
Adaptive Dragonfly Optimization Based Placement of Capacitor Banks for Voltage Stability Enhancement in Distribution Networks

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Abstract

The present day ever escalating power demand moves the operating point of the distribution networks in the vicinity of the voltage stability boundaries. Any small reactive power unbalance between the generation and demand may trigger voltage instability, which makes the voltage magnitude to fall slowly until a rapid change occurs. This paper presents an adaptive dragonfly optimization based method for placement of shunt capacitor banks with a view of improving the voltage stability besides enhancing the voltage profile and lowering the network losses. Simulation results on 33 and 69-node distribution networks exhibit the greater performances of the suggested algorithm.

Keywords: Voltage stability, distribution networks, dragonfly optimization, capacitor placement.

1 Introduction

Present day stressed distribution networks (DNs) with ever-increasing load demands experience voltage stability (VS) problems and may undergo voltage collapse (VC), when the network is unable to maintain balance between the reactive power generation and demand [1]. VC is a process that slowly varies the operating point in such a way that the voltage magnitude gradually falls until a rapid change occurs. It therefore becomes a great issue for utilities in view of ensuring stable operation. Several voltage stability studies have been performed and many VS indices have been outlined in recent decades [2, 3].

Providing reactive power support at appropriate nodes of the DN's by placing capacitor banks (CBs) has been one of the simple means of enhancing the VS, but it may not be economical to place CBs at all nodes. It thus necessitates placing CBs with appropriate capacities at the best possible node locations that attempt to reduce the network loss, improve voltage profile and enhance voltage stability. Several methods that include both classical mathematical approaches and nature-inspired algorithms such as particle swarm optimization (PSO), honey bee algorithm, etc. have been suggested for optimal placement capacitor banks (OPCBs).

A strategy for OPCBs for enhancing the profit and voltage profile of DN's with photo-voltaic systems was developed by Hernandez et al. [4]. A method employing loss sensitivity factors and PSO for OPCBs was suggested by Prakash et al. [5]. A plant growth algorithm involving loss sensitivity factors was applied for solving OPCBs by Rao et al. [6]. A VSI based ranking for selection of nodes and a fuzzy based GA for sizing of CBs for maximizing the money savings on the cost of CBs and lowering the energy loss were suggested by Ahmed et al. [7]. A clustering-based optimization was applied by Vuletic and Todorovski in solving OPCB problem, wherein the algorithm performs a simple iterative search for allocating CBs with a goal of lowering the net cost of energy [8]. A teaching and learning based optimization was applied for OPCBs for minimizing the cost associated with energy loss by Sneha et al. [9]. A bacterial foraging optimization based strategy involving VSI and loss sensitivity factors was outlined for OPCBs at changing load conditions by Devabalaji et al. [10]. A hybrid strategy combining both bat algorithm and cuckoo search was presented for OPCBs with a goal of lowering the network loss and maximizing the net cost savings by Injeti et al. [11]. A OPCBs was performed through ranking the nodes by employing loss sensitivity factors and sizing the CBs by gravitational search

algorithm by Mohamed et al. [12]. A crow search algorithm was applied in solving the OPCBs problem by Askarzadeh [13]. A salp swarm algorithm was applied for OPCBs and optimally placing distribution generation units in distribution systems by Kola Sampangi Sambaiah and Jayabarathi [14].

Recently Seyedali Mirjalili suggested Dragonfly Optimization (DFO), a population based algorithm, from the inspiration of the swarming activities of dragonflies in [15]. This algorithm has been studied in variety of engineering problems and portrayed to give good results [16, 17].

This article endeavors to develop a DFO based algorithm for solving OPCBs in DNs. It also employs an adaptive technique for tuning the parameters of DFO during the iterative solution process. This article is arranged as follows: Section 2 describes the CP problem, Section 3 explains the suggested method, Section 4 presents the results and Section 5 outlines the outcomes.

2 Problem Formulation

The problem is to place CBs with optimal ratings at appropriate locations through an objective of enhancing the VS, while maintaining the bus voltages within permissible range. While placing the CBs, it is necessary to consider the variations in the load throughout the day. In this regard, the load variations associated with four levels of load, that is, low, medium, full and excessive load levels are considered in forming the objective function. The reactive power requirements at appropriate nodes for these four load levels are to be obtained in such a way that the

The OPCBs problem can be tailored as an optimization problem as:

Maximize

$$\Phi = \sum_{\alpha=1}^4 \sum_{m=1}^{nfeeder} VSI_m = \sum_{\alpha=1}^4 \sum_{m=1}^{nfeeder} \left[2 \frac{V_m}{V_k} \cos(\delta_k - \delta_m) - 1 \right]^2 \quad (1)$$

Subject to

$$P_{Gm}(\alpha) - P_{Dm}(\alpha) - P_m(V, \delta, \alpha) = 0 \quad \alpha = 1, 2, 3, 4 \quad (2)$$

$$Q_{Gm}(\alpha) - Q_{Dm}(\alpha) - Q_m(V, \delta, \alpha) = 0 \quad \alpha = 1, 2, 3, 4 \quad (3)$$

$$V_m^{\min} \leq V_m \leq V_m^{\max} \quad (4)$$

$$Q_{CB-m}^{\min} \leq Q_{CB-m} \leq Q_{CB-m}^{\max} \quad (5)$$

where

VSI_m indicates the voltage stability index of feeder- m or node- m , wherein the feeder- m originates from node- k to node- m .

Q_{CB-m} is the reactive power support by CBs at node- m .

Q_{CB-m}^{\min} and Q_{CB-m}^{\max} is the minimum and maximum permissible reactive power compensation respectively at node- m .

V_m is voltage magnitude at node- m .

V_m^{\min} and V_m^{\max} is the lower and upper permissible limit respectively for V_m .

α indicates the load level which equals 1, 2, 3 or 4 for low, medium, full or excessive load levels respectively

3 Problem Formulation

The proposed method aims to solve the OPCBs problem using DFO, which requires representation of solution variables and formation of augmented cost function. The node location for k -th CB (L_k) and the required number of CBs with available reactive power rating at load level- α , $\{n_{CB-L_k}(\alpha)\}$, for placement at node- L_k are the problem variables, which form the dragonfly (*dflly*) as denoted below:

$$Dflly = \left\{ \begin{array}{l} L_1, n_{CB-L_1}(1), n_{CB-L_1}(2), n_{CB-L_1}(3), n_{CB-L_1}(4), \\ L_2, n_{CB-L_2}(1), n_{CB-L_2}(2), n_{CB-L_2}(3), n_{CB-L_2}(4), \\ \dots \dots \dots \\ L_{nc}, n_{CB-L_{nc}}(1), n_{CB-L_{nc}}(2), n_{CB-L_{nc}}(3), n_{CB-L_{nc}}(4) \end{array} \right\} \quad (6)$$

where nc indicates the number of nodes for CBs placement.

B The values of dragonfly are constrained by

$$Dflly^k(\min) \leq Dflly^k \leq Dflly^k(\max) : k = 1, 2, \dots, ndflly \quad (7)$$

where $ndflly$ indicates the number of variables in the dragonfly.

Initially, a swarm of dragonflies are randomly formed. The quality of each dragonfly in the swarm is assessed by a cost function, formulated from the problem objective and constraints as:

Minimize

$$\begin{aligned} Cost = & \frac{1}{1 + \Phi} + \sum_{\alpha=1}^4 \sum_{j \in \theta} \left(V_j(\alpha) - V_j^{\text{limit}} \right)^2 \\ & + \sum_{\alpha=1}^4 \sum_{i \in \Omega} \left(Q_{CB-i}(\alpha) \leq Q_{CB-i}^{\text{limit}} \right)^2 \end{aligned} \quad (8)$$

Where

$$Q_{CB-i}(\alpha) = n_{CB-L_i}(\alpha) \times Q_{rating-CB} \quad (9)$$

$$V_j^{limit} = \begin{cases} V_j^{\min} & \text{if } V_j < V_j^{\min} \\ V_j^{\max} & \text{if } V_j > V_j^{\max} \\ V_j & \text{otherwise} \end{cases} \quad (10)$$

$$Q_{CB-i}^{limit} = \begin{cases} Q_{CB-i}^{\min} & \text{if } Q_{CB-i}(\alpha) < Q_{CB-i}^{\min} \\ Q_{CB-i}^{\max} & \text{if } Q_{CB-i}(\alpha) > Q_{CB-i}^{\max} \\ Q_{CB-i} & \text{otherwise} \end{cases} \quad (11)$$

$Q_{rating-CB}$ is the minimum available rating of CBs

Ω represents a set of nodes for CBs placement

θ denotes a set of nodes, whose voltage magnitude violates the limits of Equation (4)

The survival of k -th dragonfly in the population of dragonflies is characterized by separation from neighbors ($Seper_k$), alignment with neighbors ($Align_k$), cohesion with neighbors ($Cohes_k$), attraction towards food source ($Attract_k$) and distraction from an enemy ($Distract_k$), as modeled by the following equations:

$$Seper_k = - \sum_{j \in \Psi} Dfly_k - Dfly_j \quad (12)$$

$$Align_k = \frac{\sum_{j \in \Psi} Velocity_j}{no. \text{ of neighbours}} \quad (13)$$

$$Cohes_k = \frac{\sum_{j \in \Psi} Dfly_j}{no. \text{ of neighbours}} - Dfly_i \quad (14)$$

$$Attract_k = Food - Dfly_k \quad (15)$$

$$Distract_k = Enemy + Dfly_k \quad (16)$$

Where

Ψ is a set of neighboring dragonflies

$w_1 - w_6$ represent respective weight factors

$Food$ and $Enemy$ indicates the food source and enemy respectively. The best and worst dragonflies in the swarm are considered as $Food$ and $Enemy$ respectively.

The velocity of movement of k -th dragonfly from current position to next position can be defined by

$$Velocity_k(t+1) = w_1 Seper_k + w_2 Align_k + w_3 Cohes_k + w_4 Attract_k + w_5 Distract_k + \omega_6 Velocity_k(t) \quad (17)$$

The position of k -th dragonfly can be modified as

$$Dfly_k(t+1) = Dfly_k(t) + Velocity_k(t+1) \quad (18)$$

If there are no neighbors around k -th dragonfly, then the fly of k -th dragonfly is modeled by Levy's flight as

$$Dfly_k(t+1) = Ffly_k(t) + \mathfrak{S} \times Dfly_k(t) \quad (19)$$

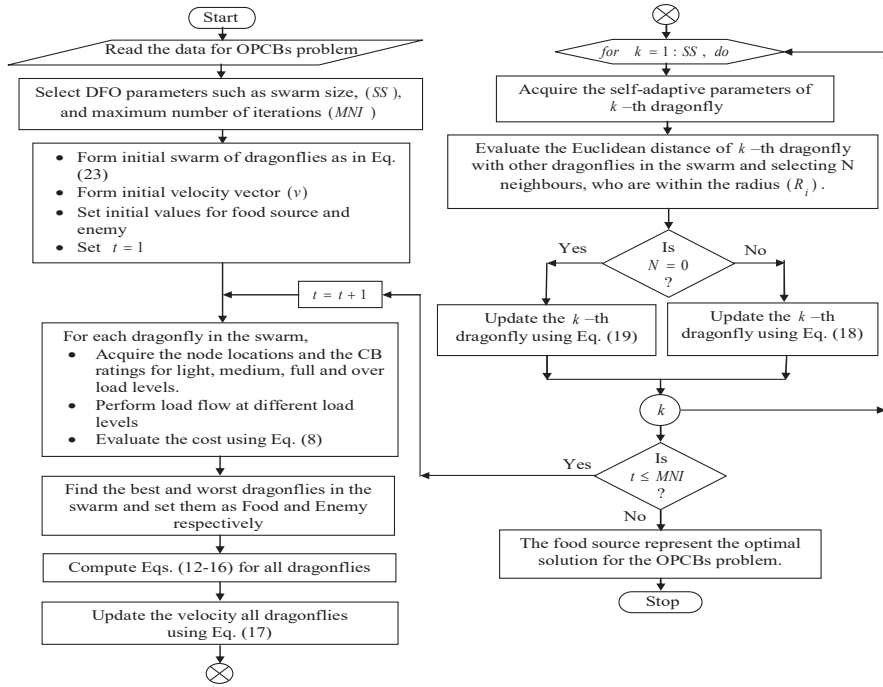


Figure 1 Flow chart of the PADFOM.

where

$$\mathfrak{S} = 0.01 \times \frac{R_1 \times \aleph}{|R_2|^{1/\gamma}} df_i(t) \quad (20)$$

$$\aleph = \left(\frac{\Gamma(1 + \gamma) \times \sin\left(\frac{\pi\lambda}{2}\right)}{\Gamma\left(\frac{1+\gamma}{2}\right) \times \gamma \times 2^{(\gamma-1/2)}} \right)^{1/\gamma} \quad (21)$$

$$\Gamma(x) = (x - 1)! \quad (22)$$

R_1 and R_2 are the random numbers

γ is a constant

The DFO parameters such as $w_1 \sim w_6$ and γ are usually tuned by a trial and error process to obtain the best solution. These parameters can be automatically tuned by an adaptive mechanism by treating them as additional variables and including them in the representation of dragonfly as

$$Dfly = \left\{ \begin{array}{l} L_1, n_{CB-L_1}(1), n_{CB-L_1}(2), n_{CB-L_1}(3), n_{CB-L_1}(4), \\ L_2, n_{CB-L_2}(1), n_{CB-L_2}(2), n_{CB-L_2}(3), n_{CB-L_2}(4), \\ \dots \quad \dots \quad \dots \\ L_{nc}, n_{CB-L_{nc}}(1), n_{CB-L_{nc}}(2), n_{CB-L_{nc}}(3), n_{CB-L_{nc}}(4), \\ w_1, w_2, w_3, w_4, w_5, w_6, \gamma \end{array} \right\} \quad (23)$$

A swarm of dragonflies is initially formed and the cost function of each dragonfly is evaluated. The processes representing exploitation and exploration by Equations (11)–(15) are performed and the positions are adjusted by Equations (16)–(17) for each member in the swarm with a goal of lowering the cost. This process represents one iteration and this process is repeated till convergence. The proposed adaptive DFO based method (PADFOM) is well explained in Figure 1.

The optimal solution attained by the above solution process indicates the optimal node locations and number of CBs required for different load levels. The CBs can be spitted into fixed and switched type by the following mechanism.

- $Q_{CB-L_j}(1)$, obtained by Equation (9) is considered as fixed capacitor.
- $Q_{CB-L_j}(\alpha)$ for other load levels ($\alpha = 2, 3, 4$) are considered as switched capacitors.

4 Simulation

The PADFOM has been applied on 33 and 69-node DNs, whose data are available in [18] and [19]. The procedure outlined in [20] has been engaged for performing the power flow, which is required for evaluating the cost function. The available minimum rating of CBs has been chosen as 150 kVAR. The load factors of 0.5, 0.8, 1.0 and 1.1 are multiplied with base-load powers to get different load levels of low, medium, full and excessive load scenarios respectively. The PADFOM has been obtained by setting the number of node locations for CB placement as 2 and then increased up to 6 for both systems, and found that the performances are satisfactory with compensation at 2 and 3 node locations for 33 and 69 nodes systems respectively.

33 Node Test System

The optimal locations and the number of CBs required for four distinct loading levels are given in Table 1. At low load level, there is no requirement for any compensation, while in medium load, three CBs are required at node-6. In case of full load and excessive load, compensation at nodes-6 and -8 are required as indicated in Table 1. As there is no need for reactive power compensation at low load level, the system does not require any fixed type of CBs, but it requires 9 and 2 numbers of switched type of CBs at node-6 and -8 respectively as furnished in Table 2. The performances in terms of the lowest VSI index observed in the network, the lowest VM observed in the network and the network real power loss before and after compensation by CBs are

Table 1 Number of CBs required for 33 node system

Load Level	$n_{CB-L_k}(\alpha)$	
	Node-6	Node-8
Low	—	—
Medium	3	—
Full	8	1
Excessive	9	2

Table 2 Type of CBs required for 33 node system

Node Nos.	Fixed CBs	Switched CBs
6	—	150 kVAR * 9 nos.
8	—	150 kVAR * 2 nos.

given in Table 3. It can be noticed that there is significant improvement in VS and VP and notable reduction in network loss.

69 Node System

The optimal locations and the number of CBs required for four distinct loading levels are given in Table 4. At all load levels, there is a need for reactive power compensation at nodes 54, 57 and 58. As this system requires compensation even at low load level, a fixed CB at node-54 and two fixed CBs at node-57 are required as indicated in Table 5. It also requires 3, 3 and 9 switched CBs at nodes-54, -57 and -58 to meet medium, full and excessive load levels respectively. The performances in terms of the lowest VSI index seen in the network (VSI^{low}), the lowest VM seen in the network (VM^{low}) and the network real power loss before and after compensation by CBs are

Table 3 Performance for 33 node system

		Low	Medium	Full	Excessive
Before	VSI^{low}	0.964	0.941	0.926	0.917
placing	VM^{low}	0.954	0.924	0.904	0.893
CBs	Loss (kW)	48.78	130.71	210.97	259.64
After	VSI^{low}	0.979	0.963	0.952	0.947
placing	VM^{low}	0.967	0.937	0.921	0.916
CB	Loss (kW)	38.01	101.89	163.32	197.21

Table 4 Number of CBs required for 69 node system

Load Level	$n_{CB-L_k}(\alpha)$		
	Node-54	Node-57	Node-58
Low	1	2	—
Medium	2	4	—
Full	4	4	7
Excessive	4	5	9

Table 5 Type of CBs required for 69 node system

Node Nos.	Fixed CBs	Switched CBs
54	150 kVAr * 1 no.	150 kVAr * 3 nos.
57	150 kVAr * 2 nos.	150 kVAr * 3 nos.
58	—	150 kVAr * 9 nos.

Table 6 Performance for 69 node system

		Low	Medium	Full	Excessive
Before	VSI^{low}	0.942	0.903	0.874	0.859
placing	VM^{low}	0.942	0.903	0.875	0.861
CBs	Loss (kW)	70.20	192.88	317.73	395.50
After	VSI^{low}	0.968	0.932	0.927	0.914
placing	VM^{low}	0.960	0.926	0.910	0.905
CBs	Loss (kW)	64.17	143.591	247.936	319.10

given in Table 6. It can be seen that there is significant enhancement in VS and VP and notable reduction in network loss.

5 Conclusion

Dragonfly Optimization (DFO) is a swarm based method, built from the inspiration of the static and dynamic swarming activities of dragonflies. The PADFOM employs the DFO in solving the OPCBs problem. The node locations and number of CBs to be placed at the chosen nodes are considered as problem variables and the enhancement of VS is considered as problem objective. The method has been featured by an adaptive mechanism that attempts to enhance the convergence and land at global best solution quickly. The simulation results on two standard DNs clearly exhibits the superiority in terms of improvement in VP, enhancement in VS and reduction in network loss.

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Biography



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