, move freely with respect to each other. By gradually cooling (thermodynamic process of annealing) thermal mobility is lost. The atoms start to get arranged and finally form crystals, having the minimum energy which depends on the cooling rate. If the temperature is reduced at a very fast rate, the crystalline state transforms to an amorphous structure, a meta-stable state that corresponds to a local minimum of energy.

To conclude, the main point of the process is slow cooling, that leads to a crystallized solid state, which is a stable state, corresponding to a minimum energy. This is the technical definition of annealing and it is essential for insuring that a low energy state will be achieved.

There are similarities between the thermodynamic simulation annealing process and a combinatorial optimization problem.

Table I. Correspondence between thermodynamic simulation and combinatorial optimization

Thermodynamic Simulation	**Combinatorial Optimization**
System States	Feasible Solutions
Energy	Cost
Change of State	Neighboring Solutions
Temperature	Control Parameter
Frozen State	Heurestic Solution

The annealing process of metal influences SA algorithm.

If the system is at a thermal balance for given temperature T, then the probability $P_T(s)$ that it has a configuration s depends on the energy of the corresponding configuration $E(s)$, and is subject to the Boltzmann distribution:

$$P_T(s) = \frac{e^{-E(s)/\kappa T}}{\sum_W e^{-E(w)/\kappa T}} \tag{2}$$

Where κ is the Boltzmann constant and the sum Σ_W includes all possible states W.

Metropolis et al [9] were the first to suggest a method for calculating a distribution of a system of elementary particles (molecules) at the thermal balance state.

Let's suppose that the system has a configuration g, which corresponds to energy $E(g)$. When one of the molecules of the system is displaced from its starting position, a new state σ occurs which corresponds to energy $E(\sigma)$. The new configuration is compared with the old one. If $E(\sigma) \leq E(g)$, then the new state is accepted. If $E(\sigma) > E(g)$, then the new state is accepted with probability :

$$e^{-(E(\sigma)-E(g))/\kappa T}$$

Where κ is the Boltzmann constant.

The basic structure of the algorithm is presented at the following flow diagram (Figure 1) :