An Improved Lightning Search Algorithm Employed Performance Enhancement in Distribution System

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Abstract

The proposed research work minimizes the power loss in distribution system under load conditions which is the major issue nowadays that has been reduced to reach the maximum possible power for satisfying the customer needs. Optimal siting of Distribution Static Compensator (DSTATCOM) and Photo-Voltaic (PV) array in distribution system is used to attain voltage profile improvement, reduced voltage instability and less power loss. For this, Improved Lightning Search Algorithm (ILSA) has been proposed to accomplish the objectives. The proposed ILSA has reached the Voltage Stability Index (VSI) value as 0.9877 and it outstandingly decreased the power loss to 55.92 kW which are validated with IEEE 30-bus system using MATLAB toolbox. The obtained results are compared with the existing optimization algorithms and it depicts that the proposed ILSA is more advantageous than other optimization algorithms.

Keywords DSTATCOM · Load conditions · Optimization · PV array · Radial distribution network

1 Introduction

At present, electrical energy demand increases because of the increasing utilization in industries and in daily life. Good quality and uninterrupted electrical energy should be provided to the customer for their needs is an important issue at present. To meet this challenge, power plants are increasing to deliver the expected energy demand. Consequently, emissions present in air causes harmful defects and using fuels to generate electricity are going to be exhausted. Because of this, renewable energy sources such as wind energy, solar system, hydro power plant etc., are used presently in the distribution systems. To obtain the maximum potential benefits of distributed generation, optimal allocation is important in distribution systems [1, 2]. Conservation Voltage Reduction

(CVR) in real time management has been solved with optimally placing DG in the distribution systems [3–6].

To enhance the voltage profile values under load conditions DG has been located optimally in the distribution system [7]. However, improving voltage stability value is needed in distribution system. To achieve this aspect, renewable energy-based DG has been optimally allocated in the distributed systems [8, 9]. To attain the maximum power loss reduction in distribution system, multiple DGs are placed appropriately with new method [10]. However, PV array-based DG in distribution system for optimal location requires reactive power compensation [11].

Because of reactive power compensation in distribution system, power electronics component like Distributed Flexible Alternating Current Transmission System (DFACTS) devices came into picture because of its low cost, portable size and increasing system stability [12]. Many DFACTS devices are there like DSTATCOM, Unified Power Flow Controller (UPFC), Static Var Compensator (SVC) etc. In distributed system, SVC device has been used as reactive power controller to improve the voltage profile values and to reduce the system losses [13].

Many optimization techniques have been proposed with FACTS devices to improve the system stability. The Particle Swarm Optimization (PSO) technique is used with FACTS devices for improving the system loading capability with

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optimal allocation [14, 15]. In DFACTS devices, DSTATCOM is the most advantageous and portable size controller to reduce the power loss and voltage instability [16, 17]. The Bacteria Foraging (BF) algorithm has been proposed to optimize the Real Power Loss (RPL) and voltage stability limit. The BF algorithm depends on random search directions which may lead to delay in reaching the global solution [18].

For finding the optimal allocation of DG and DSTATCOM, several optimization techniques have been proposed. This consists of Harmony Search Algorithm (HSA) [19], Improved Harmony Search Algorithm (IHSA) [20], Artificial Bee Colony Optimization (ABCO) and Interactive Artificial Bee Colony Optimization (IABCO) [21], complex artificial bee colony algorithm [22], Comprehensive Learning Particle Swarm Optimization (CLPSO) [23], hybrid algorithm [24] and Grey Wolf Optimization (GWO) [25], Differential Evolution Algorithm (DEA) [26] etc. However, these algorithms cause slow convergence speed, low solving precision, bad local searching capability and lack in providing the best fit with respect to limited time duration.

To solve the constrained optimization problems, hybrid algorithms like Genetic Algorithm–Gravitational Search Algorithm (GA–GSA) [27], Particle Swarm Optimization–Genetic Algorithm (PSO–GA) [28], Time Varying Acceleration Coefficient–Particle Swarm Optimization (TVAC–PSO) [29], Gravitational Search Algorithm–Genetic Algorithm (GSA–GA) [30] have been used.

To attain the global minima, an efficient optimization technique is required. For this exploitation and exploration, ILSA is proposed for optimal placement. The power flow can be controlled by Newton–Raphson method in the radial distribution system, by which the voltage profile and losses of the system for various load levels i.e., 0.5 (light), 1.0 (nominal), and 1.6 (heavy) can be found.

The load models and impact indices are presented in Sect. 2. Illustrations of proposed methodology is given in Sect. 3. Analysis of the results is resumed in Sect. 4 and conclusions are presented in Sect. 5.

2 Load Models and Impact Indices

The power equations can be written as,

$$p_j = \sum_{k=1}^n |Y_{jk}| |e_k| |e_j| \cos(\theta_{jk} + \phi_k - \phi_j) \quad (1)$$

$$q_j = - \sum_{k=1}^n |Y_{jk}| |e_k| |e_j| \sin(\theta_{jk} + \phi_k - \phi_j) \quad (2)$$

2.1 Power Balance Limits

$$\sum_{j=1}^N P_{pv,j} = \sum_{j=1}^N P_{DSTAT,k} + P_{loss} \quad (3)$$

2.2 Voltage Limits

$$0.95 \text{ perunit} \leq |e_j| \leq 1.10 \text{ perunit} \quad (4)$$

2.3 Voltage Stability Index (VSI)

VSI among sending and receiving end can be expressed as,

$$VSI = \frac{4z_{jk}^2 q_j}{e_j^2 x_{jk}} \quad (5)$$

where, ' z_{jk} ' is the magnitude of line impedance, ' x_{jk} ' is the line reactance, ' q_j ' is the reactive power value of receiving end and ' e_j ' is the voltage of sending end. The highest VSI value of bus can be chosen as optimum bus for placement of DSTATCOM and PV array.

2.4 Total Voltage Deviation (TVD)

TVD can be written as,

$$TVD = \sum_{n=1}^k |e_{nref} - e_n| \quad (6)$$

where, ' e_n ' is the bus voltage magnitude and ' e_{nref} ' is the reference voltage.

3 Proposed Methodology

LSA is based on the natural phenomenon of lightning and it is inspired by the probabilistic nature and sinuous characteristics of lightning discharges during a thunderstorm. The mechanism of step leader propagation utilizing the theory of fast particles known as projectiles. In LSA, three types of projectile models named transition, space and lead projectiles are used to find the optimal solution. Like other algorithms, here projectiles are act as particles. The advantage of using LSA compared to other optimization algorithm is fast tracking and high accurate results. However, its searching capability is very poor. To avoid this, ILSA is proposed here. The flow diagram of the proposed model has been presented in Fig. 1 to explain the working of ILSA easily.

Fig. 1 Flow diagram of proposed mode

The proposed method to improve LSA with the allocation of DSTATCOM and PV array simultaneously in the distribution network for various load conditions to accomplish the goals is abridged in the following steps.

Step 1: Load the bus data and line data to get the base case (1) values at each bus using Newton–Raphson's method of load flow analysis, under various load conditions like light load (0.5), nominal load (1), and heavy load (1.6).

Step 2: Initialize the higher and smaller limits, iteration counts, channel time for the limits.

Step 3: Calculate the value of KVAR to be added within the smaller and higher limits and set the random LSA population.

Step 4: Form the collection of solution vectors $f(x)$.

Step 5: Check whether the maximum population has been reached by the obtained value. If this has been satisfied, then proceed with the next step or else store the value and increase the value of 'j'.

Step 6: Check whether the maximum iteration has been reached by the obtained value. If this has been satisfied, then save the value as the final optimal value otherwise continue the next step.

Step 7: The projectile values and leader tips energies are updated.

Step 8: The worst and best optimal solutions are updated and estimate the objective function of the step leader $f(SL)$. Rank the step leader in descending order.

Step 9: Check whether the maximum channel time has been reached by the obtained value. If this has been satisfied, update the direction and energy otherwise eliminate the worst channel and then update the values.

Step 10: Assess the performance of the projectile's energies.

Step 11: Repeat the same procedure in step 5. Update the LSA projectile value using fuzzy. Make another solution by revising LSA and make a comparison with the fitness value of the new solution and the best solution. If the newly formed solution has a better fitness value than best solution, then save this as the best solution.

Step 12: Evaluate the actual function of solution vector $f(x)$.

Step 13: If $f(x) > f(SL)$ condition is satisfied then check the forking event possibility and update the SL positions else stay on the same point and increase the iteration value and the channel time.

Step 14: Next go to step 6, check whether the maximum iteration is reached. If this has been satisfied then save the value as the best result otherwise repeat the steps 7–13.

Step 15: Exhibit the optimum value.

4 Results and Discussion

The Optimal siting of DSTATCOM and PV array using ILSA for different load conditions has been done in IEEE 30-bus test system using MATLAB software to calculate the power loss and voltage profile values. In this, the load factor values of light load, nominal load and heavy load are 0.5, 1.0 and 1.6 respectively. The four cases used to demonstrate the usefulness of the proposed ILSA are,

Case (1): system without compensation under load conditions.

Case (2): system with DSTATCOM under load conditions.

Case (3): system with PV array under load conditions.

Case (4): system with DSTATCOM and PV array under load conditions.

Case (1): system without compensation under load conditions

Load flow analysis is done using the Newton Raphson method for an uncompensated IEEE 30-bus system. At light load, the minimum voltage is 0.9850pu and the minimum angle is -17.7024 which are presented in Table 1. At this condition, the power loss is 369.11 kW and VSI value is 0.8436 which are given in Table 5. The optimal location can be found by using the Improved Lightning Search Algorithm. At nominal load, the minimum voltage is 0.9761pu and the minimum angle is -20.6883 which are shown in Table 1. In this condition, the power loss is 495.59 kW which is given in Table 5. At heavy load, the minimum voltage is 0.9668pu and the minimum angle is -21.4409 and these values are tabulated in Table 1. At heavy load, the power loss is 879.46 kW which is shown in Table 5. Figure 2 shows the voltage graph under various load levels for network without compensation.

Case (2): System with DSTATCOM under load conditions

The voltage profile values have been calculated and are presented in Table 2. At light load, the power loss is 40.98 kW and VSI value is 0.9811 which are observed from Table 5. At nominal load, the power is 83.34 kW and the VSI value is 0.9795 which are tabulated in Table 5. At heavy load, the power loss is 143.28 kW and the VSI value is 0.9795 which are presented in Table 5. Figure 3 shows the voltage graph under various load levels for network with DSTATCOM under load conditions.

Case (3): system with PV array under load conditions

The voltage values have been calculated and are given in Table 3. At light load, the power loss is 45.64 kW and the VSI value is 0.9804 which are shown in Table 5. At nominal load, the power loss is 69.43 kW and the VSI value is 0.9802 which are shown in Table 5. At heavy load, the power loss is 224.27 kW and VSI value is 0.9800

Table 1 Voltage profile and angle in each bus without compensation of load variation

Bus No	Light load		Nominal load		Heavy load	
	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)
1	1.0640	0.0000	1.0640	0.0000	1.0612	0.0000
2	1.0490	− 5.3412	1.0390	− 6.0260	1.0362	− 6.4819
3	1.0231	− 7.4499	1.0198	− 8.4944	1.0147	− 9.1816
4	1.0137	− 9.1841	1.0102	− 10.4676	1.0051	− 11.3139
5	1.0140	− 14.0498	1.0140	− 15.2382	1.0112	− 16.0565
6	1.0130	− 10.9504	1.0104	− 12.4381	1.0059	− 13.4217
7	1.0057	− 12.7467	1.0039	− 14.1403	0.9999	− 15.0765
8	1.0140	− 11.7166	1.0140	− 13.2988	1.0112	− 14.3481
9	1.0382	− 13.9513	1.0356	− 16.1511	1.0309	− 17.5931
10	1.0207	− 15.5612	1.0172	− 18.0248	1.0118	− 19.6406
11	1.0760	− 13.9513	1.0760	− 16.2581	1.0732	− 17.7655
12	1.0471	− 14.9893	1.0449	− 17.2819	1.0404	− 18.7888
13	1.0640	− 14.9893	1.0640	− 17.3541	1.0612	− 18.9050
14	1.0298	− 15.8711	1.0262	− 18.3374	1.0207	− 19.9568
15	1.0232	− 15.8859	1.0191	− 18.3805	1.0134	− 20.0174
16	1.0286	− 15.5029	1.0252	− 17.9493	1.0198	− 19.5540
17	1.0177	− 15.7563	1.0139	− 18.2488	1.0084	− 19.8836
18	1.0099	− 16.4909	1.0045	− 19.1562	0.9978	− 20.9030
19	1.0053	− 16.6534	0.9997	− 19.3463	0.9929	− 21.1114
20	1.0083	− 16.4388	1.0030	− 19.1041	0.9965	− 20.8506
21	1.0073	− 16.1068	1.0028	− 18.6650	0.9968	− 20.3430
22	1.0114	− 15.8714	1.0065	− 18.4887	1.0002	− 20.2019
23	1.0076	− 16.1176	1.0030	− 18.6913	0.9969	− 20.3789
24	0.9988	− 16.1924	0.9930	− 18.8952	0.9860	− 20.6639
25	1.0044	− 15.9724	0.9972	− 18.7905	0.9894	− 20.6305
26	0.9865	− 16.4031	0.9765	− 19.4525	0.9668	− 21.4409
27	1.0166	− 15.5608	1.0110	− 18.2099	1.0041	− 19.9420
28	1.0112	− 11.6080	1.0080	− 13.2540	1.0030	− 14.3383
29	0.9966	− 16.8073	0.9881	− 19.7428	0.9794	− 21.6629
30	0.9850	− 17.7024	0.9761	− 20.6883	0.9671	− 22.6469

Fig. 2 Network without compensation under load conditions

Table 2 Voltage profile and angle in each bus with DSTATCOM of load variation

Bus No	Light load		Nominal load		Heavy load	
	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)
1	1.0610	0.0000	1.0680	0.0000	1.0619	0.0000
2	1.0440	− 5.1683	1.0510	− 5.4304	1.0449	− 5.9216
3	1.0239	− 7.4523	1.0295	− 7.8631	1.0185	− 8.5600
4	1.0154	− 9.1719	1.0210	− 9.6744	1.0092	− 10.5352
5	1.0110	− 13.4249	1.0180	− 13.8151	1.0119	− 14.7441
6	1.0166	− 10.8382	1.0225	− 11.4154	1.0093	− 12.3949
7	1.0099	− 11.8996	1.0162	− 12.4138	1.0057	− 13.3868
8	1.0210	− 11.6767	1.0280	− 12.2851	1.0119	− 13.2703
9	1.0443	− 14.1770	1.0506	− 15.0521	1.0400	− 16.5370
10	1.0278	− 15.9032	1.0340	− 16.8799	1.0230	− 18.5558
11	1.0830	− 14.2297	1.0900	− 15.1562	1.0839	− 16.7062
12	1.0562	− 15.3610	1.0630	− 16.2686	1.0547	− 17.8734
13	1.0720	− 15.3964	1.0790	− 16.3385	1.0729	− 17.9868
14	1.0460	− 16.5778	1.0530	− 17.5818	1.0469	− 19.4267
15	1.0331	− 16.3360	1.0393	− 17.3282	1.0301	− 19.0683
16	1.0366	− 15.8965	1.0428	− 16.8681	1.0330	− 18.5554
17	1.0250	− 16.1265	1.0311	− 17.1146	1.0203	− 18.8179
18	1.0182	− 16.9765	1.0238	− 18.0386	1.0128	− 19.8775
19	1.0129	− 17.1282	1.0183	− 18.1998	1.0068	− 20.0499
20	1.0157	− 16.8935	1.0212	− 17.9546	1.0097	− 19.7801
21	1.0147	− 16.5051	1.0206	− 17.5199	1.0092	− 19.2710
22	1.0179	− 16.2857	1.0235	− 17.3316	1.0114	− 19.1093
23	1.0151	− 16.5300	1.0209	− 17.5524	1.0096	− 19.3158
24	1.0050	− 16.6461	1.0102	− 17.7285	0.9970	− 19.5651
25	1.0089	− 16.4626	1.0133	− 17.6038	0.9977	− 19.4957
26	0.9897	− 16.9991	0.9929	− 18.2444	0.9754	− 20.2923
27	1.0211	− 15.9616	1.0262	− 17.0280	1.0107	− 18.7984
28	1.0152	− 11.5765	1.0209	− 12.2209	1.0063	− 13.2970
29	0.9998	− 17.3300	1.0037	− 18.5147	0.9862	− 20.4965
30	0.9882	− 18.2362	0.9919	− 19.4308	0.9739	− 21.4669

Fig. 3 Networks with DSTATCOM under load conditions

Table 3 Voltage profile and angle in each bus with PV array of load variation

Bus No	Light load		Nominal load		Heavy load	
	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)
1	1.0700	0.0000	1.0725	0.0000	1.0750	0.0000
2	1.0550	− 5.6079	1.0475	− 5.7811	1.0500	− 6.1617
3	1.0287	− 7.8868	1.0274	− 8.3875	1.0278	− 8.9672
4	1.0195	− 9.7181	1.0176	− 10.3362	1.0178	− 11.0491
5	1.0200	− 14.4483	1.0225	− 15.0588	1.0250	− 15.6962
6	1.0189	− 11.5513	1.0184	− 12.2896	1.0190	− 13.1139
7	1.0116	− 13.2722	1.0122	− 13.9703	1.0135	− 14.7322
8	1.0200	− 12.3339	1.0225	− 13.1452	1.0250	− 14.0274
9	1.0485	− 14.8456	1.0492	− 15.9186	1.0467	− 17.1399
10	1.0305	− 16.5478	1.0310	− 17.7395	1.0299	− 19.1054
11	1.0920	− 14.8976	1.0945	− 16.0224	1.0870	− 17.3075
12	1.0588	− 15.9282	1.0596	− 17.0299	1.0603	− 18.3193
13	1.0800	− 15.9633	1.0825	− 17.0998	1.0850	− 18.4309
14	1.0407	− 16.8724	1.0409	− 18.0565	1.0407	− 19.4427
15	1.0337	− 16.8928	1.0337	− 18.0942	1.0332	− 19.4929
16	1.0393	− 16.4943	1.0396	− 17.6727	1.0391	− 19.0405
17	1.0277	− 16.7557	1.0280	− 17.9591	1.0270	− 19.3448
18	1.0195	− 17.5619	1.0190	− 18.8452	1.0173	− 20.3368
19	1.0147	− 17.7312	1.0141	− 19.0280	1.0121	− 20.5323
20	1.0177	− 17.5069	1.0173	− 18.7917	1.0154	− 20.2786
21	1.0168	− 17.1287	1.0171	− 18.3668	1.0159	− 19.7949
22	1.0203	− 16.9247	1.0207	− 18.1989	1.0197	− 19.6669
23	1.0171	− 17.1473	1.0173	− 18.3939	1.0162	− 19.8338
24	1.0070	− 17.2758	1.0076	− 18.6065	1.0072	− 20.1472
25	1.0100	− 17.2758	1.0125	− 18.6065	1.0150	− 20.2314
26	0.9909	− 17.0968	0.9921	− 18.5454	0.9930	− 21.0004
27	1.0223	− 17.6321	1.0241	− 19.1870	1.0262	− 21.0004
28	1.0167	− 16.6183	1.0167	− 17.9333	1.0173	− 19.4589
29	1.0011	− 12.2720	1.0016	− 13.1009	1.0021	− 14.0271
30	0.9894	− 17.9834	0.9897	− 19.4262	0.9901	− 21.1047

Fig. 4 Network with PV array under load conditions

Table 4 Voltage profile and angle in each bus with DSTATCOM and PV array of load variation

Bus No	Light load		Nominal load		Heavy load	
	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)
1	1.0700	0.0000	1.0725	0.0000	1.0750	0.0000
2	1.0530	− 5.0772	1.0555	− 5.3851	1.0580	− 5.7603
3	1.0346	− 7.3374	1.0357	− 7.8129	1.0365	− 8.3902
4	1.0264	− 9.0277	1.0275	− 9.6104	1.0282	− 10.3182
5	1.0200	− 13.1804	1.0225	− 13.6909	1.0250	− 14.3175
6	1.0281	− 10.6959	1.0296	− 11.3689	1.0308	− 12.1869
7	1.0205	− 11.7166	1.0223	− 12.3364	1.0239	− 13.0918
8	1.0300	− 11.4869	1.0325	− 12.1980	1.0350	− 13.0634
9	1.0563	− 13.8970	1.0581	− 14.8893	1.0596	− 16.0927
10	1.0466	− 15.5397	1.0484	− 16.6442	1.0500	− 17.9835
11	1.0820	− 13.9492	1.0845	− 14.9932	1.0870	− 16.2583
12	1.0680	− 14.9283	1.0703	− 15.9566	1.0724	− 17.2048
13	1.0810	− 14.9630	1.0835	− 16.0258	1.0860	− 17.3150
14	1.0550	− 15.9516	1.0575	− 17.0855	1.0600	− 18.4634
15	1.0477	− 15.9171	1.0495	− 17.0390	1.0510	− 18.4002
16	1.0515	− 15.4889	1.0532	− 16.5864	1.0548	− 17.9175
17	1.0427	− 15.7438	1.0444	− 16.8608	1.0458	− 18.2153
18	1.0345	− 16.5524	1.0356	− 17.7485	1.0363	− 19.1988
19	1.0301	− 16.7077	1.0311	− 17.9145	1.0316	− 19.3777
20	1.0334	− 16.4853	1.0344	− 17.6801	1.0351	− 19.1286
21	1.0361	− 16.1699	1.0376	− 17.3178	1.0390	− 18.7099
22	1.0464	− 16.0530	1.0479	− 17.2314	1.0492	− 18.6600
23	1.0372	− 16.2111	1.0388	− 17.3671	1.0401	− 18.7690
24	1.0453	− 16.6564	1.0469	− 17.8801	1.0482	− 19.3640
25	1.0920	− 17.3723	1.0945	− 18.6739	1.0970	− 20.2531
26	1.0744	− 17.8289	1.0757	− 19.2213	1.0768	− 20.9093
27	1.0827	− 16.0717	1.0850	− 17.2696	1.0872	− 18.7220
28	1.0313	− 11.5538	1.0326	− 12.3047	1.0337	− 13.2169
29	1.0628	− 17.2860	1.0639	− 18.5964	1.0646	− 20.1843
30	1.0518	− 18.0870	1.0527	− 19.4107	1.0533	− 21.0155

Table 5 Results of IEEE 30-bus system

Cases		Total power loss (kW)	VSI	TVD	V _{min}	% Power loss reduction
1	Light Load	369.11	0.8436	3.8133	0.9850	−
	Nominal Load	495.59	0.8431	3.8177	0.9761	−
	Heavy Load	879.46	0.8466	3.8531	0.9668	−
2	Light Load	40.98	0.9811	0.1952	0.9882	88.89
	Nominal Load	83.34	0.9790	0.1919	0.9919	83.18
	Heavy Load	143.28	0.9894	0.2080	0.9739	83.70
3	Light Load	45.64	0.9804	0.7066	0.9894	87.63
	Nominal Load	69.43	0.9802	0.7060	0.9897	85.99
	Heavy Load	224.27	0.9800	0.7055	0.9901	74.49
4	Light Load	27.01	0.9881	0.0078	1.0200	92.68
	Nominal Load	55.92	0.9877	0.0076	1.0223	88.71
	Heavy Load	95.72	0.9875	0.0075	1.0239	89.11

which are shown in Table 5. Figure 4 shows the voltage graph under various load levels for network with PV array.

Case (4): System with DSTATCOM and PV array under load conditions

The voltage values have been calculated and are presented in Table 4. At light load, the power loss is 27.01 kW and the VSI value is 0.9881 which are shown in Table 5. At nominal load, the power loss is 55.92 kW and the VSI value is 0.9877 which are shown in Table 5. At heavy load, the power loss is

95.72 kW and the VSI value is 0.9875 which are tabulated in Table 5. Figure 5 shows the voltage graph under various load levels for network with DSTATCOM and PV array.

Table 5 represents the results of the IEEE-30 bus system with DSTATCOM and PV array for various load levels. From this, the system with DSTATCOM and PV array (case 4) for various load levels gives the better results compared to other three cases. Figure 6 depicts the comparison of total power loss for various load levels. It clearly exhibits that the

Fig. 5 Network with DSTATCOM and PV array under loading conditions

Fig. 6 Comparison of total power loss for various load conditions

Fig. 7 Comparison of % power loss reduction for various load conditions

Fig. 8 Comparison of VSI for four cases under load conditions

total power loss is very low in proposed case (4). Figure 7 represents the comparison of % power loss reduction for various load levels. From this figure, the proposed case (4) has high percentage of loss reduction is verified. Figure 8 demonstrates the VSI comparison for various load levels. From

this, the voltage is highly stable in proposed system has been proved. Figure 9 depicts the comparison of TVD for various load levels. This figure illustrates that the proposed system has less voltage deviation. Figure 10 shows the comparison of minimum voltage ($V_{\min}$) for various load levels.

Fig. 9 Comparison of TVD for four cases under load conditions

Fig. 10 Comparison of minimum voltage for four cases under load conditions

Figure 11 depicts the power loss for all the cases and the values are tabulated in Table 6. It clearly shows that the proposed system has very low loss for all the load levels.

The proposed ILSA method is compared with other algorithms which is shown in Table 7 to show the effectiveness of the proposed method with IEEE 30-bus system for various load levels. Figure 12 illustrates the

comparison of power loss with existing methods. From this, the power loss in proposed method is very less has been proved. From Fig. 13, % P_{loss} reduction in the proposed method is very high has been verified. Figure 14 depicts that the voltage value is improved in the proposed approach.

Fig. 11 Power loss Vs Load factor

Table 6 Power loss values for all cases

Load factor	Power loss (kW)			
	Without compensation	DSTATCOM	PV array	DSTATCOM and PV array
0	120	21.07	13.63	7.00
0.1	89.73	18.34	17.54	6.82
0.2	155.11	30.02	24.31	11.29
0.3	223.45	43.63	30.74	16.29
0.4	293.76	56.34	37.92	21.29
0.5	369.11	40.98	45.64	27.01
0.6	441.89	49.73	54.27	32.72
0.7	334.34	57.26	65.92	38.92
0.8	386.98	65.82	82.82	43.63
0.9	439.09	74.82	57.82	49.06
1	495.59	83.34	69.43	55.92
1.1	553.54	92.62	83.53	62.73
1.2	612.46	102.23	116.72	68.56
1.3	674.01	111.11	139.72	75.81
1.4	738.93	12,292	166.28	81.91
1.5	804.93	132.92	196.82	88.23
1.6	879.46	143.28	224.27	95.72

5 Conclusion

The proposed ILSA is an effective method to optimally allocate the DSTATCOM and PV array in the distribution system for various loading conditions. Using IEEE 30-bus system, the effectiveness of the proposed ILSA method has been verified in the distribution system. The ILSA method has been investigated with the various scenarios in IEEE 30-bus system to show the proposed fourth case is more advantageous than others in reduce the power loss and voltage profile improvement. In this, the total power loss is 55.92 kW and the percentage power loss reduction is 88.71% by the improvement in voltage profile. Obviously, the results show the proposed method is better than other algorithms with comparison.

Table 7 Comparative analysis of proposed algorithm with existing algorithms

Algorithms	Power loss (kW)	Percentage power loss reduction	$V_{\min}$ (pu)
Genetic Algorithm (GA) [31]	98.36	80.15	0.9506
Harmony Search Algorithm (HSA) [31]	97.13	80.40	0.9479
Fire Works Algorithm (FWA) [32]	83.91	83.06	0.9612
Comprehensive Teaching Learning Harmony Search Optimization (CTLHSO) Algorithm [33]	58.877	88.11	0.9741
ILSA (Proposed method)	55.92	88.71	1.0223

Fig. 12 Power loss for comparative analysis of proposed method with existing methods **Fig. 13** % P_{loss} reduction for comparative analysis of proposed method with existing methods

Fig. 14 $V_{\min}$ for comparative analysis of proposed method with existing methods

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