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Optimal reactive power dispatch under unbalanced conditions using hybrid swarm intelligence☆

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ABSTRACT

This paper focuses on the minimization of the voltage deviation and power loss associated with optimal reactive power dispatch (ORPD) under unbalanced conditions. A combination of two swarming algorithms is proposed called the artificial bee colony with firefly (ABC-FF) algorithm. This algorithm operates on control variables, such as load reactance and voltage and transformer tap settings, which are varied to achieve optimum results. The entire experiment is conducted on two IEEE benchmark test bus systems, namely, the IEEE 14 and the IEEE 39 benchmark bus systems. The experimental results of the proposed ABC-FF approach are compared with those of other evolutionary methods to ensure that the proposed approach provides the best ORPD operation when compared with conventional methods.

1. Introduction

In power systems, the two main conditions for economical operation are active power regulation and reactive power dispatch (RPD) [15]. Generally, the production reactive power cost is less, but it effects the production cost of the active power transmission loss. The active power flow through the distribution and transmission systems requires the reactive power to control the voltage in the transmission line. The transmission of real power, along with the maintenance of reliability and voltage stability in the system, serves as the major role of reactive power. Thus, it is necessary to optimize the reactive power dispatch. The non-linear and intermittent constraints as well as a large amount of local minima in the functions create complex problems in RPD. To solve these issues, several classic optimization techniques [3,7–10], such as linear programming, the interior point method, the Newton method and quadratic programming are employed. These methods offer fast processing; however, they suffer from complexity while attaining the global minima.

Various evolutionary computing (EC) techniques, such as EP (evolutionary programming) [22], AGA (adaptive genetic algorithm) [23], PSO (particle swarm optimization) [24], HPSO (hybrid PSO) [25], BFA (bacterial foraging algorithm) [26], QEA (quantum-inspired evolutionary algorithm) [27], CLPSO (comprehensive learning PSO) [28], HSFLA (hybrid shuffled frog leaping algorithm) and their modified versions, as well as hybrid EC algorithms including HMPSO (hybrid multi-swarm PSO) [1,15–22], have been used to solve the problem of ORPD. However, they are not applicable for finding the pareto-optimal solutions of MORPD (multi-objective reactive power dispatch) problems. The weighted sum of the objectives has the capability to transfer the problem of multi-objectives into a problem of single objectives [3,12,13] and thus makes the non-commensurable objectives suffer from losing their importance while merging into a single- objective function.

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Recently, an improved version of GA [14] (called the differential evolution (DE) algorithm [5,29]) has been modified and is involved in multi-objective evolutionary optimization techniques, such as enhanced FA (EFA) [2,11], multi-objective differential evolution (MODE) [3], and conventional quasi-oppositional differential evolution (QODE) [5], to solve the problem of single-objective as well as multi-objective RPD and to provide better solutions than other evolutionary algorithms in many applications. The main contribution of this paper is to propose the ABC-FF algorithm to solve the ORPD problem. Initially, the challenges associated with the ORPD problem under unbalanced environments are addressed. Second, the ability of the ABC-FF algorithm to handle the nature of an unbalanced distribution system is illustrated. As a result, the optimal reactive power dispatch is estimated competently. The second section of this paper presents a literature review, while the third section depicts the ORPD model under unbalanced conditions. The fourth section describes Hybrid Swarm Intelligence for ORPD. The fifth section states the results and discussion, while the sixth section provides the concluding remarks of this paper.

2. Literature review

2.1. Related works

In 2015, Srivastava and Singh [1] proposed the hybrid multi-swarm PSO algorithm to remove the problem of multi-objective RPD by reducing the real power loss and increasing the voltage profile. In 2015, Liang et al. [2] adopted EFA to solve the multi-objective optimally active and RPD problems. In 2016, Basu [3] proposed MODE to solve the problem of optimization by reducing the voltage deviation as well as the power loss and increasing the voltage stability. In 2015, Robbins and Dominguez-Garcia [4] suggested the convex quadratic optimization program to maintain the voltage bus under the unbalanced distribution system. In 2016, Basu [5] successfully applied QODE (quasi-oppositional differential evolution) to solve the RPD problem, which was achieved by minimizing the power loss and increasing the stability and the profile of voltage. In 2014, Zhou et al. [6] developed SPMGSO (pareto multi-group search optimizer) for solving the MORD (multi-objective optimal reactive power dispatch) problem. In 2017, Tian [30] studied wind farms; on the basis of the analysis of the wake effect, the reactive power capability of a doubly fed induction generator (DFIG) wind turbine (WT) and the lifetime of the power coverer of the DFIG WT, a reactive power dispatch method, was proposed for the wind farm (WF) with DFIG WTs.

2.2. Review

The literature review reveals numerous advancements, which were reported based on meta-heuristic principles. The improvements over Des, such as MODE and QODE, showed good efficiency in handling the ORPD problem to provide diverse solutions with less iteration. However, the computational complexity and the failure rate still remained; the reliability of identifying a better reactive power dispatch was uncertain. The variants of swarm intelligence, such as HMPSO, EFA and SPMGSO, were proven for their separability in local and global searching, their avoidance from trapping into the local optimal solution and their ability to solving the Pareto optimal solution search, respectively. However, these variants required a computationally simple process to intensify the search. Moreover, these swarm intelligence variants were not suitable for handling unbalanced distribution systems, which have been recently reported. Hence, the results demonstrate that the search process to identify a current solution requires mandatory improvement. Table 1 summarizes the state-of-the-art metaheuristic approaches for reducing the power loss.

Table 1
State-of-the-art metaheuristic approaches for reducing power loss.

Author	Adopted methodology	Merits	Demerits
Laxmi Srivastava and Himmat Singh [1]	Hybrid multi swarm PSO algorithm (HMPSO)	• Separate swarms for local and global solutions	• Requires more computing time
Ruey-Hsun Liang et al [2]	Enhanced firefly algorithm (EFA)	• Avoids the trapping of solution into local minimum • Requires smaller number of iterations	• CPU time, at each iteration for the EFA, is more than that of the FA
M. Basu [3]	Multi objective differential evolution (MODE)	• Good convergence rate • Able to provide diverse solutions	• Computationally complex
Brett A. Robbins and Alejandro D. Dominguez-Garcia [4]	Alternating direction method of multipliers (ADMM)-based algorithm.	• Good convergence	• Lack of solution exploration
M. Basu [5]	Quasi-oppositional differential evolution (QODE)	• Improves the effectiveness and the quality of the solution • Requires less iteration cycles	• Low success rate
Bin Zhou et al [6]	Strength pareto multi group search optimizer (SPMGSO)	• Able to solve Pareto optimal problems • High computational efficiency	• Diverse searching procedure