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Ant-lion Optimizer Based Optimal Allocation of Distributed Generators in Radial Distribution Networks

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Abstract— *This paper presents the use of a recently developed algorithm inspired by the hunting mechanism of ant-lions in nature, called ant lion optimizer (ALO). The ALO algorithm is used for solving the voltage instability problem in radial distribution networks. The proposed method ensures system operation within voltage standard limits and with minimum power losses. The proposed method implies the following main tasks; load flow analysis with forwarding/backward sweep method, voltage stability index calculation and optimizing the distributed generators (size, location, and power factor) by applying the ALO. The brilliant performance of hybridizing these tasks will be able to give an overall view of voltage stability for radial distribution system; calculate the voltage stability index; detect the most sensitive node to collapse and presents a solution (to mitigate voltage instability problem and reduce system power losses). The performance and feasibility of the proposed method are demonstrated through simulation case on IEEE 69-bus. The obtained results provide the optimal solution.*

Keywords— Distribution system; voltage stability index; forward/backward sweep; Ant Lion Optimizer; Distributed Generation; Optimal location; Optimal size

1. INTRODUCTION

A power distribution system is the last segment of the overall power system. It links the bulk electricity system to the customer points [1]. The distribution network, typically passive radial networks with the unidirectional power flow, has a high R/X ratio in addition to the significant voltage drop that may cause significant undesirable power losses [1]. These problems not only lead to declining voltages at all load points but also cause a blackout and this catastrophic result called voltage collapse [2].

Electric utilities suggest new technologies to overcome these problems and enhance the power quality. Of course, this enhancement in power quality will increase the reliability and the stability of the system as well as system efficiency. However, the system efficiency is directly affected by the real power; the reactive power should be taken into consideration to maintain the voltage profile within an acceptable range [3]. Distributed Generation (DG) is used as a probable solution to these problems [4]. This is due to the positive impact of the DGs on reducing the system power loss, enhance system voltage profile and hence increased power quality as well as peak saving and grid reinforcement [4]. Improper sizing or allocation of DG unit may lead to a voltage rise or voltage fall [5]. Therefore, the problem of DG planning has recently received much attention by researchers to garner maximum benefits from DG allocation in radial distribution systems (RDSs). In [6] authors investigate the Optimal DG placement in power distribution systems. In [7] two analytical methods one applies to allocation single DG with a fixed size in RDS and the second one applies to meshed power systems. Based on the exact loss formula, an analytical method is proposed to allocate a single DG in RDS [8]. In [9] an analytical method is developed using a loss sensitivity factor to assign a single DG in RDS. In [10] an analytical method is proposed to find the optimal locations of multiple DG units. The authors of [11], had presented analytical expressions for finding optimal size and power factor of different types of DGs. An analytical method described in [12] calculates the optimal location and size of multiple DGs, also considering different types of DGs.

This paper proposes the implementation of ALO and PSO algorithms for solving the voltage instability problem. The proposed method will be able to determine the optimum DG locations, sizes and power factors to improve the voltage profile while minimizing the system power loss. The standard system IEEE 69-Bus is selected to demonstrate the performance of the proposed approach. The paper has the following structure; the second section describes the voltage instability problem in RDSs. The third section discusses the description of the proposed method. The fourth section shows the test system and results. Finally, the conclusion is drawn in the fifth part.

2. VOLTAGE INSTABILITY PROBLEM IN RADIAL DISTRIBUTION SYSTEMS

The rapid increase in the load demands, particular characteristics of radial distribution systems which having high (r/x) ratio, high exploitation, and aging of existing distribution networks are the reasons responsible for the problem of voltage instability [2]. The reasons above cause a significant power loss associated with a rapid voltage drop in the system. Consequently, the voltage magnitude of some buses reduces rabidly for small increments in load and the system may not be able to prevent the voltage decay [2]. Hence, the distribution networks are operating closer to the voltage instability boundaries with significant low voltage level. Accordingly, system instability can be characterized by a variation in the system operating point toward stability boundaries. The recent experiences from blackouts indicate that, in many cases, the triggering events for such widespread failures occur in the distribution systems. Statistically, most of the service interruptions to the customers come from the distribution systems, to avoid the voltage instability problem and provide high supply reliability, the system must be able to meet the sharp and continuous increase in the load demand of the modern society [13, 14].

3. THE PROPOSED METHOD

The common trend in how voltage stability index is calculated and mitigation of voltage instability is based on the three most important steps; Load flow analysis, Voltage stability analysis, and Voltage stability enhancement as shown in *Fig. 1*. These steps are discussed in the next subsections.

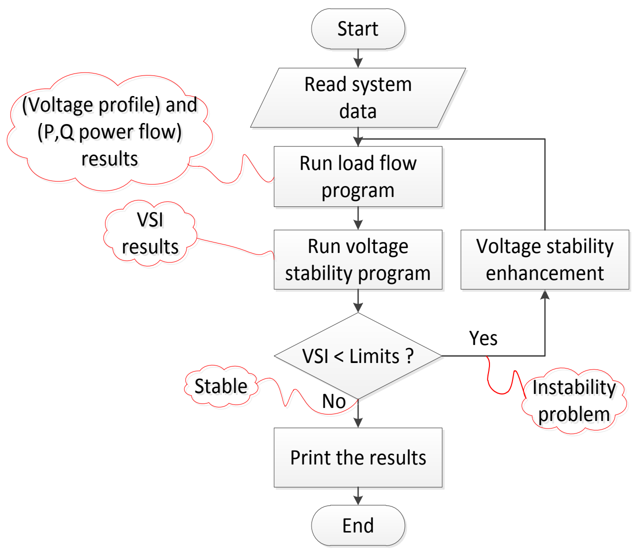

Fig. 1 Overall procedure of the proposed method.

3.1 LOAD FLOW ANALYSIS

In General, radial distribution systems are usually with a high R/X ratio of distribution cables. Also, the presence of DG and Capacitors is considered as one of the main features of such systems nowadays. For these reasons, the conventional methods for load flow analysis, such as the Newton-Raphson (NR) [15], the Gauss-Seidel [16] and the Fast Decoupled [17] methods became inefficient while dealing with such distribution systems as repeatedly proven in [18] and [19]. Moreover, most of these conventional methods consider power demands as specified constant values, an assumption which is not accepted while dealing with distribution systems which are characterized by different load models.

Accordingly, to solve these problems in (RDSs), many methods have been developed. Forward/Backward (F/B) sweep process which relies on the ladder system theory is considered to solve this problem [20]. A feasible implementation flow chart of the forward/backward-sweep approach to resolve the distribution power flow problem is shown in Fig. 2.

3.2 Voltage stability analysis

In the study of [21], authors developed a voltage sensitivity analysis method that calculates an index at each node and can detect the most sensitive node for the collapse. Equation (1) is defined as the stability indicator SI(r) of the line's receiving end bus (r) as follows:

$$SI(r) = V_s^4 - 4(PX - QR)^2 - 4V_s^2(PR + QX) \qquad (1)$$

After the load flow study implementation, using equation (1) the voltage stability index (VSI) of each bus can be calculated.

The flowchart of the proposed algorithm for calculating the (VSI) of each node and find the minimum value of VSI and its node is given in Fig. 3.

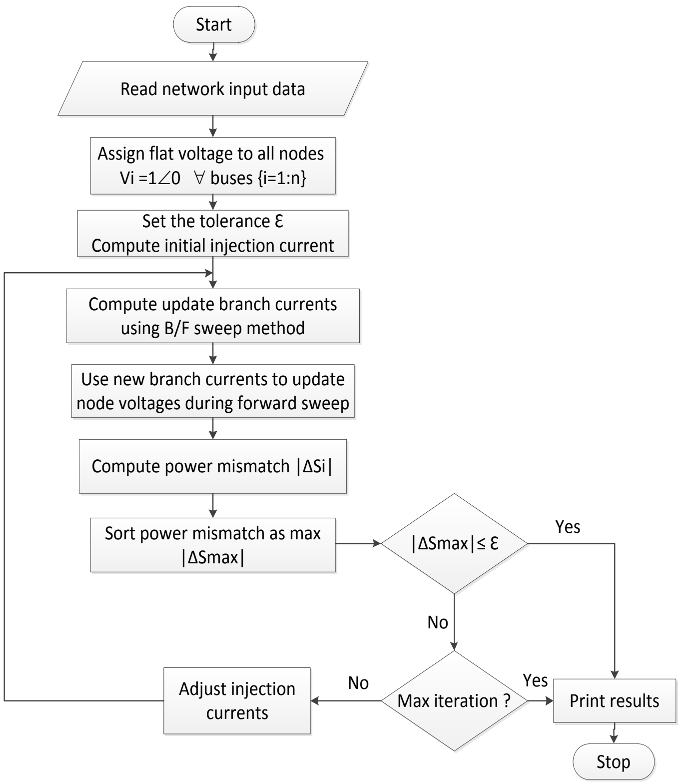

Fig. 2 *Forward/backward sweep algorithm [20].*

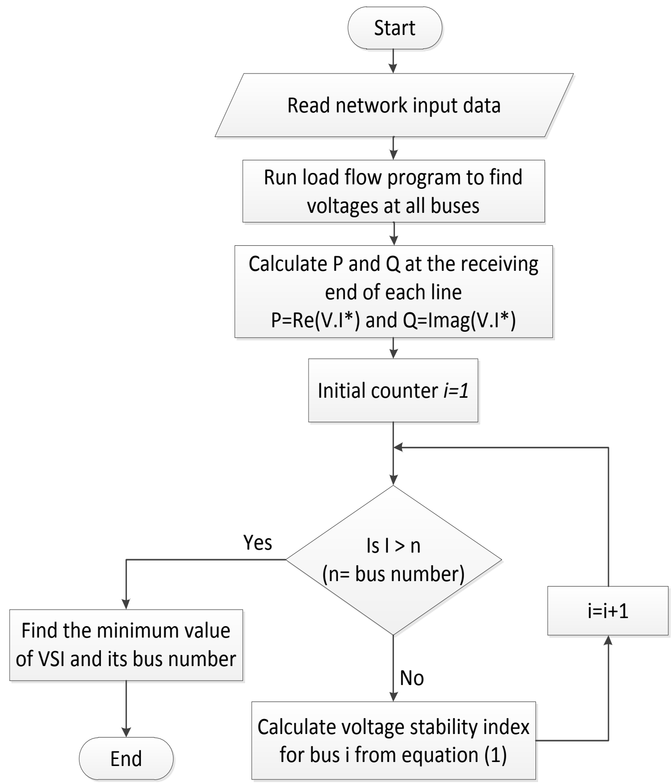

Fig. 3 *The Flowchart of the used stability indicator.*

The level of stability of radial distribution networks can be measured using the load flow technique and the derived voltage stability index, and these by the appropriate action may be taken if the index indicates a poor level of stability. In this case, the bus, which has minimum stability index value, is defined as the critical bus, which is the most sensitive to voltage collapse.

3.3 Voltage stability enhancement

Pushing the power systems to their stability boundaries increases the risk of widespread or partial blackouts. A robust electric power system is a well-planned system. The planning and implementation of a robust system are the long-term solutions to the problems facing the power systems today [22]. DGs increase the power injected into the bus to maintain the voltage, so it is used in distribution systems to minimize line losses and improve the voltage profile and hence mitigate voltage instability problem. However, Installation of DGs in non-optimal sizes or places can result in system losses increasing, voltage instability problems and voltage problems. So, DGs placement must be optimal. Table 1 shows the main DG types that may be used for voltage stability enhancement [22].

Table 1: Main types of DGs

DG type	Active power	Reactive power	Example
1	+	0	PV arrays, Battery, fuel cells
2	0	+	FACTS and Capacitors
3	+	+	Synchronous generators
4	+	-	Induction generators

(+) produces (-) Absorbs (0) Zero

3.3.1 The objective function

Voltage stability enhancement in many kinds of literature is formulated via the objective function of either losses minimization or maximization of the stability index. The used objective function will combine the maximization of VSI from the equation and the minimization of power losses as the following:

$$F = Minimize[W_1 \times P_{loss} + W_2 \times (1 - VSI)] \qquad (2)$$

Where w_1 and w_2 are the width of minimization of power loss and (1-VSI) respectively and varies from (0) to (1), and the summation of w_1 and w_2 must equal to one (w_1+w_2=1).

- **Voltage constraints:**

$$0.95\ PU \leq |V_i| \leq 1.05\ PU \qquad (3)$$

Where i=1, 2, 3,... n. And n is the number of buses.

- **Maximum DG size:**

$$0 < P_{DG} < \sum P_{demand} + \sum P_{loss}$$
$$0 < P_{DG} < \sum P_{demand} + \sum P_{loss} \qquad (4)$$

3.3.2 Optimization technique

Recently the optimization techniques are employed to solve many engineering problems [23-35]. In this work, a single DG with a different type is used in each time capable of delivering power. The Particle Swarm Optimization (PSO) [36-38] and Ant Lion Optimizer (ALO) [39, 40] are used to finding the optimal size and location under the constrained objective function mentioned in Equations (2-4).

3.3.2.1 The particle swarm optimization

Eberhart and Kennedy introduced the PSO algorithm as a heuristic method in 1995 [36-38]. Original PSO was inspired by the behaviors of a group of birds or a school of fish during their food searching activities. Typically, a group of birds that have no leaders will find food by random, keep an eye on one of the members of the group that has the closest location with a food source. The groups achieve their best condition simultaneously through communication between members who by this time have a better situation. The bird which has a better situation will inform it to its group, and the others will move simultaneously to that place. This would repeatedly happen until the best conditions or a food source discovered. The flow chart of optimization technique using PSO is shown in Fig. 4.

However, (PSO) algorithm can easily fall into local optimum in high dimensional space and has a low convergence rate in the iterative process also it takes a long time of calculations to get the optimal result, To deal with these problems, the antlion optimizer can be implemented.

3.3.2.2 The Ant Lion Optimizer (ALO)

Ant Lion Optimizer (ALO) is a modern nature-inspired algorithm suggested by Seyedali Mirjalili in 2015 [39, 40]. The ALO algorithm simulates the hunting mechanism of antlions in nature. Five main procedures of hunting prey as the random walk of ants, building traps, entrapment of ants in traps, catching preys, and re-building traps are implemented. The antlion is a type of insect in the class of net-winged or Neuroptera order. There are two main phases of the antlions life cycle: larvae and adult that consists of a total natural lifespan up to 3 years, which mostly occurs in larvae (only3–5 weeks for adulthood). Prior adulthood, antlions undergo metamorphosis in a cocoon. During the larvae phase, antlions mostly hunt. The adulthood period is for reproduction. To hunt insects such as ants, the antlion larva will build a trap by digging a cone-shaped pit in the sand. This is done by moving along a circular path and tossing out sands with its jaw. Then, the larva hides underneath the bottom of the cone and waits for insects to be trapped in the pit. The edge of the cone is sharp enough for insects to fall into the lower part of the trap easily. Finally, the antlion will catch its prey in the trap. Once the antlion realizes that prey is in the trap, it tries to catch it. The overall procedure to determine the optimal solution in the form of the flowchart as shown in Fig. 5.

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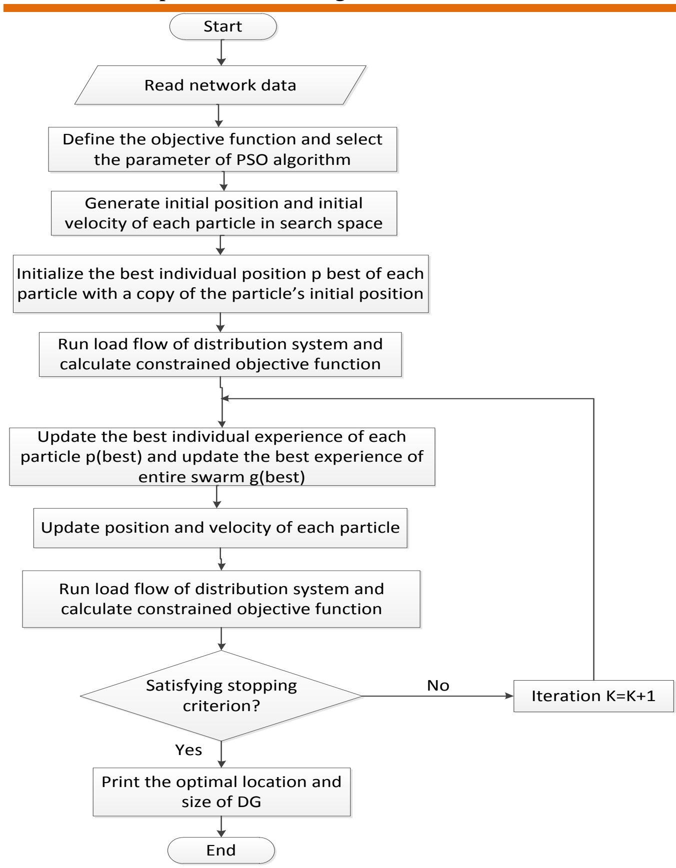

Fig. 4 *Particle swarm optimization.*

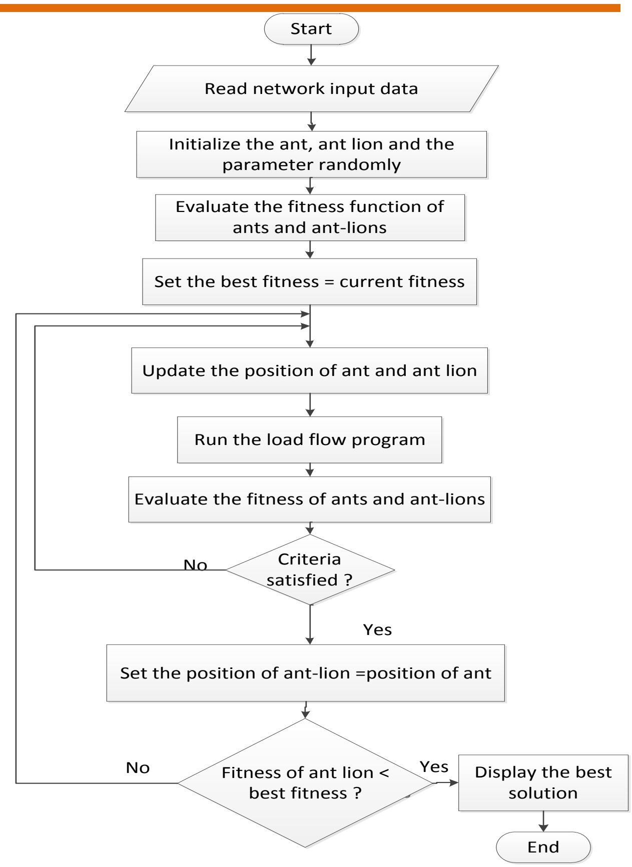

Fig. 5 *Antlion optimizer.*

4. TEST SYSTEM AND RESULTS

The IEEE 69-bus standard distribution network is considered to demonstrate the performance of the proposed algorithms in solving the DG allocation and sizing problem, The single line diagram of this scheme is shown in Fig. 6. The total real and reactive load power in this system are 3.8 MW and 2.7 MVAR respectively [41]. The initial power loss in this system is 0.225 MW, and the lowest bus voltage is 0.91 p.u. at node 65.

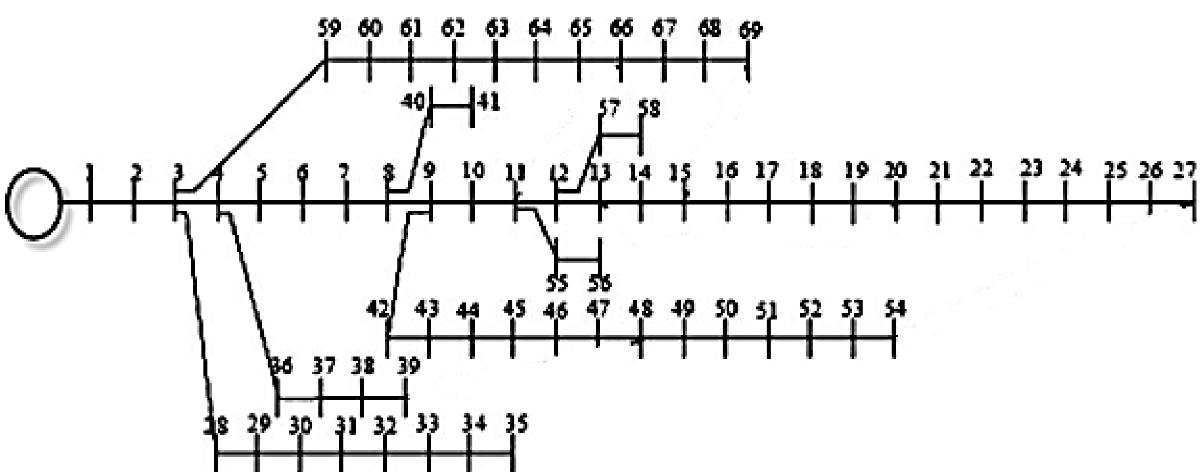

Fig. 6 *Single line diagram of IEEE 69-bus system*

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4.1 Load flow analysis results

A load flow program is developed based on the forward/backward sweep load flow algorithm using MATLAB as a platform. This program is tested on IEEE 69-bus system. The results are compared with published results using NR method [15] and ETAP package. The load flow solution, minimum voltage and total losses of IEEE 69-Bus system results are shown in Table 2 and Table 3.

Table 2: Minimum voltage and total losses of IEEE 69-Bus system

Method	Minimum voltage		Total losses	
	Value (pu)	Location	Active Power (kW)	Reactive power (kVAR)
Forward/Backward Sweep	0.9101	65	224.663	102
Newton Raphson [15]	0.91	65	225	102
ETAP	0.909	65	224.7	102

Table 3: Load Flow Solution of IEEE 69-Bus system

Bus Number	Using Forward/Backward Sweep method Voltage		Using NR [15] Voltage		Using ETAP Voltage	
	Magnitude (pu)	Angle (Deg.)	Magnitude (pu)	Angle (Deg.)	Magnitude (pu)	Angle (Deg.)
1	1	0	1	0	1	0
2	1.0000	-0.0012	1.0000	-0.0011	1.000	0.000
3	0.9999	-0.0024	0.9999	-0.0023	0.99990	0.000
4	0.9998	-0.0057	0.9998	-0.0057	0.99981	0.000
5	0.9990	-0.0168	0.9990	-0.0182	0.99905	0.02
6	0.9901	0.0670	0.9901	0.0497	0.99008	0.05
7	0.9809	0.1557	0.9808	0.1216	0.98078	0.1
8	0.9787	0.1770	0.9786	0.1388	0.97862	0.1
9	0.9775	0.1874	0.9774	0.1476	0.97737	0.2
10	0.9726	0.2763	0.9724	0.2324	0.97238	0.2
11	0.9715	0.2961	0.9713	0.2512	0.97129	0.3
12	0.9683	0.3518	0.9682	0.3040	0.96820	0.3
13	0.9654	0.4013	0.9653	0.3505	0.96526	0.4
14	0.9625	0.4507	0.9624	0.3968	0.96242	0.4
15	0.9597	0.4998	0.9595	0.4427	0.95952	0.4
16	0.9591	0.5090	0.9590	0.4513	0.95891	0.5
17	0.9583	0.5241	0.9581	0.4654	0.95807	0.5
18	0.9583	0.5243	0.9581	0.4656	0.95807	0.5
19	0.9578	0.5334	0.9576	0.4741	0.95756	0.5
20	0.9575	0.5392	0.9573	0.4796	0.95732	0.5
21	0.9570	0.5486	0.9568	0.4884	0.95678	0.5
22	0.9570	0.5488	0.9568	0.4886	0.95678	0.5
23	0.9570	0.5502	0.9567	0.4899	0.95670	0.5
24	0.9568	0.5533	0.9566	0.4928	0.95664	0.5
25	0.9566	0.5566	0.9564	0.4960	0.95641	0.5
26	0.9566	0.5580	0.9563	0.4973	0.95630	0.5
27	0.9565	0.5584	0.9563	0.4976	0.95630	0.5
28	0.9999	-0.0026	0.9999	-0.0025	0.99990	0
29	0.9999	-0.0052	0.9999	-0.0051	0.99990	-0.01
30	0.9997	-0.0031	0.9997	-0.0030	0.99973	0
31	0.9997	-0.0027	0.9997	-0.0026	0.99973	0

Bus Number	Using Forward/Backward Sweep method Voltage		Using NR [15] Voltage		Using ETAP Voltage	
	Magnitude (pu)	Angle (Deg.)	Magnitude (pu)	Angle (Deg.)	Magnitude (pu)	Angle (Deg.)
32	0.9996	-0.0008	0.9996	-0.0007	0.99957	0
33	0.9993	0.0036	0.9994	0.0037	0.9994	0
34	0.9990	0.0094	0.9990	0.0095	0.99901	0.01
35	0.9989	0.0105	0.9989	0.0106	0.99890	0.01
36	0.9999	-0.0029	0.9999	-0.0028	0.99998	0
37	0.9997	-0.0093	0.9998	-0.0092	0.99988	-0.01
38	0.9996	-0.0117	0.9996	-0.0116	0.99957	-0.01
39	0.9995	-0.0124	0.9995	-0.0123	0.99952	-0.01
40	0.9995	-0.0125	0.9995	-0.0123	0.99952	-0.01
41	0.9988	-0.0235	0.9988	-0.0233	0.99878	-0.02
42	0.9986	-0.0282	0.9986	-0.0279	0.99862	-0.03
43	0.9985	-0.0288	0.9985	-0.0286	0.99850	-0.03
44	0.9985	-0.0289	0.9985	-0.0287	0.99850	-0.03
45	0.9984	-0.0307	0.9984	-0.0305	0.99842	-0.03
46	0.9984	-0.0308	0.9984	-0.0305	0.99842	-0.03
47	0.9998	-0.0075	0.9998	-0.0075	0.99988	-0.01
48	0.9985	-0.0528	0.9985	-0.0523	0.99850	-0.05
49	0.9947	-0.1936	0.9947	-0.1914	0.99469	-0.2
50	0.9942	-0.2137	0.9942	-0.2112	0.99423	-0.2
51	0.9786	0.1773	0.9785	0.1391	0.97848	0.1
52	0.9786	0.1775	0.9785	0.1393	0.97848	0.1
53	0.9748	0.2162	0.9747	0.1695	0.97469	0.2
54	0.9715	0.2498	0.9714	0.1952	0.97143	0.2
55	0.9671	0.2966	0.9669	0.2307	0.96692	0.2
56	0.9628	0.3428	0.9626	0.2657	0.96259	0.3
57	0.9406	0.7985	0.9401	0.6622	0.94008	0.7
58	0.9297	1.0311	0.9290	0.8648	0.92889	0.9
59	0.9255	1.1239	0.9248	0.9457	0.92482	0.9
60	0.9206	1.2424	0.9197	1.0503	0.91973	1.05
61	0.9133	1.3328	0.9123	1.1193	0.91226	1.12
62	0.9130	1.3363	0.9121	1.1220	0.91214	1.12
63	0.9126	1.3411	0.9117	1.1257	0.91166	1.13
64	0.9107	1.3646	0.9098	1.1435	0.90981	1.14
65	0.9101	1.3717	0.91	1.1489	0.90915	1.15
66	0.9714	0.2973	0.9713	0.2524	0.97132	0.3
67	0.9714	0.2973	0.9713	0.2524	0.97132	0.3
68	0.9680	0.3581	0.9679	0.3101	0.96789	0.3
69	0.9680	0.3581	0.9679	0.3101	0.96789	0.3

4.2 Results of voltage stability analysis

Based on the discussed voltage stability algorithm and load flow results, a voltage stability program is developed using MATLAB as a platform. This program is implemented in the previously tested system. Table 4 shows the (VSI) of all nodes. It is shown that node (65) at which the (VSI) attains a minimum value, is more sensitive to voltage collapse, and is corresponding to the minimum voltage mode.

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Table 4: stability index for IEEE 69-Bus system

Bus No.	Voltage (PU)	VSI	Bus No.	Voltage (PU)	VSI
1	1.0000	1.0000	36	0.9999	0.9998
2	1.0000	1.0000	37	0.9997	0.9999
3	0.9999	0.9999	38	0.9996	0.9989
4	0.9998	0.9998	39	0.9995	0.9984
5	0.9990	0.9990	40	0.9995	0.9982
6	0.9901	0.9783	41	0.9988	0.9979
7	0.9809	0.9430	42	0.9986	0.9953
8	0.9787	0.9213	43	0.9985	0.9942
9	0.9775	0.9150	44	0.9985	0.9941
10	0.9726	0.9008	45	0.9984	0.9940
11	0.9715	0.8917	46	0.9984	0.9937
12	0.9683	0.8828	47	0.9998	0.9994
13	0.9654	0.8718	48	0.9985	1.0005
14	0.9625	0.8613	49	0.9947	0.9983
15	0.9597	0.8511	50	0.9942	0.9796
16	0.9591	0.8463	51	0.9786	0.9170
17	0.9583	0.8437	52	0.9786	0.9169
18	0.9583	0.8425	53	0.9748	0.9077
19	0.9578	0.8415	54	0.9715	0.8966
20	0.9575	0.8402	55	0.9671	0.8825
21	0.9570	0.8388	56	0.9628	0.8665
22	0.9570	0.8381	57	0.9406	0.8051
23	0.9570	0.8380	58	0.9297	0.7575
24	0.9568	0.8375	59	0.9255	0.7363
25	0.9566	0.8370	60	0.9206	0.7209
26	0.9566	0.8366	61	0.9133	0.7045
27	0.9565	0.8364	62	0.9130	0.6924
28	0.9999	0.9998	63	0.9126	0.6914
29	0.9999	0.9998	64	0.9107	0.6881
30	0.9997	0.9991	65	0.9101	0.6842
31	0.9997	0.9989	66	0.9714	0.8901
32	0.9996	0.9986	67	0.9714	0.8900
33	0.9993	0.9978	68	0.9680	0.8779
34	0.9990	0.9966	69	0.9680	0.8775
35	0.9989	0.9959			

4.3 Optimization results

Based on the proposed optimization algorithms optimum sizes of DGs are calculated at various nodes for the test system. Table 5 shows the optimal location, size and power factor using (ALO) and (PSO) by adding a single DG with a different type in each time to minimize power losses while achieving the optimum voltage profile enhancement. The results show the following cases:

Table 5: Optimal location, size, power factor and System Performance

DG Type	Objective	Optimization Technique						System Performance								Optimal solution
		Installed Unit						Minimum Voltage		Active Power Loss (kW)			Reactive Power Loss (kVAR)			
		PSO			ALO											
		Location	Size	pf	Location	Size	pf	Before	After	Before	After	Active loss reduction	Before	After	Reactive loss reduction	
Type 1	Loss Minimization	61	1.88	1	61	1.87	1	0.91	0.968	225	83.2	63 %	102	40.50	60.3%	√
	VSI Maximization	57	3.8	1	57	3.8	1	0.91	0.979	225	178.9	20.5 %	102	77.95	23.6%	√
	Loss Min + VSI Max	61	1.95	1	61	1.96	1	0.91	0.969	225	83.4	63%	102	40.5	60.3 %	√
Type 2	Loss Minimization	61	1.31	0	61	1.33	0	0.91	0.931	225	152.1	32.4%	102	70.5	30.9%	×
	VSI Maximization	61	2.6	0	61	2.6	0	0.91	0.948	225	213.26	5.2 %	102	94.5	7.35%	×
	Loss Min + VSI Max	61	1.58	0	61	1.56	0	0.91	0.934	225	154.5	31.3%	102	71.24	30.2%	×
Type 3	Loss Minimization	61	2.23	0.9	61	2.2	0.9 lead	0.91	0.97	225	27.968	87.57 %	102	16.4	83.9 %	√
	VSI Maximization	57	4.7	0.9	57	4.7	0.9 lead	0.91	0.987	225	164.7	26.8%	102	69.9	31.4 %	√
	Loss Min + VSI Max	61	2.3	0.87	61	2.29	0.87 lead	0.91	0.975	225	28.193	87.47 %	102	16.4	83.9%	√
Type 4	Loss Minimization	61	1.24	-0.9	61	1.23	0.9 lag	0.91	0.943	225	170.35	24.3 %	102	78.3	23.2 %	×
	VSI Maximization	57	4.6	-0.9	57	4.6	0.9 lag	0.91	0.973	225	418.36	-85.9 %	102	183.6	-80 %	×
	Loss Min + VSI Max	61	1.54	-0.9	61	1.54	0.9 lag	0.91	0.95	225	175.75	21.9%	102	80.3	21.3%	√

4.3.1 Using a (DG) unit of type (1)

In case of loss minimization, the system losses decreased by (63.01%), and the minimum voltage rises to (0.9684), which referred to an optimal solution. Moreover, in case of voltage stability index maximization, the minimum voltage rises to (0.979), and the system losses decreased by (20.49%), which referred to an optimal solution. Also, in case of loss minimization and voltage stability index maximization, the minimum voltage rises to (0.9688), and the system losses decreased by (62.9%), which referred to an optimal solution. Fig. 7 shows the voltage profile before and after adding DG units with type (1).

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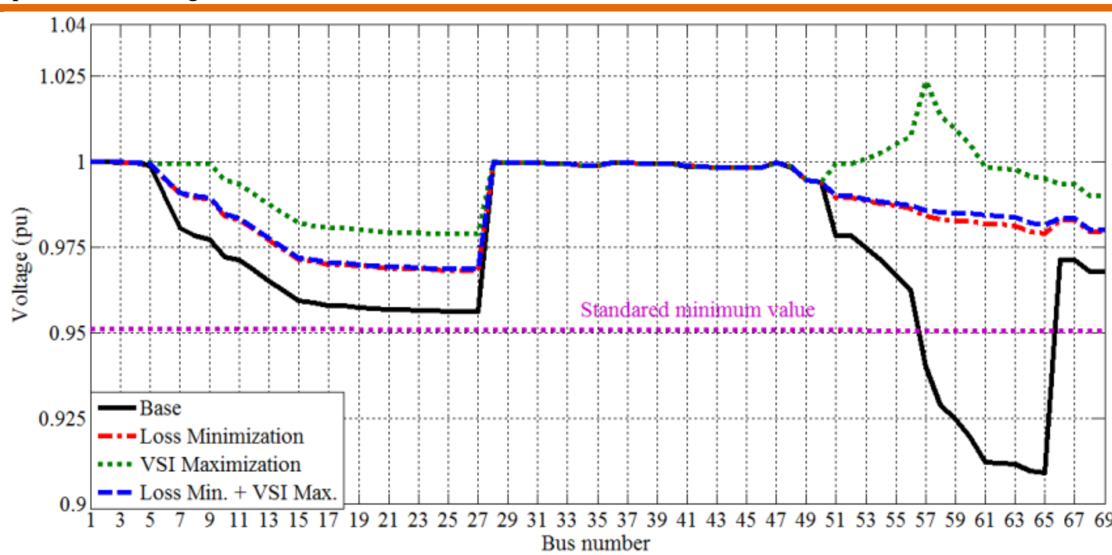

Fig. 7 *Voltage profile before and after adding DG of type (1)*

4.3.2 Using a (DG) unit of type (2)

In case of loss minimization, the system losses decreased by (32.4%), but the minimum voltage was (0.9305), which does not achieve the voltage constraints which referred to the non-optimal solution. Moreover, in case of voltage stability index maximization, the minimum voltage raises to (0.948) which does not achieve the voltage constraints, and the system losses decreased by (5.2%), which referred to the non-optimal solution. Also in case of loss minimization and voltage stability index maximization, the minimum voltage raises to (0.934) which does not achieve the voltage constraints and the system losses decreased by (31.3%), which referred to an optimal solution. Fig. 8 shows the voltage profile before and after adding DG units with type (2).

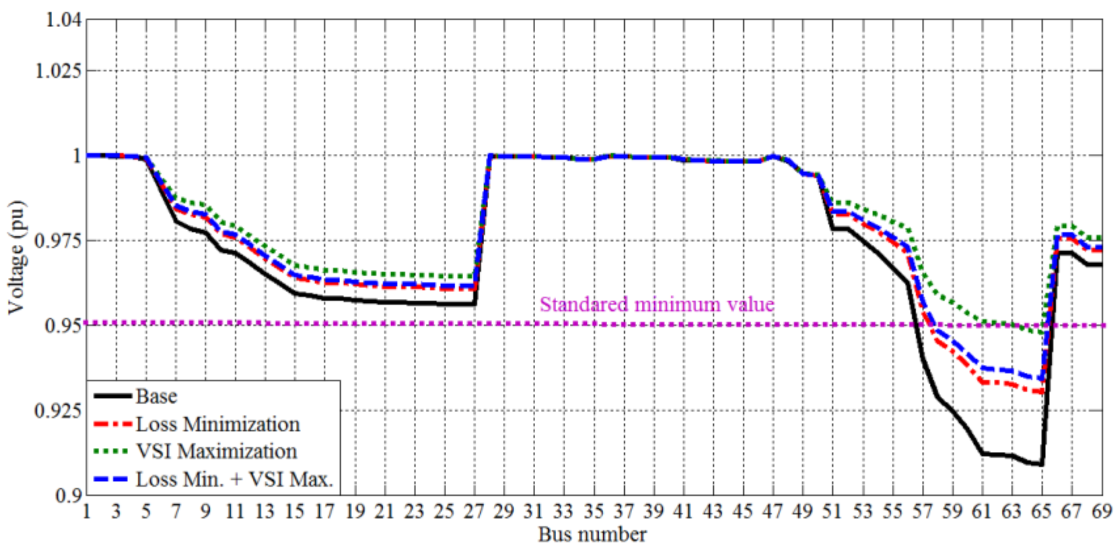

Fig. 8 *Voltage profile before and after adding DG of type (2)*

4.3.3 Using a (DG) unit of type (3)

In case of loss minimization, the system losses decreased by (87.56%), but the minimum voltage was (0.9725), which referred to an optimal solution. Also, in case of voltage stability index maximization, the minimum voltage rises to (0.987), and the system losses decreased by (26.79%), which referred to an optimal solution. Moreover, in case of loss minimization and voltage stability index maximization, the minimum voltage rises to (0.9728), and the system losses decreased by (88.87%), which referred to an optimal solution. Fig. 9 shows the voltage profile before and after adding DG units with type (3).

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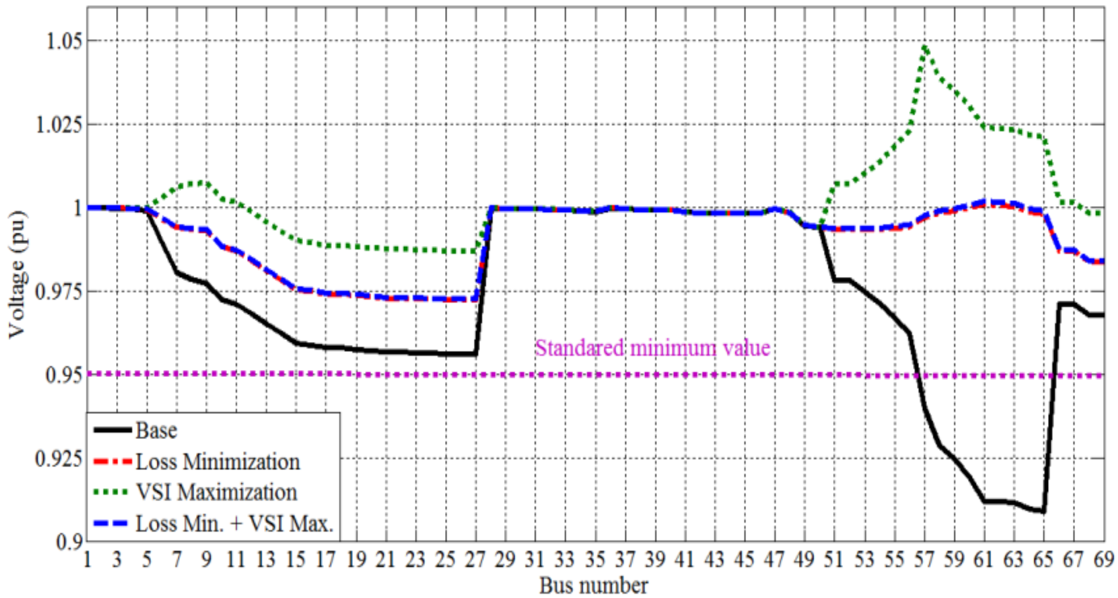

Fig. 9 *Voltage profile before and after adding DG of type (3)*

4.3.4 Using a (DG) unit of type (4)

In case of loss minimization, the system losses decreased by (24%), but the minimum voltage was (0.9427) which does not achieve the voltage constraints, which referred to the non-optimal solution. Also, in case of voltage stability index maximization, the minimum voltage rises to (0.9733) but the system losses increased by (85.9%), which referred to the non-optimal solution. However, in case of loss minimization and voltage stability index maximization, the minimum voltage rises to (0.9505), and the system losses decreased by (21.88%), which referred to an optimal solution. Fig. 10 shows the voltage profile before and after adding DG units with type (4).

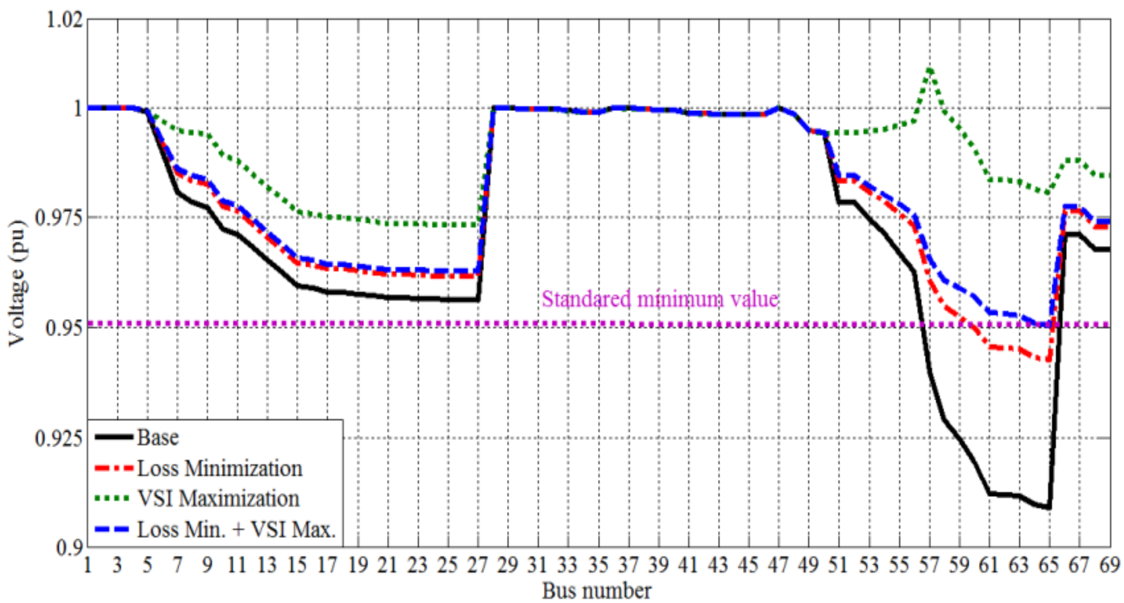

Fig. 10 *Voltage profile before and after adding DG of type (4)*

According to the previous results, it was found that DG of type (3) showed a strong impact on system enhancement, then in second place DG of type (1) and finally, DGs of type (2) and type (4) showed a slight effect on improving the system stability and minimizing the system losses. The appropriate solution can be selected from the various optimal solutions depending on the required operating performance and also the economic differentiation.

5. Conclusion

In this paper, an integrated method is developed to deal with the voltage instability problem in radial distribution systems by implementing three main steps; forward/backward sweep load flow analysis, voltage stability index calculation and two different optimization techniques (Particle swarm optimization and Ant-lion optimizer) to allocate different DG types with the optimal location, size, and power factor. These tasks are achieved by employing a multi-objective function to mitigate system voltage instability and minimize power losses. The developed strategy is implemented on IEEE 69-bus system using MATLAB developed software. Moreover, results found to be effective.

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