

Biogeography based Optimization for Multi-Objective Reconfiguration Problem in Distribution Networks

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Abstract

Background/Objectives: The focus of this article is to develop a new strategy for solving multi objective reconfiguration problem with a aim of obtaining the global best solution. **Methods/Statistical Analysis:** The traditional solution methods for reconfiguration may not provide the global best solution. Besides they may not handle non differentiable objective and constraint functions. Recently a Biogeography based Optimization (BBO). A method of meta Heuristic optimization has been outlined for solving optimization problems. This paper develops an effective method using BBO for solving reconfiguration problem with objectives of loss minimization, voltage profile enhancement and voltage stability improvement. **Findings:** The results of IEEE 33 and 69 node networks indicate that the proposed method is able to provide better solutions than the existing methods. **Application/Improvement:** The method can be applied in distribution automation systems for online operations. It can be further improved by combining the BBO with Heuristic rules for enhancing the research process.

Keywords: Biogeography based Optimization, Distribution Networks, Reconfiguration

1. Introduction

Network reconfiguration is a method of modifying the topological structures of the distribution networks by changing the open/close status of the sectionalising and tie switches. Usually, networks are reconfigured to reduce network Real Power Loss (RPL), achieve load balancing and relieve network overloads. These objectives are built from the view point of service providers, but the consumers require quality power supply with a voltage nearer to nominal voltage. Besides, networks are operating nearer to the Voltage Stability (VS) boundaries. There is thus a need to explore avenues to simultaneously reduce RPL, improve Voltage Profile (VP) and enhance VS in distribution networks¹. The reconfiguration problem can be tailored as an optimization problem.

Numerous mathematical methods have been outlined for solving the network reconfiguration problem²⁻⁷. They start with a radial configuration of the network and alter

the network configuration using heuristic formulas in order to reduce the RPL. They are usually efficient but may not achieve the optimal configuration. To overcome these drawbacks, bio-inspired algorithms such as hyper-cube ant colony optimization⁸, bacterial foraging optimization algorithm⁹, particle swarm optimization¹⁰, binary particle swarm optimization¹¹, adaptive imperialist competitive algorithm¹², and genetic algorithms¹³ have been applied for reconfiguration problems.

Recently, a Biogeography-Based Optimization (BBO), a meta-heuristic optimization method has been outlined for solving optimization problems by Simon¹⁴. It has been used to a variety of engineering optimization problems¹⁵⁻¹⁸ and found to yield satisfactory results. This paper attempts to apply BBO in solving the reconfiguration problem with multiple objectives of RPL reduction, VP improvement and VS enhancement and presents the results for 33- and 69-node radial distribution networks for exhibiting the superiority of the developed method.

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2. Problem Formulation

The reconfiguration problem is tailored as an optimization problem of minimizing/maximizing one or more objective functions while satisfying network constraints. The objectives of the reconfiguration problem are RPL reduction, VP improvement through reducing Net Voltage Deviations (NVD) and VS enhancement by maximizing the lowest VS index (LVSI) seen in the system¹⁹. These objectives can be formulated as

$$\text{Minimize } f_1 = RPL = \sum_{m=1}^{nb} |i_{km}|^2 r_{km} \quad (1)$$

$$\text{Minimize } f_2 = NVD = \sum_{j=1}^{nn} |V_j - 1.0| \quad (2)$$

$$\text{Maximize } f_3 = LVSI = \min \{VSI(m); m \in 1 : nn\} \quad (3)$$

Where

$$VSI(m) = V_k^4 - 4 \{P_{km}x_{km} - Q_{km}r_{km}\}^2 - 4 \{P_{km}r_{km} - Q_{km}x_{km}\}V_k^2 \quad (4)$$

The above objectives can be calculated from the distribution power flow solution for a given load, and status of tie and sectionalizing switches. They can be blended into a single objective function through appropriate weight factors so as to minimise all the objectives simultaneously and formulated as

$$\text{Minimize } \Phi = w_1 \left(\frac{f_1}{f_1^0} \right) + w_2 \left(\frac{f_2}{f_2^0} \right) + w_3 \left(\frac{f_3}{f_3^0} \right) \quad (5)$$

Where

f_1^0, f_2^0 and f_3^0 represents the RPL, NVD and LVSI evaluated for base-configuration respectively.

w_1, w_2 and w_3 indicates weight factors, whose sum is equal to 1

The switching operation may sometimes make certain nodes disconnected from the live network, thereby making the configuration not radial. A check is therefore made to confirm whether the resulting configuration is radial²⁰. Besides, the substation should satisfy the power demand in the network, which is realised by the power flow. The resulting flows in the lines should not exceed their respective thermal limits. It is represented by a constraint

$$|i_{km}| \leq i_{km}^{\max} \quad (6)$$

3. Proposed Method

This section explains the proposed BBO based reconfiguration method (BRM), which requires representation of problem variables and formation of a *HSI* function. The decision variable in BRM is the open-switch numbers. Each habitat of the BBO is therefore represented in vector form to denote the open-switches as

$$h = [OS_1, OS_2, \dots, OS_n] \quad (7)$$

The BBO generates real numbers and hence to obtain integer values for open-switches, the real numbers are converted into the nearest integer values. The *HSI* function is built using the problem objective function and line flow constraint as

$$\text{Maximize } HSI = \begin{cases} \frac{1}{1 + \Phi + w_b \sum_{i \in \mathfrak{R}} (|i_{kj}| - i_{kj}^{\max})^2} & \leftarrow \text{if the network is radial} \\ 0 & \leftarrow \text{otherwise} \end{cases} \quad (8)$$

The habitats in the population are initialized at the beginning of the iterative process. For each habitat in the population, the *HSI* is calculated, after altering the network topology according to the status of open-switches. The BBO operators are applied for non-elite habitats in order to maximize the *HSI*. This procedure is repeated till convergence¹⁴.

4. Simulation

The BRM is tested on two standard distribution networks. The first one is a 33 node network with 5 normally open switches²¹. The second network is a 69 node network comprising of 5 tie-loops²². The reconfiguration problem is solved by GA and PSO in addition to solving by BRM. The results of 33 and 69 node networks, containing details of open-switches, RPL, NVD, LVSI and Lowest Voltage Magnitude (LVM) seen in the network, before and after reconfiguration are presented in Table 1 and 2 respectively. As the solution point and the associated performances can be adjusted by varying the respective weight parameters, the quality of the solution cannot be assessed. The %RPLS, %VPI and %VSE of these three methods are graphically presented for 33 and 69 node systems in Figures 1 and 2 respectively. The figures also exhibit that if one performance improves, the other deteriorates due to conflicting nature of the objectives. It is observed from the table that

Table 1. Summary of Results for 33 node network

	Open-switches	RPL (kW)	NVD	LVSI	LVM
Initial Configuration	33, 34, 35, 36, 37	210.97	1.8046	0.6672	0.9038
BRM	7, 9, 14, 32, 27	143.2987	1.1135	0.7801	0.9398
GA	7, 34, 11, 36, 28	144.2890	1.1005	0.7734	0.9378
PSO	33, 34, 10, 32, 28	144.7994	1.1104	0.7806	0.939

Table 2. Summary of Results for 69 node network

	Open-switches	RPL (kW)	NVD	LVSI	LVM
Initial Configuration	69, 70, 71, 72, 73	225	1.8370	0.683301	0.9092
BRM	10 13 58 62 12	105.1541	1.0427	0.8087	0.9483
GA	10 18 13 58 62	106.2272	1.0674	0.8087	0.9483
PSO	9 14 58 62 70	105.7078	1.0569	0.8087	0.9483

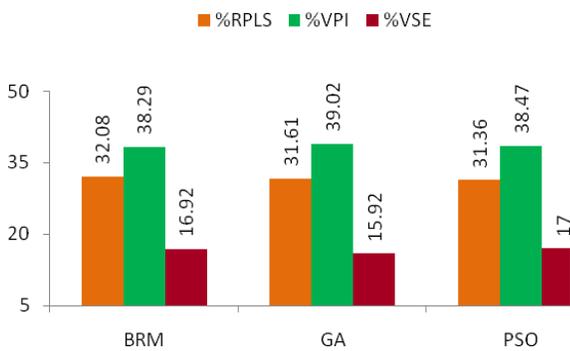


Figure 1. % Performance Enhancement for 33 node network.

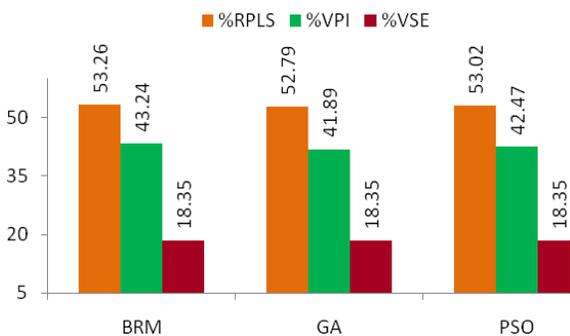


Figure 2. % Performance Enhancement for 69 node network.

there is significant improvement in LVM of the network after reconfiguration.

The VM at all nodes of 33 and 69 node systems are pictorially depicted in Figures 3 and 4 respectively. The figures also include the initial VMs before reconfiguration. It is seen from the figures that there is significant improvement in the VP after reconfiguration.

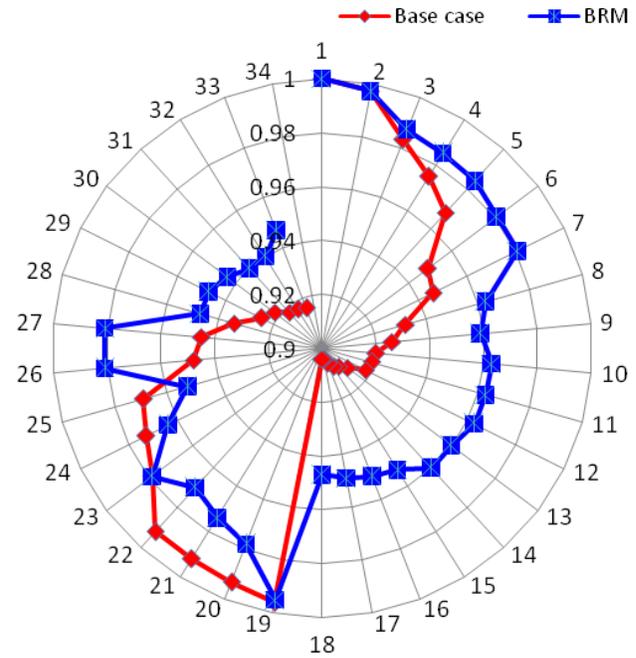


Figure 3. VP of BRM for 33 node network.

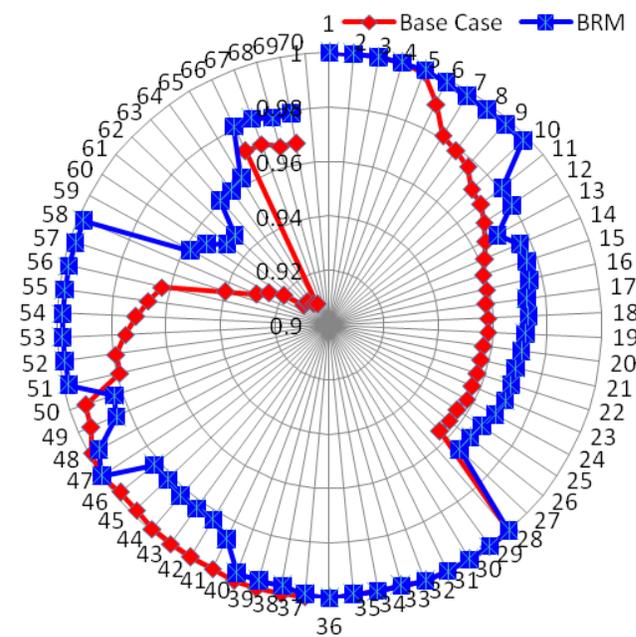


Figure 4. VP of BRM for 69 node network.

The VSI at all nodes of 33 and 69 node systems are graphically presented in Figures 5 and 6 respectively. The figures also include the initial VSIs before reconfiguration. It is seen from the figures that there is noteworthy improvement in the VS after reconfiguration.

It can be observed from these results that the proposed BRM provides a better configuration that enhances the network performances for both the test networks. The smart nature of the proposed BRM serves to eliminate

additional infrastructural cost, fits itself suitable for online applications in systems of any size.

5. Conclusion

An effective reconfiguration scheme using BBO for RPL reduction, VP improvement and VS improvement of radial distribution networks has been proposed. This method uses a simple distribution power flow taking into the status of open-switches for calculating the RPL, NVD and LVSI. The method is able to offer a better VP without any additional infrastructural cost. The algorithm is suitable for real distribution networks.

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7. References

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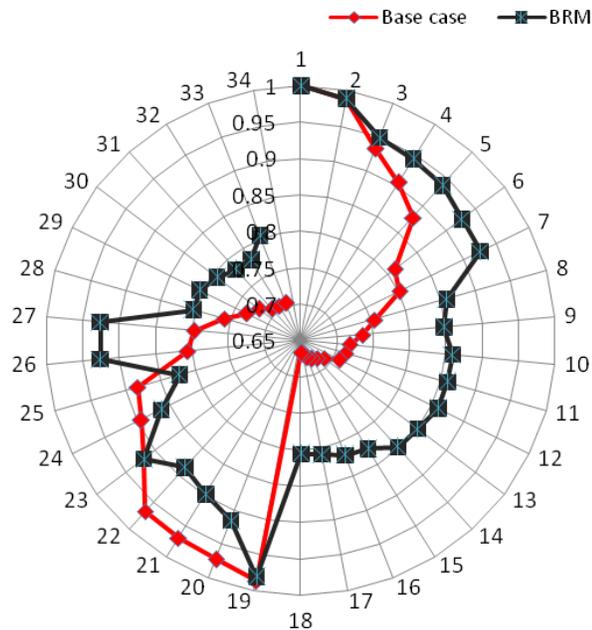


Figure 5. VSI of BRM for 33 node network.

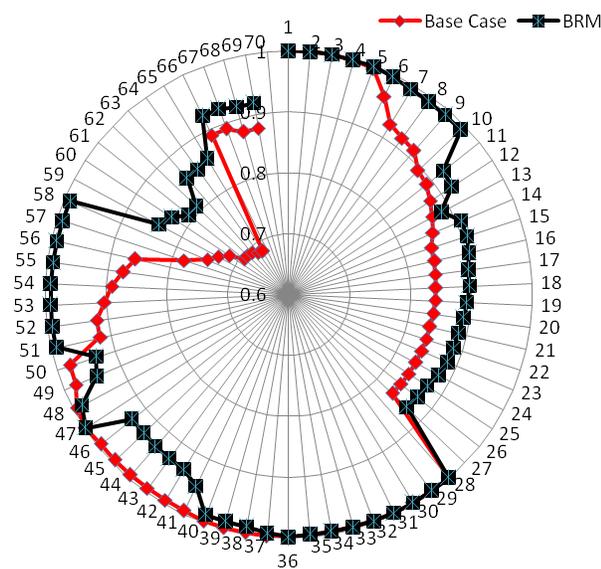


Figure 6. VSI of BRM for 69 node network.

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Nomenclature

BBO	biogeography based optimization
HSI	habitat suitability index
h_i	i^{th} habitat
i_{km}^{max}	maximum permissible current through branch between nodes-k and m
nn	number of nodes
nb	number of branches
LVM	lowest voltage magnitude seen in the network
VS	voltage stability
VSI	voltage stability index
LVSI	lowest VSI seen in the network
OS_j	branch number of j^{th} open switch
P_{km}	real power flow from node-k to node-m
Q_{km}	reactive power flow from node-k to node-m
r_{km}	resistance of distribution line connected between nodes-k and m
RPL	real power loss
x_{km}	reactance of distribution line connected between nodes-k and m
V_m	voltage at node-m
w_b	penalty factor for handling violation of line flow constraint
\mathfrak{R}	a set of branches, whose current flow exceed the respective thermal limit