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Three powerful nature-inspired algorithms to optimize power flow in Algeria's Adrar power system

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ABSTRACT

This paper is intended to solve the optimal power flow (OPF) dispatch in the presence of wind power generation (WPG) in the Adrar power system. Towards this aim, the performances of three powerful meta-heuristic algorithms-namely, the cuckoo search algorithm (CSA), firefly algorithm (FFA), and flower pollination algorithm (FPA) are investigated. The proposed algorithms are applied to best capture the active power produced with the minimum value of a multi-objective function. This latter includes: the fuel cost, the NOx emissions, and the imbalance cost of the WPGs. Furthermore, considering the uncertainties governing wind resources, the maximum wind power output is estimated using the wind speed carrying maximum energy. It was found that all algorithms perform well in providing accurate solutions. Interestingly, the convergence is reached in the first 135 iterations. A remarkable outcome of the present work is that CSA outperforms FPA and FFA. CSA has proved itself to be a great tool to optimize Adrar's power flow system in term of iterations and computational time.

1. Introduction

Due to the uncertainties related to wind speed prediction, the integration of wind power generation (WPG) into the grid on a large scale is not always considered as the best investment. Unlike traditional forms of electricity generation, energy from wind power sources is intermittent by nature; this brings new challenges for both planners and operators of power systems. WPG cannot be predicted and is, therefore, non-dispatchable, whereas power from traditional generations is instantly dispatchable. In the absence of careful planning, capacity reserves may decrease and threaten power system reliability. A review on the reliability assessment of WPG has been presented in Ref. [1]. Ref. [2] proposes a model to study the impacts of intermittent renewable-energy sources on electrical systems. The impact of WPG is particularly significant for a small isolated power system that requires knowledge of the constraints and the corrective measures to preserve system reliability. In this context, and in order to achieve an increased capacity utilization of WPG, the planners and operators of power systems must establish, in advance, the volume of energy generated from both conventional and renewable sources, by optimizing power flow problems.

Optimal power flow (OPF) problems could be challenging to be solved by means of conventional methods. Momoh et al. presented a review of literature on OPF application using nonlinear and quadratic programming [3]. The same authors [4] offered an additional review on OPF treated by Newton-based, linear programming and interior point methods. Due to a large number of constraints and the nonlinear, non-convex optimization problem, these methods often cannot guarantee obtaining the global minima. Moreover, their performance depends on the initial points and sometimes requires large computation times.

In this respect and in order to overcome the limitations of the conventional methods, several meta-heuristic algorithms have been applied successfully in recent times. The robustness of such algorithms overcomes the deficiencies of the traditional methods and allows finding the global optimum with shorter computation times. Moreover, due to their simple mathematical models, these methods are easy to apply and among the most efficiently used approaches. Other advantages and disadvantages of the meta-heuristic algorithms are carefully examined by Sorensen [5]. The literature shows that several researches have been proposed to deal

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with OPF and economic dispatch (ED) and carry out emission reduction in the power system-integrated WPG. A novel evolutionary algorithm for dynamic ED with emission reduction and WPGs has been proposed by Liao [6]. Shi et al. [7] proposed a risk-limiting OPF with high penetration of WPG. In doing so, the researchers only took the wind power fluctuation into account and did not consider the imbalance cost of the WPG, associated with the uncertainty of wind resources. Panda and Tripathy [8] employed a modified bacteria foraging algorithm for OPF, considering the cost origins from wind power variability and the reactive power capability of DFIG (doubly fed induction generator). Hetzer et al. [9] developed a model including the overestimation and underestimation of available wind power in the ED. The same model is used by Jabr and Pal [10] to solve OPF problem including reactive power model of WPG.

Since none of the meta-heuristic algorithms proposed in previous studies is able to provide the best solution for multi-objective optimization problems, new algorithms have been developed and are being improved. Xing and Gao [11] offered a meaningful comparison analysis and synthesis of existing research on applications of the meta-heuristic algorithms. Cuckoo search algorithm (CSA) [12], the firefly algorithm (FFA) [13], and the flower pollination algorithm (FPA) [14] are considered among the more recently presented approaches that have proven their ability and efficiency in solving all kinds of science, engineering, and industrial problems. Such algorithms hold considerable promise and are still undergoing improvement. Liang et al. [15] developed an enhanced FFA to optimize both active and reactive power dispatches while considering load and WPG uncertainties. Younes et al. [16] combined the FFA with a modified genetic algorithm and implemented this to minimize the fuel cost and emissions simultaneously. Basu [17] recommended the CSA approach to tackle convex and non-convex ED with WPG. In Ref. [18], the CSA has been successfully applied to reduce power loss, enhance voltage profile, and minimize thermal generators cost of distribution network reconfiguration. A high quality solution of short-term hydrothermal scheduling problem, given in Ref. [19], has been achieved by a modified CSA. In Ref. [20], the FPA was implemented to solve a combined economic and emission dispatch problem.

Since CSA, FFA, and FPA improve their solutions using random decisions, the required number of iterations for reaching an optimal solution mainly determines the overall computational efforts and the performance of such algorithm. A better algorithm should obtain the optimal solution in a reasonable iterations number with less running time.

It is worth noting that in previous Refs. [15–20], performance and computational efficiency are demonstrated considering the standard test power systems. These works did not study a real power system in which finding better solutions, within a practically acceptable timescale, is important for choosing a powerful algorithm. Moreover, for a real power system with several variables, the best solution under several constraints cannot be easily obtained using meta-heuristic algorithms, which are basically iterative approaches, with fewer iterations number. Consequently, the time to achieve a suitable number of iterations is important.

In fact, despite the cost of the wind power is very low comparing to the thermal power generation (TPG) one; the uncontrollable nature of wind power introduces an additional managing intermittency cost. The minimization of this cost requires modelling the wind variability. For an isolated power system, which not contain a dispatching centre, the operators must have the power generation schedule in advance; this gives a good vision for an economically and safely future operation. At the same time, due to the intermittent nature and uncertainty of the wind resource, considering the rated power of the wind turbine as its upper bound is not applicable in the practical power systems.

Therefore, the first contribution of this paper is to develop a powerful approach to OPF dispatching applied to a real power system using the FFA, the CSA, and the FPA. This work is intended for implementation in an existing power system in the region of Adrar, located in south-western of Algeria. The main purpose of OPF is to establish the volume of active power generated by the production units, with the minimum value of a multi-objective function involving the fuel cost, the NOx emission, and the cost caused by the uncertainties of the wind resources. The wind power cost is based on the calculation of the overestimation and underestimation costs of available wind energy, using the Weibull distribution function of wind speed and the wind turbine power curve. The second contribution consists in the proposition to use the wind speed carrying maximum energy for computing the maximum power output of WPG at the Adrar's site. Such formulation has never been proposed in the field of OPF problems so far.

The rest of this paper is organized as follows. Section 2 presents the mathematical model expressing the typical OPF in the presence of WPG and NOx emission. Section 3 describes the concept of the employed CSA, FFA, and FPA for solving OPF problem. Section 4 performs the efficiency of the solutions obtained by these algorithms and demonstrates their merit considering their computational time and iterations taken to converge as criteria. Finally, Section 5 concludes the paper.

2. OPF formulation with WPG

2.1. Multi-objective function

Nowadays, OPF is becoming an important and powerful tool for ensuring better operation and planning of a modern power system. The main purpose of OPF is to establish the volume of active power generated by the production units. This is achieved by minimizing the total operating costs, while facing various equality and inequality constraints [21].

In recent years, with rising interest in environmental issues and large-scale integration of renewable energies, it has become more necessary than ever before to consider them in the OPF. Helpful guides on theoretical and application of OPF considering renewable energies [22] and environmental issues [23] can be found.

In this context, a multi-objective (fitness) function that sums up the operating costs of the TPGs and WPGs, and NOx emission targets to formulate an OPF problem is expressed as:

$$\text{fitness} = \sum_{i=1}^{TPG} (\text{Cf} + \text{Em})_i + \sum_{j=1}^{WPG} \text{Cost}\left(P_j^{WPG}\right) \quad (1)$$

With: $\sum_{i=1}^{TPG}(\text{Cf}+\text{Em})_i = \mathbb{C}_i$ where $(\text{Cf}+\text{Em})_i$: the sum of the fuel cost and the NOx emission of the ith TPG; P_j^{WG}: the power generated by the jth WPG.

2.1.1. Cost of TPG

The first term of Eq. (1) represents the total cost of the fuel and the NOx emission, approximated by two quadratic functions of P_{Gi}:

$$\mathbb{C}_i = \omega_1 \sum_{i=1}^{TPG}\left(a_i + b_i P_{Gi} + c_i P_{Gi}^2\right) + \omega_2 h \sum_{i=1}^{TPG}\left(d_i P_{Gi}^2 + e_i P_{Gi} + f_i\right) \quad (2)$$

where a_i, b_i, and c_i:the constants of the ith TPG fuel cost; d_i, e_i, and f_i: the NOx emission coefficients; ω_1 and ω_2: the weighting factors; h: the price penalty factor.