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Oppositional teaching learning based optimization approach for combined heat and power dispatch

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ABSTRACT

This paper presents a new optimization technique i.e. teaching learning based optimization (TLBO) to solve combined heat and power dispatch (CHPD) problem with bounded feasible operating region. To accelerate the convergence speed and improve the simulation results, opposition based learning (OBL) is incorporated in basic TLBO algorithm. The potential of the proposed TLBO and oppositional TLBO (OTLBO) algorithms are assessed by means of an extensive comparative study of the solutions obtained for three different standard combined heat and power dispatch problems of power systems. The results of the proposed methods are compared with other popular optimization techniques like evolutionary programming (EP), three variants of particle swarm optimization (PSO), real coded genetic algorithm (RCGA), differential evolution (DE) and bee colony optimization (BCO). Through the simulation of MATLAB programming it is seen that OTLBO provides better results than all other optimization techniques at less computational time.

1. Introduction

With increasing fuel prices and environmental concerns of the power industry, the optimal utilization of multiple combined heat and power units has become one of the fundamental issues in power systems. The principle of combined heat and power (CHP), also known as cogeneration, is to generate both electricity and useful heat simultaneously. CHP is an efficient and reliable approach for generating power and thermal energy from a single fuel source. It can greatly increase the operational efficiency and decrease energy cost. At the same time, CHP reduces the emission of greenhouse gases, which contribute to global climate change.

Conversion from fossil fuels and coal to electricity is a complicated process and most of the heat energy is wasted through this conversion process. For this reason, efficiency achieved by most of the conventional power plants is only of 50–60%. Combined heat and power (CHP) unit reduce fuel and primary energy consumption without compromising the quality and reliability of the energy supply to consumers. Best CHP system can increase the efficiency up to 80% or more at the point of use. Moreover, significant reduction of environmental pollutants like CO_X, SO_X and NO_X can be achieved by CHP system. Consequently it provides a cost-efficient means of generating low-carbon or renewable energy. Immingham is one of the largest and efficient combined heat power plants in Europe. It increases its electricity generation capacity by 60% and significantly increases its future capacity to supply heat to support local industry development.

The objective of economic load dispatch (ELD) is to find the optimal output of a number of electricity generating units to meet the system load at the lowest possible cost, while serving power to the public in a robust and reliable manner. Complication arises if both of heat and power demands are required to meet simultaneously. The utility of cogeneration unit over conventional power generating unit and heat only unit is that it satisfies both heat and electricity demands in an economical way. It makes the CHP dispatch (CHPD) problem more complex than the conventional ELD problem.

To find quality solution with good computational efficiency, different approaches have been evolved in last two decades to solve CHPD problem. Nonlinear optimization methods, such as dual and quadratic programming [1] and gradient descent approaches, such as lagrangian relaxation [2] are the oldest techniques used to solve CHPD problem. Larsen et al. [3] proposed probability production simulation technique to solve CHPD problem of power system having single as well as multiple heat area and back pressure type CHP units. Thomson et al. described a statistical process control method [4] of fault detection of combined heat and power units. However, these traditional approaches may generate local optimal solution for CHP dispatch problem when the fuel cost functions of units are much more complicated due to the presence of valve point effects of generating units.

To overcome these deficiencies, many artificial intelligence (AI) techniques are evolved to solve the CHPD problem. Wong and Algie [5] developed an evolutionary programming (EP) based algorithm

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for solving the combined heat and power dispatch problem for cogeneration systems. The algorithm was tested for a system containing two cogeneration units. Song et al. [6] solved the CHPD problems using an improved ant colony optimization (ACO) technique. To solve CHPD problem, an improved genetic algorithm with multiplier updating (IGA-MU) technique was presented by Su and Chiang [7]. The proposed method which integrated the IGA and the MU to reduce the population size was successfully applied to solve CHPD problem. Vasebi et al. [8] presented a harmony search (HS) algorithm to solve CHPD problem and the numerical results revealed that the proposed algorithm could find better solutions when compared with the conventional methods. Wang and Singh proposed [9] a stochastic model for combined heat and power (CHP) dispatch problem, and used an improved particle swarm optimization (IPSO) method to deal with the CHPD problem and the simulation results of the proposed method were compared with those of GA. Rong et al. introduced dynamic programming (DP) approach [10] to solve unit commitment based CHPD problem. Moreover, the proposed algorithm was compared with the traditional priority listing method. The proposed method produced more accurate results with less computational burden. Subbaraj et al. [11] proposed a self-adaptive real-coded GA (SARGA) to solve CHPD problem. Later, Hosseini and Gandomi [12] applied the same SARGA algorithm for enhancement of combined heat and power economic dispatch solutions. Hosseini et al. developed mesh adaptive direct search (MADS) [13] algorithm to solve the CHPD problem. To improve the effectiveness of MADS algorithm, three powerful search strategies like lat in hypercube sampling (LHS), PSO and design analysis of computer experiments (DACE) were used in this paper. Basu presented bee colony optimization algorithm (BCO) [14] to solve CHPD problem and performance of the proposed method was compared with PSO, EP and real-coded genetic algorithm (RCGA). Sashirekha et al. [15] presented a flexible algorithm based on lagrangian relaxation with surrogate sub gradient multiplier updates to solve CHPD problem. An artificial immune system (AIS) algorithm [16] was presented by Basu. In this paper the author successfully implemented the proposed method to solve CHPD problem and its performance was compared with PSO and EP. Geem and Cho [17] proposed a technique considering the non-convex heat power feasible region in the CHPD problem more accurately. The proposed approach enhanced the conversion efficiency from fossil fuels to electricity, reducing green house gasses. An approach based on the direct search algorithm (DSM) [18] was proposed by Chen et al. to solve CHPD problem. Piperagkas et al. proposed multi-objective PSO [19] approach to solve environmental constraints CHPD problem. Some studies of cogeneration applications using gas turbines and thermal engines were presented in [20]. A detailed study of thermodynamic modelling cycles with energy recovery was presented in this paper. Sudhakaran and Slochanal [21] implemented a hybrid stochastic searching technique to solve CHPD problem. In this approach, conventional GA was integrated with tabu search (TS) to improve the convergence speed and solution quality. A novel charged system search algorithm for finding the optimal generation cost of CHP units having the nonlinearities of valve point effect and ramp rate constraints was presented by Bahmani-Firouzi et al. [22] and the methodology was implanted on small, medium and large scale power systems. Motevasel et al. proposed modified bacterial foraging optimization (MBFO) algorithm [23] to solve multi-objective CHP problems of micro grid system where, total operation cost and the emission were considered as the objectives. Huang et al. investigated hybrid heuristic algorithm based on GA and harmony search (HS) [24] to minimize the generation cost of combined heat and power unit. To validate its performance, the proposed hybrid algorithm was compared with other algorithms reported in the literature. A non dominated sorting genetic algorithm-II (NSGA-II) [25] was presented by Basu for solving combined heat and power economic emission dispatch problem of two different test systems and the results of the proposed approach were compared with those obtained from strength pareto evolutionary algorithm 2 (SPEA 2). A pareto based θ-self adaptive gravitational search algorithm (θ-SAGSA), algorithm was implemented on 69-bus radial distribution system by Niknam et al. [26] for finding optimal position of combined of heat, power, and hydrogen source (CHPH) generated fuel cell power plants (FCPPs). A non dominated sorting pareto based enhanced firefly algorithm (FA) [27] was introduced by Niknam et al. to solve multi-objective dynamic economic emission problem of combined heat and power units. Motevasel et al. introduced a modified bacterial foraging optimization (MBFO) [28] algorithm to minimize the cost and emission simultaniously of a CHP-based micro-grid over a 24-h time interval. A pareto based self adaptive charged system search (SACSS) algorithm applied to CHPD problem [29] was developed by Niknam et al. to determine the optimal size and optimal placement of fuel cell power plants (FCPPs) for simultaneously minimizing the total cost, emissions of FCPPs and substation and voltage deviation. Moreover, Niknam et al. recently developed few new heuristics algorithms [30–34] to solve various power system optimization problems.

Though the above mentioned optimization methodologies have successfully been applied for the CHPD problem, the algorithm complexity, premature convergence and large computational time are the common drawback of most of these algorithms. In this context, the objective of this work is to demonstrate a simple and efficient approach to quickly and accurately produce the optimum solutions of CHPD problems. This paper presents teaching and learning based optimization (TLBO) algorithm for fulfilment of these objectives. The literature survey reveals that TLBO is one of the newest evolutionary algorithms proposed by Rao et al. [35], which has already proven itself a worthy optimization technique compared to other existing techniques. Roy in his most recent endeavor solved hydro-thermal scheduling (HTS) problem using TLBO [36] algorithm. Niknam et al. in their recent endeavor modify the original TLBO algorithm [37] to find the optimal setting and location of automatic voltage regulator (AVR) for simultaneous minimization of the energy generation cost, electrical energy losses and the voltage deviation of 70-bus distribution network. Niknam et al. applied modified TLBO [38] to solve spinning reserve constrained dynamic economic load dispatch (DELD) problem and its performance was analyzed by applying it on 5-unit, 10-unit, 30-unit, 40-unit, and 140-unit test systems. θ-Multi objective TLBO algorithm [39] was implemented by Niknam et al. for solving dynamic economic emission dispatch problem of 5-unit, 10-unit, and 120-unit test systems. Recently, Niknam et al. proposed modified TLBO (MTLBO) [40] algorithm to solve multi-objective Volt/VAr control problem of distribution networks. In this article, the authors used MTLBO algorithm for simultaneous minimization of the electrical energy losses, voltage deviations, total electrical energy costs, total emissions of renewable energy sources and grid. An improved pareto based multi-objective TLBO algorithm [41] for minimizing cost and emission of micro grid system was proposed by Niknam et al. Azizipanah et al. developed modified non dominated TLBO algorithm [42] to solve combined economic emission dispatch problem. A modified TLBO algorithm [43] to find the optimal size and location of distributed generator (DG) for minimizing the distribution loss was proposed by Garcia et al. In this modified TLBO algorithm, mutation phase was integrated with teaching and learning phase to improve the convergence speed of conventional TLBO algorithm. Mandal et al. proposed quasi-oppositional TLBO (QOTLBO) [44] to solve optimal reactive power dispatch (ORPD) problem in which quasi-oppositional based learning (QOBL) was incorporated in basic TLBO to increase the convergence speed and provide global optimal solution. However, as per authors' knowledge, the TLBO has never been