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A novel approach based on cuckoo search for DG allocation in distribution network

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ABSTRACT

This paper presents a novel approach based on cuckoo search (CS) which is applied for optimal distributed generation (DG) allocation to improve voltage profile and reduce power loss of the distribution network. The voltage profile which is the main criterion for power quality improvement is indicated by two indices: voltage deviations from the target value which must be minimized and voltage variations from the initial network without DG which must be maximized. The CS was inspired by the obligate brood parasitism of some cuckoo species by putting their eggs in the nests of other species. Some host birds can engage direct contest with the infringing cuckoos. For example, if a host bird detects the eggs are not their own, it will either throw these alien eggs away. The CS has been compared with other evolutionary algorithms such as genetic algorithm (GA) and particle swarm optimization (PSO) and different cases have been investigated for indicating the applicability of the proposed algorithm. The results indicate the better performance of CS compared with other methods due to the fewer parameters which must be well-tuned in this method. In addition, in this method the convergence rate is not sensitive to the parameters used, so the fine adjustment is not needed for any given problems.

1. Introduction

According to IEEE, distributed generation is defined as generation of electricity by facilities that are sufficiently smaller than central generating plants and can be connected at nearly any point in power system [1,2]. The penetration level of DGs in power system have been increasing during the last few years due to the significant advances in several generation technologies, deregulation of power systems, environmental impacts and construction issues of new transmission lines [3,4]. Moreover DG may give rise various benefits such as voltage control, ancillary services, power quality and reliability improvement, loss reduction, energy savings and distribution capacity deferral [5–11].

Recently, several papers have been published to study optimal DG sitting and sizing problems. In [12] the power loss of system was minimized by proper DG allocation with application of an analytical method. In [13] a multi-objective index was used to reduce voltage drop and power loss. In [14–16] a multi-objective GA was performed for optimizing corrective actions [14], planning and operation of distribution network [15,16]. The multi-objective function used was the combination of all the objectives by using a weighted sum of the single objective function. In [17–20] the authors determined optimal DG apportionment by using several factors related to both DG and network such as reliability, voltage profile, system efficiency, power losses and load variation and also in [21] the location and contract pricing of dispatchable DG units is determined by specialized genetic algorithm.

In [22] the optimal approach was used to determine the optimal sitting and sizing of DG with multi-system constraints to achieve a single or multi objectives using GAs while in [23] a visual optimization approach was used which defined the planner role as a critical role in determining the optimum DG allocation through the choice of the appropriate weighting factors.

From the methodology point of view, various approaches have been used for proper DG apportionment such as hybrid genetic algorithm and simulated annealing [18], combined genetic algorithm and particle swarm optimization [24], tabu search [25], non-linear and dynamic programming [26,27], differential evolution algorithm [28], power flow approach [29,30], and heuristic methods [31].

In this paper a novel approach based on cuckoo search is proposed for optimal DG allocation to improve voltage profile which is the main criterion for power quality enhancement and mitigate power losses of the distribution network. The CS will be compared with other evolutionary algorithms such as GA and PSO by investigating the results of various cases for two different distribution networks.

The optimization process is carried out in MATLAB environment.

2. Cuckoo search

Cuckoo search (CS) was inspired by the obligate brood parasitism of some cuckoo species by laying their eggs in the nests of

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other host birds (of other species). Some host birds can engage direct contest with the infringing cuckoos. For example, if a host bird discovers the eggs are not their own, it will either throw these alien eggs away or simply abandon its nest and build a new nest elsewhere. In addition, the timing of egg-laying of some species is also amazing. Parasitic cuckoos often choose a nest where the host bird just laid its own eggs. In general, the cuckoo eggs hatch slightly earlier than their host eggs. Once the first cuckoo chick is hatched, the first instinct action it will take is to evict the host eggs by blindly propelling the eggs out of the nest, which increases the cuckoo chick's share of food provided by its host bird. Studies also show that a cuckoo chick can also mimic the call of host chicks to gain access to more feeding opportunity [32].

In nature, animals search for food in a random manner. In general, the foraging path of an animal is effectively a random walk because the next move is based on the current location/state and the transition probability to the next location. Which direction it chooses depends implicitly on a probability which can be modelled mathematically. For example, various studies have shown that the flight behavior of many animals and insects has demonstrated the typical characteristics of Levy flights.

CS is based on three idealized rules [33]:

- Each cuckoo lays one egg at a time, and dumps its egg in a randomly chosen nest.
- The best nests with high quality of eggs will carry over to the next generation.
- The number of available host nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability $P_a \in (0, 1)$ discovering operate on some set of worst nests, and discovered solutions dumped from further calculations.

An important issue is the applications of Levy flights and random walks in the generic equation for generating new solutions. When generating new solutions $X_i^{(t+1)}$:

$$X_i^{(t+1)} = X_i^{(t)} + \alpha \oplus \mathrm{Levy}(\lambda) \quad (1)$$

where $\alpha > 0$ is the step size which should be related to the scales of the problem of interests. In most cases, we can use $\alpha = 1$. The Levy flight essentially provides a random walk while the random step length is drawn from a Levy distribution.

$$\mathrm{Levy} \sim U = t^{-\lambda}, \quad (1 < \lambda \leq 3) \quad (2)$$

Which has an infinite variance with an infinite mean. Here the steps essentially form a random walk process with a power-law step-length distribution with a heavy tail. Some of the new solutions should be generated by Levy walk around the best solution obtained so far, this will speed up the local search. However, a substantial fraction of the new solutions should be generated by far field randomization and whose locations should be far enough from the current best solution, this will make sure the system will not be trapped in a local optimum [33].

3. Problem formulation

The DG impacts can be classified into positive impact; which is improving the voltage profile, and negative impacts; which is the increase in the system losses. The goal of this paper is to implement the proposed method to maximize the positive impact and to minimize the negative ones. The voltage profile is indicated by two indices: voltage deviations from the target value (VI_1) which must be minimized and voltage variations from the initial network without DG (VI_2) which must be maximized.

The objective function proposed in this study is defined as

$$\mathrm{OF} = \mathrm{Min}[(W_L * \text{power loss}) + (W_{V1} * VI_1) - (W_{V2} * VI_2)] \quad (3)$$

where OF is the objective function, W_L is the weighting factor for power loss, W_{V1} is the weighting factor for VI_1 and W_{V2} is weighting factor for VI_2. Each of the components will be mentioned in detail.

3.1. Evaluation of power loss

Power loss in the network is the summation of loss of each branch. So total power loss can be defined as

$$\text{Power loss} = \frac{1}{\text{MVA base}}\left(\sum_{i=1}^{N}\sum_{j=1}^{N}(V_i - V_j) \times I_{ij}\right) \quad (4)$$

The whole power loss is divided by MVA base in order to be normalized (a value between 0 and 1).

3.2. Evaluation of VI_1

One of the advantages of proper DG allocation is the improvement in voltage profile. On the other hand, improper allocation will increase voltage deviations from the nominal value ($V_{\text{target}} = 1$ pu). In this way, closer the index to zero will give the better performance of the network so this index must be minimized to improve the voltage profile. The voltage deviations index can be defined as follows:

$$VI_1 = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{|V_i - V_{\text{target}}|}{V_{\text{target}}}\right) \quad (5)$$

3.3. Evaluation of VI_2

The second index of voltage profile is defined as [34]

$$VI_2 = \frac{1}{N}\frac{\sum_{i=1}^{N}|V_i^{\mathrm{DG}} - V_i^{\mathrm{no}}|}{\sum_{i=1}^{N}V_i^{\mathrm{no}}} \times 100 \quad (6)$$

In order to have better voltage profile this index must be maximized.

By evaluating the three components explained above, Eq. (1) can be stated as follows which is the main objective function.

$$\mathrm{OF} = \mathrm{Min}\left[\left(W_L * \frac{1}{\text{MVA base}}\left(\sum_{i=1}^{N}\sum_{j=1}^{N}(V_i - V_j) \times I_{ij}\right)\right) + (W_{V1} * VI_1) - (W_{V2} * VI_2)\right] \quad (7)$$

With

$$W_L + W_{V1} + W_{V2} = 1 \quad (8)$$

where N is the total number of buses, V_i and V_j are the voltages at buses i and j, V_i^{DG} is the voltage at bus i with DG,V_i^{no} is the voltage at bus i without DG and I_{ij} is the current between buses i and j.

3.4. Constraints

The operating constraints are defined as follows:

- Voltage limitation

$$V_{\min} \leq V_i \leq V_{\max} \quad (9)$$

where $V_{\min}$ and $V_{\max}$ are the minimum and maximum allowed voltage (±5%) and V_i is the voltage at bus i.

- Power balance constraints

$$\sum_{g=1}^{N_g} Pg_{gw/\mathrm{DG}} + \sum_{d=1}^{N_{\mathrm{DG}}} Pg_d = P_d + P_L \quad (10)$$

where N_g and N_{DG} are the total number of traditional generation unit and total number of DGs, $Pg_{gw/DG}$ is operating active power of