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Dragonfly Optimization Based Load Shedding for Avoiding Voltage Collapse in Distribution Networks

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ABSTRACT: Voltage collapse has become a major issue in distribution networks due to ever-rising load demands. As the networks are operating in stressed condition, even a simple disturbance may collapse the network. The simplest way to bring the network to a stable operating zone is to perform load shedding. This paper presents a methodology involving dragonfly optimization (DO), inspired from the static and dynamic swarming behaviours of dragonflies, for finding appropriate node locations for load shedding and the quantity of sheddable load with a view of bringing the network to a stable voltage region. It employs a voltage stability index for assessing the nearness of the current operating point to the voltage collapse region. The method not only enhances the voltage stability but also improves the voltage profile. It presents the results of the proposed method for 33-node distribution network to exhibit its effectiveness.

KEYWORDS: distribution networks; voltage collapse; dragonfly optimization; voltage stability index.

I. INTRODUCTION

The ever-rising load demand at distribution level drives the network towards the verge of voltage collapse (VC), which is featured by a slow voltage drop initially and a rapid voltage fall after some time. This VC is generally initiated by some kind of disturbances in terms of changes in real and/or reactive load powers. When the network is operating near VC region, the prime objective of the network engineer is to bring the network to a stable voltage region by switching capacitor banks, bringing standby DG units on-line, changing the transformer tap settings and controlling the other reactive power sources. If the network still remains in the voltage collapse region, the last priority is the load shedding. Smaller amount of load shedding may not be effective, while at the same time, larger amount of load shedding affects more number of consumers. The load shedding should be performed in an optimal way with least amount of load shedding at the most appropriate node locations in order to bring the network far away from the VC point [1].

Over the years, extensive research has been performed on under-frequency load shedding [2-5] and load shedding on transmission systems for avoiding VC [6-8], but a little focus is oriented towards load shedding of distribution networks for avoiding VC [9-11]. The voltage stability of distribution networks has become a prime topic of research in recent years and therefore several voltage stability indices to assess the distance between the current operating point to the VC region were suggested [12].

Dragonfly Optimization (DO), inspired from the static and dynamic swarming behaviours of dragonflies, was suggested for solving optimization problems [13]. This paper attempts to apply DO in solving the optimal load shedding problem of distribution networks. The method employs the voltage stability index (VSI) suggested in [12]. The results of the proposed method for 33-node system is included in this paper.

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II. PROBLEM FORMULATION

The load shedding problem can be formulated as an optimization problem involving the VSI, suggested in [12]. The VSI assesses the operating state of the distribution network and varies between unity at no load and zero at VC point. The node locations and amount of sheddable load are considered as the problem variables and optimized to bring the lowest VSI of the network to lie above a level of a critical threshold value. The problem can be formulated as

$$\text{Maximize} \quad \Phi(x) = \left\{ \min(L_m) - L^{th} \right\} + w \left\{ 1 \Big/ 1 + \sum_{j=1}^{nsn} psP_j \right\} \tag{1}$$

Subject to

$$P_{Gm} - P_{Dm} - P_m(V,\delta) = 0 \tag{2}$$

$$Q_{Gm} - Q_{Dm} - Q_m(V,\delta) = 0 \tag{3}$$

$$V_m^{\min} \le V_m \le V_m^{\max} \tag{4}$$

Where L_m represents the VSI at node-m and calculated by

$$L_m = V_k^{\,4} - 4\{P_{km}x_{km} - Q_{km}r_{km}\}^2 - 4\{P_{km}r_{km} + Q_{km}x_{km}\}V_k^{\,2} \tag{5}$$

V_k : voltage magnitude at node- k
L_m : VSI at node- m
$r_{km} + jx_{km}$: resistance and reactance of feeder- m
$P_{km} + jQ_{km}$: real and reactive powers at the receiving end of feeder- m
$P_{Gm} + jQ_{Gm}$: real and reactive power generation at node- m
$P_{Dm} + jQ_{Dm}$: real and reactive power demand at node- m
$psP_j + jpsQ_j$: percentage of sheddable real and reactive power load at chosen node location- j
nsn : number of sheddable nodes

III. PROPOSED METHOD

The proposed method employs DO in solving the load shedding problem. It requires representation of problem variables in the form of dragonflies and formation of a fitness function. Each dragonfly [13] in the load shedding problem is modelled to represent the sheddable node locations (snL) and the percent of sheddable load (psP) at each node as

$$df_i = \left[snL_1, sPnL_2, \cdots, nL_{nsn} \quad psP_1, psP_2, \cdots, psP_{nsn} \right] \tag{6}$$

The fitness function is formed as

$$\text{Maximize} \quad F = \left\{ \min(L_m) - L^{th} \right\} + w \left\{ 1 \Big/ 1 + \sum_{j=1}^{nsn} psP_j \right\} \tag{7}$$

Initially a population of dragonflies is randomly generated and the fitness of each dragonfly is calculated using Eq. (7) with a chosen threshold value (L^{th}). The exploration and exploitation phases, modelling the social interaction of dragonflies in navigating and searching for foods and avoiding enemies, are carried out for all the dragonflies in the population so as to maximize their finesses. The process of generating a new set of dragonflies is represented as an iteration, which is continued by considering the population obtained in the previous iteration as the initial population for next iteration. The DO iterative process of generating new population can be terminated after a fixed number of iterations. The dragonfly having the best fitness function value is considered as the optimal solution after convergence. The pseudo code for DO is available in [13].

IV. SIMULATION RESULTS

The proposed method (PM) is tested on a 33-node distribution network, whose data are available in [14]. The distribution power flow proposed in [15] is used in this study. The load demand at all nodes are increased by a load factor of 1.1, 1.2 and 1.3 and the threshold value for VSI is chosen as 0.66. The number of nodes for load shedding is heuristically chosen as 4.

The results comprising the lowest VSI (L^{LOW}), lowest voltage magnitude (VM^{LOW}), the sheddable node locations, and percent of sheddable power at chosen nodes are presented in Table 1. At base-case, that is when the load factor is 1.0, the lowest value of VSI is 0.6672, which is higher than the threshold value, and indicates that the operating point is far away from the VC zone. When the load is increased by a factor 1.1, the lowest value of VSI is 0.6363 and indicates that the operating point is nearer to the VC point, and a small disturbance in the network may initiate VC. The PM chooses nodes 20,9,28 and 17 as the most appropriate nodes and also instructs to shed 12, 18, 17 and 8% of loads at the respective nodes to bring the network away from the VC region. After load sheddding, the lowest VSI comes to a safe value of 0.6692 from the value of 0.6363. It can also be seen that the lowest VM is improved from 0.8931 to 0.9031. Similar improvement can be seen for the results with load factors of 1.2 and 1.3.

It is very clear from the results that the PM performs optimal load shedding and improves both the voltage stability and voltage profile.

Table 1 Results of proposed load shedding

Load Factor	Nodes for Load Shedding	Percent of Sheddable load				Before Load Shedding		After Load Shedding	
						L^{LOW}	VM^{LOW}	L^{LOW}	VM^{LOW}
1.00	---	---	---	---	---	0.6672	0.9038	0.6672	0.9038
1.10	20,9,28,17	12	18	17	8	0.6363	0.8931	0.6692	0.9031
1.20	20,8,28,13	27	32	38	18	0.6058	0.8822	0.6619	0.9014
1.30	20,8,28,17	33	36	42	31	0.5758	0.8711	0.6627	0.9001

V. CONCLUSION AND FUTURE WORK

Dragonfly Optimization (DO), inspired from the static and dynamic swarming behaviours of dragonflies, searches for optimal solution for multimodal optimization problems. A methodology using DO was developed for solving load shedding problem, which is a complex, mixed integer and non-linear optimization problem. The PM was applied on a 33-node distribution network with four load levels and the results were found to improve both voltage stability and voltage profile. The load shedding problem can be modified to include the other objectives such as improving the voltage profile and reducing the network loss in future and solved using DO. The other methodologies such as reconfiguration and DG placement can be combined with load shedding and studied.

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