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ORIGINAL ARTICLE

Optimization of power and heating systems based on a new hybrid algorithm

M.J. Mahmoodabadi [a,*], **A.R. Ghavimi** [b], **S.M.S. Mahmoudi** [b]

[a] *Department of Mechanical Engineering, Sirjan University of Technology, Sirjan, Iran*
[b] *Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran*

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Abstract A novel combination of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) is applied on a base case cogeneration optimization problem called the modified CGAM problem with two objective functions. The first objective function, the exergetic efficiency, should be maximized and the second one is the total cost rate that should be minimized. The effects of important parameters, such as equivalence ratio, emission, and unit cost of fuel are studied on the exergetic and economic performance of the system.

1. Introduction

Apparently, the oldest available evidence of the effort of human being for optimization comes back to the year 300 B.C., when Euclid of Alexandria tried to find the minimum distance between a point and a line. Today, it is fully accepted for us that optimization is being applied widely in different branches of science, industry and commerce. As time went by, the need of resolving various problems, regarding the number of objective functions, being constrained or unconstrained and the solution duration, optimization techniques have undergone many changes.

Moreover, optimization algorithms, specially the evolutionary ones, have some both advantages and disadvantages compared to each other. Hence, it could not be claimed that a specific algorithm is able to successfully solve all optimization problems. Thus, researchers use hybrid algorithms in which two (several) ones are combined to maintain the advantages of both (all) used algorithms. For instance, Arumugam et al. proposed a new real coded genetic algorithm to compute optimal control of a class of hybrid systems [1]. Elliott et al. used standard and hybrid genetic algorithms for optimization of modeling aviation fuel oxidation [2]. Gao et al. applied a new parallel hybrid algorithm combining NSGA-II with SQP for multi-objective optimization of the periodic operation of the naphtha pyrolysis process [3]. Luo et al. proposed a hybrid genetic algorithm for synthesis of heat exchanger networks [4]. Liu et al. utilized an effective hybrid particle swarm optimization for batch scheduling of polypropylene processes [5]. Abd-el-wahed employed an integrating particle swarm optimization with genetic algorithms for solving nonlinear optimization problems [6]. Katagiri et al. proposed a hybrid algorithm based on tabu search and ant colony optimization for k-minimum spanning tree problems [7]. Zhao et al. used an effective hybrid genetic algorithm with flexible allowance technique

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* Corresponding author. Tel.: +98 9132795909.
E-mail address: Mahmoodabadi@sirjantech.ac.ir (M.J. Mahmoodabadi).

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Nomenclature

P_{tc}	probability of the traditional crossover
N	population size
$\gamma_1, \gamma_2, \lambda_1, \lambda_2, \lambda_3, r_1, r_2 \in [0,1]$	random values
$\in [0,1]$	random values
$\vec{x}_{\max}(t)$	upper bounds of searching domain
$\vec{x}_{\min}(t)$	lower bounds of searching domain
$\upsilon \in [0,1]$	random value
$\vec{x}_i(t)$	position of particle i at iteration t
$\vec{v}_i(t)$	velocity of particle i at iteration t
C_1	cognitive learning factor
C_2	social learning factor
W	inertia weight
$\vec{x}_{pbest_i}$	personal best position of the particle i
$\vec{x}_{gbest}$	position of the best particle
Z_{AC}	purchase cost for the compressor
Z_{CC}	purchase cost for the combustion chamber
Z_{GT}	purchase cost for the turbine
Z_{AP}	purchase cost for the air preheater
Z_{HRSG}	purchase cost for the heat recovery steam generator
m_a	mass flow rate of air
m_g	mass flow rate of gas
m_{st}	mass flow rate of steam
c	unit cost ($/kJ)
$\dot{C}$	cost rate associated with a stream ($/s)
CRF	capital recovery factor
H	specific enthalpy
LHV	Lower Heating Value
$\dot{m}$	mass flow rate
p	pressure
r_{CP}	compressor pressure ratio
T	temperature
T_{pz}	adiabatic flame temperature in the primary zone
U	overall heat transfer coefficient
$\dot{W}$	power
ΔT_{lm_i}	mean logarithmic difference temperature of component i
CO	carbon monoxide gas
NO_x	nitrogen oxides gases

Greek letters

ψ	the H/C atomic ratio
θ	dimensionless temperature T/T_{ref}
π	dimensionless pressure (p/p_{ref})
ϕ	equivalence ratio
τ	residence time in the combustion zone
φ	maintenance factor

Subscripts

ref	reference environment
a	stream of air
g	stream of gas
cp	compressor
APH	air pre heater
ec	economizer
ev	evaporator

for constrained engineering design optimization [8]. Narimani et al. applied a new hybrid optimization algorithm for multi-objective optimal power flow by considering generator constraints and multi-fuel type [9]. Abarghooee utilized a new hybrid bacterial foraging and simplified swarm optimization algorithm for practical optimal dynamic load dispatch [10]. Sayah and Hamouda employed a hybrid differential evolution algorithm based on particle swarm optimization for nonconvex economic dispatch problems [11].

During last decades, some of the exergoeconomic specialists (C. Frangopoulos, G. Tsatsaronis, A. Valero, and M. Von Spakovsky) decided to develop optimization methods on the standard CGAM problem which its name is an acronym of the names of these scientists. For practical engineering applications, it is usually necessary to solve the optimization problems involving several objective functions. Thermodynamic (e.g. maximum efficiency, minimum fuel consumption, and minimum irreversibility), economic (e.g. minimum cost per unit of time and maximum profit per unit of production) and environmental (e.g. limited emissions and minimum environmental impact) are the objectives in the optimum design process of the CGAM problem [12–14].

For three basic reasons, classical optimization methods are not applicable to the multi-objective optimization of this problem [15].

- Most of them take lots of time to reach the result.
- Answers given from these methods are not much different from one another.
- Most of them are unable to handle the multi-objective problems.

Hence, in the recent decade, many researchers have returned their attention to stochastic methods (such as evolutionary algorithms) for optimization of such problems. In [16], a particle swarm optimization algorithm has been applied to optimize a CGAM problem. The cost function of investment and fuel is introduced as a single-objective function and the CGAM problem is optimized economically. Also, Hammache et al. have utilized a multi-objective self-adaptive algorithm for optimizing the modified CGAM problem [17]. Atashkari et al. have applied a multi-objective artificial bee colony algorithm to optimize the same CGAM problem [18]. Soltani et al. have implemented genetic algorithms for multi-objective optimization of a CGAM problem [19].

In the present research, a new hybrid algorithm first introduced in [20] is used to optimize the CGAM problem. It is based on a combination of the Particle Swarm Optimization (PSO) and Genetic Algorithm (GA), and as we see in [20], has been successfully implemented for Pareto optimum design of a five-degree of freedom vehicle vibration model.

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