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Multi-objective hybrid PSO-APO algorithm based security constrained optimal power flow with wind and thermal generators

Kiran Teeparthi *, D.M. Vinod Kumar

Department of Electrical Engineering, NIT Warangal, Warangal, India

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ABSTRACT

In this paper, a new low level with teamwork heterogeneous hybrid particle swarm optimization and artificial physics optimization (HPSO-APO) algorithm is proposed to solve the multi-objective security constrained optimal power flow (MO-SCOPF) problem. Being engaged with the environmental and total production cost concerns, wind energy is highly penetrating to the main grid. The total production cost, active power losses and security index are considered as the objective functions. These are simultaneously optimized using the proposed algorithm for base case and contingency cases. Though PSO algorithm exhibits good convergence characteristic, fails to give near optimal solution. On the other hand, the APO algorithm shows the capability of improving diversity in search space and also to reach a near global optimum point, whereas, APO is prone to premature convergence. The proposed hybrid HPSO-APO algorithm combines both individual algorithm strengths, to get balance between global and local search capability. The APO algorithm is improving diversity in the search space of the PSO algorithm. The hybrid optimization algorithm is employed to alleviate the line overloads by generator rescheduling during contingencies. The standard IEEE 30-bus and Indian 75-bus practical test systems are considered to evaluate the robustness of the proposed method. The simulation results reveal that the proposed HPSO-APO method is more efficient and robust than the standard PSO and APO methods in terms of getting diverse Pareto optimal solutions. Hence, the proposed hybrid method can be used for the large interconnected power system to solve MO-SCOPF problem with integration of wind and thermal generators.

1. Introduction

Due to rapid increase in electricity demand, the modern power systems run close to their security limits to enhance the system security during contingencies. The security assessment and enhancement are two major concerns in the energy control centers [1]. A security assessment is the analysis carried out to determine what level; a power system is reasonably safe from unforeseen disturbances (contingencies). The bottleneck of the security assessment is contingency analysis. Security constrained optimal power flow (SCOPF) is the highly non-linear OPF problem along with the contingency analysis. This leads to implementation of preventive control actions in the power system like generation rescheduling, phase shifter positions, switching of FACTS devices, HVDC line MW transfer, and load shedding to enhance the system security. The environmental and cost concerns of the renewable energies increase the integration to the power sector in the present scenario. The wind energy is the most proven available and growing energy in the entire world. Once wind plant is installed it requires zero production cost and less maintenance than conventional plants and also reduces the carbon emission.

Earlier, a number of conventional (mathematical based) algorithms like gradient method, quadratic programming, linear programming, mixed integer linear programming and nonlinear programming (NLP) are proposed to solve the OPF problem [2–4]. These methods face difficulty in handling the inequality constraints and not guarantee to reach an optimal solution. In addition, they will struck in the local optimum point in some cases and exhibits poor convergence characteristic. Over the last years, many researchers have tended to apply several non-conventional (heuristic) methods for solving the OPF problem like simulated annealing (SA) [5], genetic algorithm (GA) [6], enhanced GA (EGA) [7], fuzzy based GA (FGA) [8], differential evolution (DE) [9], modified differential evolution (MDE) [9], evolutionary programming (EP) [10], improved EP (IEP) [11], particle swarm optimization (PSO) [12], ant colony optimization (ACO) [13], honey bee mating optimization (HBMO) [14], modified HBMO (MHBMO) [14], modified shuffle frog leaping algorithm (MSFLA) [15].

* Corresponding author.
E-mail address: Kiran.t39@nitw.ac.in (K. Teeparthi).
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However, some of these standard algorithms are suffering from premature convergence due to lack of diversity in search space. One way to cope with these drawbacks, hybrid heuristic optimization methods are implemented in practical and academic problems. The best results are found for OPF problem by hybrid methods [16–19].

OPF is a nonlinear problem which optimizes the objection function while satisfying a set of equality and inequality constraints. The minimization of fuel cost is most generally used as the objective function. However, other traditional objectives are minimization of transmission real power losses, voltage stability index, voltage deviation, fuel emission, and security index. In traditional methods, multi-objective OPF (MO-OPF) problems are solved by evolutionary algorithms (EA) which convert multi-objective problem to a single objective problem by an assigning suitable weighting/scaling factors [20,21]. This approach gives only one solution in a single run. It should be separately run for a set of weighting factors to get the Pareto optimal solutions and this increase the computational time. To rectify the above-mentioned problem, EAs have been reported to solve MO-OPF problem to attain the Pareto optimal points [22–30]. Kadir Abaci et al. [23] implemented DEA based OPF for solving single and multi-objective functions and results are compared with other reported methods presented in the literature. An adaptive group search optimization based MO-OPF problem is presented in [24]. A modified decomposition based multi-objective OPF problem is solved with consideration of different objectives like fuel cost, emission, voltage deviation and power losses [25]. The adjustment of control variables like active power generations and TCSC device are used to alleviate line overloads during contingencies for enhancing the system security. The multi-objective optimization problem is formulated by combing the installation cost of TCSC device and fuel cost of thermal units [26]. In order to enhance the system security, a modified SFLA is proposed to solve OPF problem incorporating UPFC device [27]. In [28], fuzzy adaptive PSO method is implemented to solve OPF problem and optimal placement of UPFC device simultaneously. Cheng- Jin Ye et.al [29] proposed a multi-objective OPF model with considering rotor angle stability as the objective function rather than taking as inequality constraint. In [30], fuzzy based grenade explosion optimization method is successfully applied for solving multi-objective OPF problem.

The main contribution of this paper is to solve multi-objective security constrained OPF (MO-SCOPF) using a new hybrid particle swarm optimization and artificial physics optimization (HPSO-APO) algorithm. The APO and PSO methods are two meta-heuristic population-based optimization approaches inspired by nature of physics and behavior of bird flocking respectively. The proposed hybrid PSO-APO algorithm combines both individual algorithm strengths, to get the balance between global and local search capability. The APO algorithm is improving diversity in the search space of the PSO algorithm so as to avoid the trapping of local optima. In this paper, three different objective functions have been considered namely, total production cost, active power losses, and security index. Generally, most of the multi-objective based optimization methods use non-dominated sorting and strength Pareto approaches for achieving the optimal trade-off curve. This paper uses non-dominated sorting and crowding distance approach to maintaining a diverse in Pareto optimal points [31]. Finally, a fuzzy membership approach is used to get compromising solution over the trade-off curve. The proposed multi-objective HPSO-APO (MOHPSO-APO) algorithm is tested on IEEE 30-bus and practical Indian 75-bus systems. The simulation results show that the proposed method is more robust and efficient than the standard multi-objective PSO (MOPSO) and multi-objective APO (MOAPO) methods in terms of obtaining a well distributed Pareto front.

The rest of the paper is organized as follows. Section 2 deals with the MO-SCOPF problem with wind energy subject to equality and inequality constraints. The general framework of PSO, APO and proposed hybrid PSO-APO (HPSO-APO) algorithms for solving MO-SCOPF is discussed in Sections 3 and 4, whereas Section 5 illustrates the simulation and results of the proposed method. Finally, conclusions are given in Section 6.

2. Problem formulation

Multi-objective security constrained OPF is a special type of OPF problem to minimize the objective functions simultaneously subjected to equality and inequality constraints by choosing the optimal control variables like phase-shifter angles, active & reactive power generations, transformer tap settings and voltages at PV buses. In this paper, three objective functions were considered namely, total production cost, security index, and active power loss.

2.1. Objective functions

2.1.1. Total production cost

The total production cost including thermal and wind generator units can be expressed as follows [32].

$$f_{TPC} = \sum_{i=1}^{N_g} (a_i P_{gi}^2 + b_i P_{gi} + c_i) + \sum_{i=1}^{Nw} C_p(P_{shed,i}) + \sum_{i=1}^{Nw} C_r(P_{shed,i}) \tag{1}$$

where P_{gi} is the active power generation at ith bus; N_g and N_w represents the available number of thermal and wind generators; a_i, b_i and c_i are generator cost coefficients. The first part of Eq. (1) implies the fuel cost of available thermal generators, and second and third terms indicate the overestimation ($C_p(P_{shed,i})$) and underestimation ($C_r(P_{shed,i})$) costs of wind energy.

Mathematically, the stochastic nature of wind speed follows the Weibull probability density function (PDF) over a time which is given by

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} (e)^{(-\frac{v}{c})^k} \quad ,0 < v < \infty \tag{2}$$

where v represents the wind speed; k and c are scale and shape factors of the wind speed respectively. The output power of the wind generator with a given wind speed is expressed as

$$p = \begin{cases} 0; & 0 < v < v_{in} \\ p_r\left(\frac{v-v_{in}}{v_r-v_{in}}\right); & v_{in} \leqslant v \leqslant v_r \\ p_r; & v_r \leqslant v \leqslant v_o \\ 0; & v > v_o \end{cases} \tag{3}$$

Here v_{in}, v_r and v_o are cut-in, rated and cut-out wind speeds respectively and p_r is the rated output power of the wind generator. The probability density function ($f_P(p)$) for linear portion of the wind speed is given by

$$f_P(p) = \left(\frac{k(v_r - v_{in})}{cp_r}\right)\left(\frac{v_{in}p_r + p(v_r - v_{in})}{cp_r}\right)^{(k-1)} \times \exp\left(-\left(\frac{v_{in}p_r + p(v_r - v_{in})}{cp_r}\right)^k\right) \tag{4}$$

For discrete portion, the probabilities of getting no power output and rated power output of the wind turbine are as follows

$$f_P(p=0) = 1 - \exp\left(-\left(\frac{v_{in}}{c}\right)^k\right) + \exp\left(-\left(\frac{v_o}{c}\right)^k\right) \tag{5}$$

$$f_P(p=p_r) = \exp\left(-\left(\frac{v_r}{c}\right)^k\right) + \exp\left(-\left(\frac{v_o}{c}\right)^k\right) \tag{6}$$

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