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Security optimal power flow considering loading margin stability using hybrid FFA–PS assisted with brainstorming rules

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ABSTRACT

This paper presents a new power system planning strategy which combines firefly algorithm (FFA) with pattern search algorithm (PS). The purpose is minimizing total fuel cost, total power loss and reducing total voltage deviation, with the objective of enhancing the loading margin stability and consequently the power system security. A new interactive and simple mechanism, inspired in brainstorming process, is proposed that allows FFA and PS algorithms to explore new regions of the search space. In this study the Static VAR compensator (SVC) is modeled and integrated in an efficient location which is chosen considering the voltage stability index. The proposed algorithm is interactive and tries to optimize a set of control variables at the same time, namely, active power generations, voltage of generators, tap transformers, and the reactive power of shunt compensators to optimize three objective functions such as: fuel cost, total power loss and total voltage deviation. These variables are optimized using a flexible interactive and competitive search mechanism. The proposed planning strategy has been examined and applied to two practical test systems IEEE 14-Bus and IEEE 30-Bus. Simulation results confirm the effectiveness of this hybrid strategy for solving the security optimal power flow.

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1. Introduction

The security optimal power flow (OPF) is the most important tool for power system planning, operation and control. The main objective of OPF tool which considered as an important sub problem of power system planning is to determine the optimal operation state of multi dispersed units by optimizing multi control variables related to a specified objective function considering multi practical constraints. Active power loss, voltage deviation and voltage stability are three important tasks which interest expert specialized in power system planning operation and control. The optimization of these objective functions affect directly and indirectly the dynamic performances of practical power system [1]. Many research results confirmed that optimization of these objective functions is a complex multi objective problem which require robust and flexible strategy to enhance the performance of practical power systems under normal and at critical situations. The standard OPF problem has been widely solved using several classical mathematical optimization techniques such as linear and non linear programming (LP, NLP) [2], gradient based method [3], quadratic programming (QP) [4], Newton-based method [5,6], and interior point methods [7]. A recent survey of the major contributions related to this category based mathematical methods is presented in [8]. Based on a large number of papers proposed to solving various problems related to power system planning, operation and control, we can conclude that the deterministic optimization methods converge to local optimal solution and can not guarantee global solution when considering practical generator constraints (Prohibited zones, valve point effect, and multi-fuel options) due to sensibility to initial conditions and to the form of the objective function. These major drawbacks have contributed to the development of new stochastic based optimization techniques such as, evolutionary programming [9], improved evolutionary programming [10], enhanced genetic algorithm (EGA) [11], improved genetic algorithms (IGA) [12], adapted genetic algorithm (AGA) [13], particle swarm optimization (PSO) [14,15], differential evolution (DA) [16–19], improved harmony search algorithm [20], Imperialist competitive algorithm (ICA) [21], gravitational search algorithm (GSA) [22], artificial bee colony algorithm (ABC) [23,24], firefly algorithm (FFA) [25,26], brain storm optimization algorithm (BSA) [27], Application of brainstorming strategy for enhancement dynamic teaching based LMD education system [28]. In general view, we can conclude that the main difference between these methods is related to the robustness of their mechanism search

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determined by the number of parameters to be adjusted, an optimization method with simple and interactive mechanism search and with less parameter to control is preferred.

Recently, many research results clearly confirmed that each global optimization method has its advantages and drawbacks. Hybrid methods considered as an alternative and robust solution to combine different methods. In the recent literature various hybrid methods have been proposed and applied with success for solving many complex and combined problems related to power system planning, operation and control, some of these techniques are, Evolving ant direction differential evolution [29], A modified teaching–learning based optimization [30], hybrid differential evolution (DE) with particle swarm optimization (PSO) [31], hybrid fuzzy particle swarm optimization and Nedler–Mead algorithm (HFPSO-NM) [32], chaotic improved PSO [33], hybrid imperialist competitive-sequential quadratic programming (HIC-SQP) algorithm [34], A modified shuffle frog leaping algorithm [35], new modified and hybrid modified imperialist competitive algorithms [36], adaptive biogeography based predator–prey optimization technique [37], self-evolving brain-storming inclusive teaching–learning-based algorithm [38], A hybrid GA–PS–SQP [39] and hierarchical adaptive PSO [40]. As well described in the literature review, the structure of these methods is based on how adjusting dynamically their parameters and on combination between various methods to exploit efficiently the best performances of each method to achieve the global solution at a reduced time. The main idea introduced in the mechanism search of these methods is to provide an intelligent adaptive and flexible communication process to guide efficiently the processes search during exploration and exploitation stages.

Flexible AC transmission Systems (FACTS) first introduced by Hingorani and Gyugyi [41], is relatively considered as one of recent technology installed in many practical electrical networks. FACTS technology is an alternative solution to ensure balance between source production and power demand particularly at loading margin stability. In recent years many types of controllers based FACTS devices such as: shunt Controllers (SVC, STATCOM), series Controllers (TCSC, SSSC) and hybrid Controllers (UPFC) integrated in the electricity market to improve the performances of the practical power system [42]. In the literature many techniques and strategies have been proposed to enhance the security optimal power flow considering the integration of FACTS devices [43]. An efficient multi objective strategy based differential evolution considering multi FACTS technology is presented in [44]. Venkateswara Rao and Nagesh Kumar [45] proposed a BAT search algorithm based optimal power flow for generation reallocation with unified power flow controller, in [46] a multi-objective adaptive clonal selection algorithm is proposed for the solving optimal power flow considering multi-type FACTS devices and load uncertainty, in [47] a hybrid bacterial foraging and Nelder–Mead algorithm is adapted and applied for optimal location of series FACTS devices for congestion management, and in [48] a strategy based PSO is proposed for dynamic control of UPFC to enhance power system security.

Firefly algorithm is one of the recent metaheuristic optimization methods proposed by author in [25], this method adapted and applied by researchers to solve many complex problems related to power system planning operation and control. In this work FFA is preferred for its simplicity to adapt and program and has a few parameters to adjust. Pattern search algorithm is also an efficient evolutionary technique, adapted and applied with success to solving many practical problems related to power system operation and control. The brainstorming concept first introduced by Osborn [49], the rules proposed by Osborn demonstrated that brainstorming process was more effective in generating new ideas than individuals working. The adaptation of brainstorming principle and rules is firstly developed and formulated as an optimization problem by Shi in 2011 [27]. To date, the BSO algorithm has not been applied intensively to solving the complex problems related to power system planning and control, very recently in [50], Rezaee Jordehi proposed an efficient algorithm based brain storm optimization algorithm (BSOA) for optimal location and control of FACTS devices to improve various objective functions such as power loss and voltage deviation and overload minimization, the results achieved are important and competitive.

In this work and to enhance the performances of the two standard optimization methods (FFA and PS), the brainstorming rules are adapted and used to assist FFA and PS during search process, to exploit with efficiently the search space. In this study, FFA is considered as a global optimization technique and the PS is adapted to accomplish the task of local search, the main particularity of the proposed combined optimization method is related to the flexible communication rules inspired from brainstorming process. The proposed interactive hybrid approach applied to optimize three important objective functions: reduce the total fuel cost, the total power loss and voltage deviations by considering the integration of one SVC compensator at efficient location, The performances of the proposed planning strategy in term of solution quality and convergence characteristic have been tested on the two practical test systems, IEEE 14-Bus and IEEE 30-Bus at normal condition and considering loading margin stability.

2. Security optimal power flow

Security optimal power flow is a fundamental sub-problem of power system planning, the main objective of this strategy is to find the optimal settings of control variables in terms of one or more objective function while satisfying operating equality and inequality constraints [1]. Fig. 1 shows the strategy of security OPF, the basic structure of security OPF may be presented and described as follows:

- *Optimization method:* represent the core of the optimization strategy, it depends on the complexity of the problem to be solved, the final results achieved depend on the particularity of the algorithm used such as standard algorithms (GA, PSO, ABC), or hybrid method, how the initial parameters are chosen and adjusted during search process, how the control variables are organized, and how the global method is hybridized with other methods.
- *Power flow (PF) based Newton–Raphson algorithm*: this second task works in coordination with the optimization method, the main role of power flow is to determine the state variables and violation of constraints. The equality constraints are verified using PF algorithm.
- *Objective functions:* in general, the well known objective functions to be optimized are: fuel cost, emission, power losses, voltage deviation, and voltage stability, these objective functions are optimized individually or simultaneously.
- *Communication process*: is related to the interaction between global and local optimization methods to enhance the solution quality and convergence characteristics. The communication process depends on the global and local optimization methods used.

In this work, we have used two simple optimization methods, the *FFA* considered as a global optimization method adapted to achieve the exploration phase and the PS considered as a local search mechanism coordinated to enhance the exploitation search, these two methods are coordinated using flexible practical rules inspired from brainstorming process.

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