# Flower Pollination Algorithm Applied to the Reconfiguration Problem of Electric Power Distribution System

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**Abstract.** The electricity sector is undergoing a transformation process driven by a set of factors that have affected electricity distribution systems. The reconfiguration of the distribution system is a procedure performed mainly to minimize energy losses. A good comparison oriented to results and performance can be made using the Flower Pollination Algorithm (FPA). the FPA is a metaheuristic inspired by the pollination of plants by means of flowers and has an optimization feature to solve the problem under analysis. This work presents an application of the FPA for Reconfiguration of the Electricity Distribution System (RSDEE) aiming at the optimization of the problem under analysis. The technique was validated in small balanced systems (5 nodes, 33 nodes and 70 nodes), used in RSDEE works. The initial results were compared with other techniques, proving the efficiency in solving the problem in competitive computational time. It was concluded that the FPA metaheuristic presents an adequate performance for the reconfiguration problem in small and medium sized networks.

**Keywords:** Distribution System Reconfiguration, Flower Pollination Algorithm, Metaheuristic, Power Losses.

## 1 Introduction

The current modernization of Electrical Power Systems (EPS) has aroused the interest of researchers in doing studies to better operate electricity distribution networks [1]. These studies are accentuated in the search for the minimization of active power losses and in the improvement of energy supply efficiency in the last stage of EPS. The introduction of smart grid technologies in electricity distribution networks has definitely become one of the most explored research fronts in EPS [1]. The Distribution Network Reconfiguration (DNR) problem aims to determine a radial topology of the system with minimum technical losses, by modifying the status of switching devices. Switching devices include: sectioning or normally closed switches, and interconnection or normally open switches.

There are several techniques employed to solve the DNR problem. These techniques include metaheuristic approach-es and classical or traditional algorithms [2]. In reference [3], an evolutionary and customized algorithm was pro-posed to solve radial DNR problem. The authors presented a metaheuristic technique based on Particle Cloud Optimization for the DNR problem considering a real system. In [4], the metaheuristic Particle Swarm Optimization (PSO) technique with optimal load flow was used to reduce the actual energy loss in distribution networks. In [5], the authors presented a differential evolution-based algorithm with self-adaptive mutation to solve the DNR problem. In [6], the authors proposed a two-stage metaheuristic method to determine the configuration with minimal losses in a distribution network. The proposed algorithm is based on sensitivity analysis of power loss related to the impedances of candidate branches. In [7], a novel method is presented for modeling decision problems with restrictions for the study of DNR in the occurrence of a contingency. The proposed technique allows obtaining a rapidly optimized solution, considering several objectives simultaneously. This characteristic is important when performing analysis in real time and in emergency situations. In reference [1] a bioinspired metaheuristic optimization technique is applied to solve the problem of unbalanced three-phase DNR and variable demand.

The studies [8], [9] and [10] also presented metaheuristic method to solve the problem under analysis.

Therefore, metaheuristics are gaining ground in the literature by presenting simple algorithms that generate high quality results with reduced computational effort [4].

This work presents an application of the metaheuristic Flower Pollination Algorithm (FPA) in the solution of the DNR problem. The adopted method seeks to find a radial topology of the network in order to minimize the electrical losses of the system.

# 2 Reconfiguration problem and mathematical formulation

The DNR aims to find the best topology of a distribution network minimizing power losses, meeting operational constraints, and maintaining system radiality. The objective function for minimizing energy losses [2] can also be found in the work [11], and is described as follows:

$$Min_{losses} = \sum_{km=1}^{N_t} C_{km} g_{km} (V_k^2 + V_m^2 - 2V_k V_m cos\theta_{km}) \tag{1}$$

Subject:

$$V_k^{min} \leq V_k \leq V_k^{max} \tag{2}$$

$$Q_k + Q_k^{sh}(V_k) = \sum_{m \in k} Q_{km}(V_k, V_m, \theta_k, \theta_m) \tag{3}$$

$$P_k + P_k^{sh}(V_k) = \sum_{m \in k} P_{km}(P_k, P_m, \theta_k, \theta_m) \tag{4}$$

Topology radiality

In which:

$Min_{Losses}$: Total active system losses in configuration;
C: Switch between nodes k and m (open=0 or close=1)
g: Conductance in the branch k-m;
$V_K$: Node voltage k;
$V_m$: Node voltage m;
$\theta_{Km}$: Angular difference between nodes k-m;
$N_t$: Numbers of branches of the configuration;
$P_k$: Active power of k-node;
$Q_k$: Reactive power of k-node;
$Q^{sh}_k$: Reactive power of k node with shunt element;
$\theta_k$: Phase angle of k node k;
$\theta_m$: Phase angle of node m;

DNR is considered a difficult-to-solve mixed integer nonlinear programming problem. This paper proposes to solve the problem referred to by applying the FPA metaheuristic.

# 3 Flower Pollination Algorithm

An important feature of biological systems is the ability to adapt in an evolutionary and effective way to the constant changes of the environment. Based on this characteristic, bio-inspired algorithms in nature have been developed and applied in various engineering, medicine, industries and other areas.

The optimization process consists of the task of finding the best value of decision variables for solving a problem. In general, optimization techniques are used when there are no simple alternatives to solve a problem. Many conventional optimization techniques do not perform well when used in complex, nonlinear and multimodal problems. Consequently, in recent years, metaheuristic algorithms inspired by nature are being employed, presenting promising results [10].

The FPA optimization technique was proposed in [12], inspired by the flower pollination process. From the point of view of biological evolution, the goal of pollination of flowers is the optimal reproduction of plants in terms of numbers, as well as the survival of those stronger ones. The pollination process can be seen as a resource for the optimization of plant species.

The FPA bioinspired algorithm uses as a metaphor the pollination of plants through flowers. The ideal strategy of reproduction of plants involves the survival of the fittest, as well as the ideal reproduction of plants in terms of numbers. These factors represent the fundamentals of FPA and are oriented towards optimization [6].

In [13], the authors idealize the characteristics of the flower pollination process, the behavior of pollinating animals, the phenomenon of flower-pollinator partnership, or flower loyalty. In the global pollination stage, flower pollen is transported by pollinators such as insects and birds, and can travel a long distance, since these animals can often fly and move over large expanses. This ensures the pollination and reproduction of the fittest. Representing the fittest individual in the population as $g^*$, flower loyalty can be represented mathematically as presented in Equation (5).

$$x_i^{t+1} = x_i^t + L(x_i^t - g_*) \quad (5)$$

Where $x_i^t$ is polen i or the solution vector $x_i$ in iteration t, and $g^*$ is the best solution found among all solutions in the current generation or iteration. The L parameter is the force of pollination, which is essentially a step size. Because insects can move at a great distance, with various step distances, one can use a flight from Lévy to mimic this characteristic efficiently. That is, it is established L > 0 from a Levy distribution, represented by Equation (6).

$$L \sim \frac{\lambda\Gamma(\gamma)\sin(\pi\lambda/2)}{\pi}\frac{1}{S^{1+\lambda'}} \quad (6)$$

$$(S \gg S_0 > 0) \quad (7)$$

Where is $\Gamma(\gamma)$ the standard gamma function, and this distribution is valid for values of S < 0. Most of the problems were used λ=1.5. The second premise is flower loyalty and represents the local search or pollination stage of the FPA.

Otherwise, the local pollination process is started by generating a random number ∈, ∈ in [0, 1] as Eq. 8.

$$x_i^{t+1} = x_i^t + \in (x_i^t - x_k^t) \quad (8)$$

In this equation $x_i^t$ and $x_k^t$, are pollens of different flowers of the same plant species. They are also of the species and do random local scanning, considering a uniform distribution between [0.1].

An optimization process through bioinspired algorithms should consider two aspects: Exploration that discovers new potential locations in the search space, that is, the global search and intensification that uses promising solutions already identified in the local search. For this, a probability or proximity operator p is used to switch between the two search modes, thus doing a wide and intelligent sweep through the solution space. Thus, according to [14] the following flowchart in Fig.1 represents the search process performed through FPA.

# 4 Results

To validate the technique, the FPA algorithm was executed to find the solution to the DNR problem. For the purpose of proving the FPA and comparing with other techniques in the literature, test systems of 5, 16, 33 and 70 nodes were used. Each system was executed and the results are found in Case I, Case II, Case III and Case IV, respectively. The algorithm used was implemented in the GNU Octave program and all simulations were performed on an Acer computer with Intel® processor, with 64-bit operating system. Therefore, to adjust the metaheuristic FPA, the following basic parameters were considered: the population number is set at 50 and the maximum number of iterations is set at 50 for node systems of 5, 16 and 33, while the 70 node systems are 70 population maximum iteration.

## 4.1 Case I: 5 nodes System

The data of the 5-bar system can be found in references [2] and [5]. The system operates with a base voltage of 12.66 KV and 100 MVA respectively. The initial loss is 15.16 KW. After reconfiguration the loss was reduced to 3.20 KW. Table 2 presents the results of the technique used, as well as the results of the other techniques presented in the literature. The switches opened before reconfiguration are 2, 4, and 6.

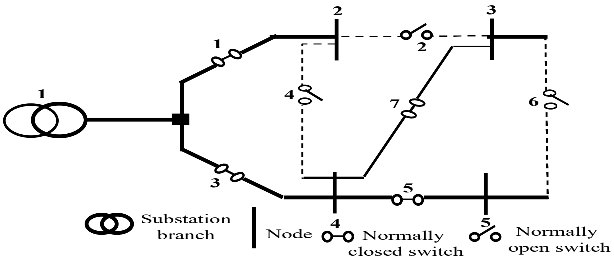


Figure 2. nodes 5 system

Table1. Results and Comparison with other Techniques

| references | Open switches | Losses (kw) | T(s) |
|---|---|---|---|
| **[5]** | 3 – 4 - 7 | 3.20 | |
| **[6]** | 3 – 4 - 7 | 3.20 | |
| **[2]** | 3 – 4 - 7 | 3.20 | |
| **FPA** | **3 – 4 - 7** | **3.20** | **2.1** |

Table 1 shows that the solution obtained using the technique used has the same quality as the referenced works in the literature. The computational time to get the solution is 2.10 seconds with 76% of the loss reduction. It is noteworthy that other studies mentioned above in Table 1 did not show the time of the solution of the problem.

Fig.3 has a voltage profile before and after reconfiguration, it is noticed that before the voltage was 1.01 pu and after reconfiguration the voltage rose to 1.04 pu.

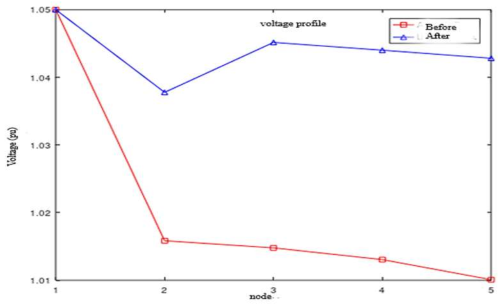


Figure 3 – profile voltage case I

## 4.2 Case III: 33 nodes system

In the 33-bar system, the operating voltage is 12.66 kV and includes 5 interconnecting slats and 32 disconnector slats. Test system data is available at [2], [5] and [6]. The losses from the initial configuration are 202.68 kW. The proposed technique was applied to this system and the results were listed in Table 3.

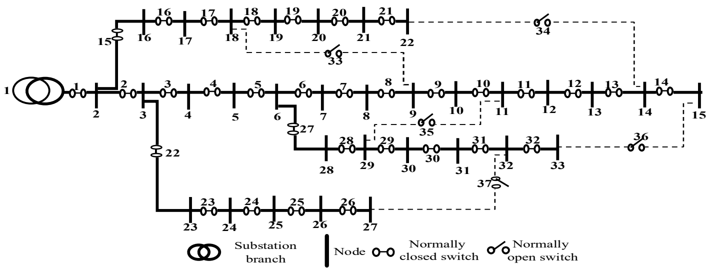


Figure 4. 33 nodes system

The results found for 33-bar system using FPA, it is noticed that the result obtained in a computational time of 76 seconds showed a satisfactory difference in relation to the results presented in Table 3. While the time to obtain the result compared to the references mentioned in Table 4, the computational time of the FPA was competitive, but not satisfactory.

Table 3. Results and Comparison with Other Techniques

| Reference | Open switches | Losses (Kw) | T(s) |
|---|---|---|---|
| **[6]** | 7 – 10 – 14 -27 -30 | 160.99 | -- |
| **[7]** | 5 -22 - 32 – 33 - 37 | 150.68 | -- |
| **[3]** | 7 – 9 – 14 -28 -32 | 140.33 | -- |
| **[2]** | 7 – 9 – 14 – 32 - 37 | 139.55 | -- |
| **[9]** | 7 – 9 – 14 – 32 - 37 | 139.55 | 2.34 |
| **[10]** | 9 – 7 – 14 – 32 - 37 | 139.55 | 14.3 |
| **[11]** | 7 – 9 – 14 – 32 - 37 | 139.55 | -- |
| **[12]** | 7 – 9 – 14 – 32 - 37 | 139.53 | 647.03 |
| **[14]** | 7 - 10 - 15 – 33- 35 | 139.42 | 29.62 |
| **[5]** | 7 -10 -14 – 28 - 32 | 138.92 | |
| **[13]** | 7 – 9 – 14 – 32 -37 | 138.91 | 49.59 |
| **[1]** | 7 – 9 – 14 – 32 - 37 | 138.60 | 3.14 |
| **[17]** | 7 – 9 – 14 – 36 - 37 | 138.57 | -- |
| **FPA** | **7 - 9 -14 - 32 - 37** | **138.55** | **146** |

In Fig. 7, it is observed that minimal gnawed was far below before and after reconfiguration the minimum voltage in the system was improved from 0.91 pu to 0.94 pu.

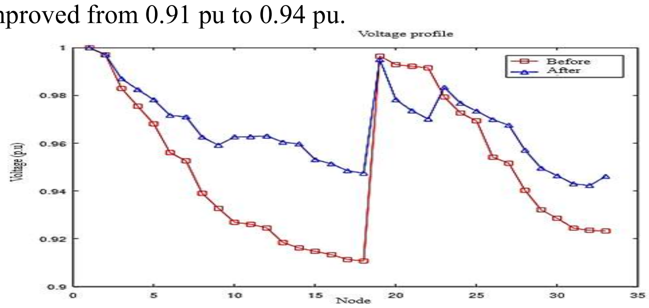


Figure 7. Case III: Voltage profile

4.3 Case IV: 70 nodes system

Fig.8 illustrates the 70-bar system, in which dashed lines represent the switches initially opened.

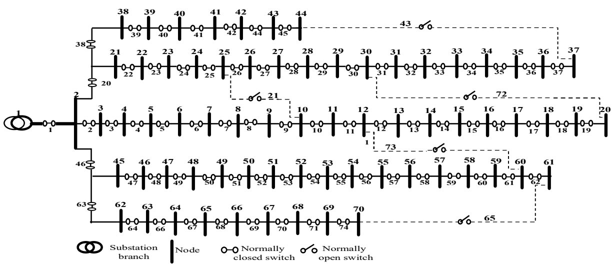


Figure 8. 70 nodes systems

This radial distribution system has 70 nodes and 74 switches, including 5 interconnection switches. The complete data of this system can be found in [2] and [5]. The operating voltage of the system is 12.66 kV with power of 100 MVA. The loss on the network before reconfiguration is 20.17 kW. The results are provided in Table 4.

Table 4. Results and Comparison with other Techniques

| Reference | Open switches | Losses (kw) | T(s) |
|---|---|---|---|
| **[9]** | 15 – 59 - 62 – 70 - 71 | 9.95 | 26 |
| **[18]** | 15 – 56 - 62 – 70 - 71 | 9.44 | 90 |
| **[9]** | 15 – 56 - 62 – 70 - 71 | 9.43 | 58 |
| **[2]** | 15 – 57 – 62 – 70 - 71 | 9.43 | - |
| **[5]** | 15 – 57 – 62 – 70 - 71 | 9.42 | - |
| **[15]** | 15 – 57 – 62 – 70 - 71 | 9.42 | - |

| | | | |
|---|---|---|---|
| **[13]** | 15 – 56 - 62 – 70 - 71 | 9.41 | - |
| **FPA** | **13 – 20 - 56 – 62 - 70** | **9.40** | **117** |

According to Table 4, it should be noted that the proposed methodology found approximately the same solution reported in the specialized literature already with the loss referenced, above all mentioned in Table 4. It is noted that some studies have limited the time of the solution of the problem while APF has found the computational time solution to find the best solution is 117 seconds.

In the initial configuration of the System fig.8, the lowest voltage was 0.97 pu. After reconfiguration, the lower voltage magnitude was improved to 0.98 pu.

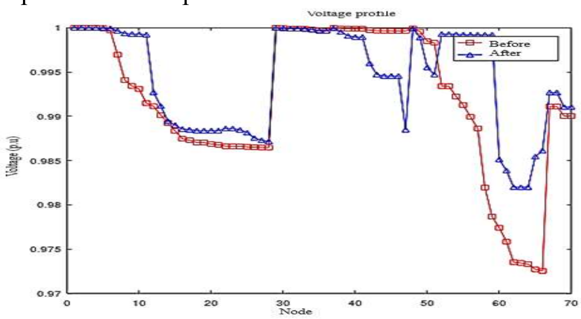


Figure 9. Case IV: Voltage profile

## 5. CONCLUSION

This work presented an optimization algorithm based on FPA metaheuristics for DNR, with the objective of minimizing energy losses. The technique proposed in this work presented satisfactory and efficient solutions when compared with other techniques found in the literature. It is concluded that the metaheuristic FPA presents an excellent performance for the reconfiguration problem in small and medium-sized distribution networks. As future works, median and large systems will be analyzed. Also, the impact of photovoltaic generation on the DNR problem will be addressed.

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