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# Economic dispatch using hybrid grey wolf optimizer

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ABSTRACT

This paper presents the application of one of the latest swarm intelligence algorithms, the grey wolf optimizer, for solving economic dispatch problems that are nonlinear, non-convex and discontinuous in nature, with numerous equality and inequality constraints. Grey wolf optimizer is a new metaheuristic algorithm that is loosely based on the behavior of the grey wolves. The optimizer has been hybridized to include crossover and mutation for better performance. Four economic dispatch problems (6, 15, 40, and 80 generators), with prohibited operating zones, valve point loading effect and ramp rate limit constraints have been solved, with and without transmission losses. The losses are calculated using *B*-coefficients. The results obtained are compared with those reported using other methods in the literature. The comparisons show that the hybrid grey wolf optimizer used in this paper either matches or outperforms the other methods.



## 1. Introduction

Economic dispatch (ED) in power systems is an important, real-world optimization problem that has minimization of generation cost as its objective. Given the importance of ED, solving the ED problem has been attempted from the early 1970's [1]. These early attempts employed classical, gradient based techniques such as lambda-iteration method, gradient method and dynamic programming [2]. However, gradient based methods require that the function to be optimized be differentiable, continuous, and convex, to successfully locate the global optimum. The ED problem has to satisfy a number of constraints including the presence of prohibited operating zones (POZ), valve point loading effect, and ramp rate constraints, which make the problem a non-convex and discontinuous one. These complicating factors gave rise to modifications to the gradient based methods that have continued up to the present. Some of these modifications are a branch and bound method applied to a quadratic programming approach [3], an improved lambda-iteration method using a two stage approach [4], and the use of the concept of decline rate, instead of incremental cost [5].

These complicating factors also led to a huge interest in gradient free, evolutionary computation (EC) or metaheuristic methods of optimization being employed to solve the ED problem. Some of these methods are the evolutionary programming (EP), PSO [9], firefly algorithm, biogeography-based optimization [12], teaching-learning algorithm [13], bee swarm optimization [14], cuckoo search algorithm [15], random drift particle swarm optimization [16], honey bee mating optimization [17], and chaotic bat algorithm [18]. [6]. contains the application of EP to the basic ED problem [7], the application of EP to the ED problem with multiple fuel options, and [8] the application of EP to all the variants of the basic ED problem [10]. has the application of the firefly algorithm to the basic ED problem, and [11] the application of the same firefly algorithm to the reserve constrained ED problem.

Given the criticism that metaheuristic methods are computationally intensive, a hybrid of both gradient based search and gradient free search approach too has been tried [19]. contains a hybrid of the metaheuristic cross-entropy and the gradient based sequential quadratic programming (SQP) [20], has a hybrid of the metaheuristic harmony search and the modified subgradient methods, and [21] has the metaheuristic ant swarm optimization

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hybridized with SQP.

Gradient free, 'hard computing' methods — distinct from meta-heuristic, or soft computing methods — have also been proposed [22]. contains a fully decentralized approach [23], a game-theoretic formulation [24], a distribution auction-based algorithm, and [25] a distribution consensus-based algorithm, for solving the ED problem.

Metaheuristic methods in turn fall into several broad categories like evolutionary algorithms (EA's), swarm intelligence and immune algorithms. Another kind of hybridization to improve the performance of a method is to hybridize the method from one category with operators from another method from a different category. Examples of this approach are the hybrid differential evolution with biogeography-based optimization [26], krill herd [27], hybrid harmony search [28], and PSOGSA [29].

This paper presents one such hybrid algorithm to solve the ED problem. The grey wolf optimizer (GWO), a swarm intelligence algorithm, is hybridized by incorporating the operators of mutation and crossover from EAs, and is referred to as the hybrid GWO (HGWO) hereafter. The main contributions of this paper are improving the performance of GWO and applying it to the economic dispatch (ED) problem. Another contribution of the paper is the use of a self-adaptive penalty approach, to deal with constraints, thereby eliminating ad hoc ways of dealing with constraints. The results obtained are either comparable with or outperform those obtained by other methods in the literature.

This paper is organized as follows: Section II explains the problem formulation, Section III summarizes the basic grey wolf optimizer, Section IV develops the hybrid grey wolf optimizer (HGWO) used in this paper, Section V outlines the constraint handling method adopted in this paper to the ED problem, Section VI applies the HGWO to solve the ED problem, Section VII contains the results and discussion, and the final Section VIII concludes the paper.

## 2. Problem formulation

The objective function of the ED problem is to minimize the fuel cost of thermal power plants for a given load demand while subject to various constraints.

### 2.1. Objective function

The cost or objective function of the ED problem is the quadratic fuel cost equation of the thermal generating units, and is given by

$$\min_{P \in R^{N_g}} \; F = \sum_{j=1}^{N_g} F_j(P_j) = \sum_{j=1}^{N_g} \left( a_j + b_j P_j + c_j P_j^2 \right) \tag{1}$$

where $N_g$ is the total number of generating units or generators, $F_j(P_j)$ is the fuel cost in \$/hr, $P_j$ is the power generated in MW, and $a_j$, $b_j$ and $c_j$ are cost coefficients of $j$th generator.

Practical generators are subject to valve point loading effect that introduces ripples into the cost function [2]. The objective function when the valve point effect is taken into account becomes

$$\min_{P \in R^{N_g}} \; F = \sum_{j=1}^{N_g} F_j(P_j) = \sum_{j=1}^{N_g} \left( a_j + b_j P_j + c_j P_j^2 \right) + \left| e_j \sin\left( f_j \left( P_j^{\min} - P_j \right) \right) \right| \tag{2}$$

where $e_j$ and $f_j$ are constants of the valve-point effect of the $j$th generator.

### 2.2. Optimization constraints

The equality and inequality constraints for the ED problem are the real power balance criterion, and real power generation limits, given by

$$\sum_{j=1}^{N_g} P_j = P_D + P_L \tag{3}$$

$$P_j^{\min} \le P_j \le P_j^{\max} \tag{4}$$

where $P_D$ is the total power demand, $P_j^{\min}$ and $P_j^{\max}$ are the minimum and maximum power generation limits of the $j$th generator, and $P_L$ represents the line losses given by

$$P_L = \sum_{j=1}^{N_g} \sum_{i=1}^{N_g} P_j B_{ji} P_i + \sum_{j=1}^{N_g} B_{0j} P_j + B_{00} \tag{5}$$

$P_j$ and $P_i$ are the real power injection at $j$th and $i$th buses, respectively. $B_{00}$, $B_{0j}$, $B_{ji}$ are the loss coefficients which can be assumed to be constant under normal operating conditions.

### 2.3. Practical operating constraints of generators

1) Prohibited operating zones (POZ)

The prohibited zones are due to steam valve operation or vibration in shaft bearing. The feasible operating zones of $j$th generator can be described as follows

$$P_j \in \begin{cases} P_j^{\min} \le P_j \le P_{j,1}^{l} \\ P_{j,k-1}^{u} \le P_j \le P_{j,k}^{l}, & k = 2,3,\ldots n_j, \; j = 1,2,\ldots N_g \\ P_{j,n_j}^{u} \le P_j \le P_j^{\max} \end{cases} \tag{6}$$

where $n_j$ is the number of prohibited zones of $j$th generator. $P_{j,k}^{l}$, $P_{j,k}^{u}$ are the lower and upper power output of the $k$th prohibited zone of the $j$th generator, respectively.

2) Ramp Rate Limits

The physical limitations of starting up and shutting down of generators impose ramp rate limits, which are modeled as follows. The increase in generation is limited by

$$P_j - P_j^0 \le UR_j \tag{7}$$

Similarly, the decrease is limited by

$$P_j^0 - P_j \le DR_j \tag{8}$$

where $P_j^0$ is the previous output power, $UR_j$ and $DR_j$ are the up-ramp limit and the down-ramp limit respectively, of the $j$th generator.

Combining (7) and (8) with (4) results in the change of the effective operating or generation limits to

$$\underline{P_j} \le P_j \le \overline{P_j} \tag{9}$$

where