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Load Flow Analysis and Optimal allocation of DG for Indian Utility 62 Bus Power System

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ABSTRACT: Load flow study is a numerical analysis of the power flow in interconnected power systems. This study is a fundamental aspect for the planning, operation, control and economic estimation of the power system. Newton Raphson (NR) method is the most successful method for solving the complex nonlinear power flow equations of the large power systems. The reliability of the solution obtained from the NR method is quite better than those obtained through other methods. Moreover, unlike other methods, it can also solve cases that lead to divergence. In this paper, the load flow analysis and distributed generation (DG) allocation in Indian utility 62-bus power system(real distribution system) is performed by using Backwards/ Forward Sweep (BFS) methods, NR method and combination of particle swarm optimization algorithm (PSO) with NR method. The solutions obtained using these methods were presented in terms of voltage magnitude, active power, reactive power, phase angle and power losses. The load flow solutions obtained using the above-said methods were validated with the results obtained using continuation power flow (CPF) and evolutionary-based optimal power flow (EPOPF) methods, published earlier. In this paper, the PSO algorithm is proposed for optimal placement, and sizing of DG with an objective of the power loss reduction and voltage profile improvement. PSO algorithm is used to find out the best location and optimal size of DG.

Keywords: Load Flow Analysis, Bus Admittance Matrix, Jacobian Matrix, Newton Raphson Method, Active and Reactive Power Flow, Particle Swarm Optimization Algorithm

I. INTRODUCTION

The network of a power system consists of generation, transmission and distribution. Power flow analysis is the backbone for analysis and design of power systems. Many researchers have developed the load flow algorithm for both the transmission and distribution system. Load flow studies are used to ensure the stable, reliable and economical transmission of electrical power from generators to consumers via the grid system. The main objective of the load flow analysis (LFA) is to estimate the individual phase voltages of each bus and its angle when the generated power and loads connected to the network are specified. LFA is also used for planning new networks, adding and removing of a new line to the existing distribution substation. Consistent reactive power flow is to ensure whether the acceptable quality of service can be provided to consumers or not [1].

Besides, this analysis is used for transient stability analysis and contingency study of the system. Performing an analysis of load flow on an existing system recommends optimized power system operation [2]. A simple and efficient method for solving the load flow analysis by using algebraic expressions have been presented [3]. A compensation-based power flow approach has been implemented to evaluate the real-time performance of a three-phase practical distribution system [4]. For unbalanced three-phase systems, a direct LFA has been proposed by using simple matrix multiplication [5].

An improved Backwards/ Forward Sweep (BFS) method have been utilized for LFA based on network topology changes have proposed in [6]. Moreover, to enhance the computational efficiency of the BFS method, Kirchhoff's current law and voltage law were incorporated in backward sweep and forward sweep, respectively [7]. The state of a power system plays a crucial role in evaluating the operation and control of the system and for future expansion of the system. The state of a power system is determined by using LFA. The various methods developed by the researchers for solving the load flow analysis of the power systems were Gauss-Seidel, Newton-Raphson and Fast-Decoupled methods etc. Transmission line characteristics and performance can change widely depending on their network.

Moreover, the NR method is used to maintain an appropriate voltage profile with varying power flow at different buses. By fact, the transmission system is a loop of the low R/X ratio. Therefore, LFA variables of transmission system differ from the distribution system because the features of the electrical distribution system being profoundly ill-conditioned and high R/X ratio. Thus, NR method is used satisfactorily for LFA in both transmission and distribution system [8]. The most preferred load flow approach is the NR method because it has dominant convergence characteristics, low computing time, high accuracy and less dependent on the effect of slack bus selection [9]. In this paper, the load flow analysis of Indian utility 62-bus power system is performed using two methods such as Backwards/ Forward Sweep (BFS) methods and NR method. Installation of the DGs in the distribution system is commonly recognized as an effective method for improving distribution system efficiency. In this paper, distributed generation (DG) placement and sizing are determined by using the NR method in combination with the particle swarm optimization algorithm (PSO). Numerous optimization techniques are used to solve DG placement and sizing problem in the literature. Among them, population-based evolutionary algorithms and artificial intelligence computational techniques are used as solution methods in most current research works. The main advantage of population-based meta-heuristics algorithms such as PSO, GA has a set of non-dominated solutions which can be found in a single iteration run process because this algorithm has multi-point search capacity. This population-based algorithm is less prone to dimensionality problems.

The results obtained were validated with those obtained using CPF and EPOPF methods published in [16, 19]. The second section outlines the formulation of the NR method and the Backwards/ Forward Sweep (BFS) methods briefly. The third section explains about PSO algorithm. The fourth section describes the test system considered, Indian Utility 62-bus power system, the result analysis, along with validation for LFA is presented, DG allocation using PSO algorithm in combination with NR method results are tabulated in the fifth section. Finally, the conclusion is given in the last section.

II. NEWTON RAPHSON METHOD (NR)

NR method is the most commonly used approach for solving a non-linear algebraic equation. This method is a successive approximation process based on an initial evaluation of the unknown and using the expansion of Taylor's series [10, 11]. The general terminology used in Load flow analysis is:

V_i - $\boldsymbol{i}^{th}$ bus voltage; V_j - $\boldsymbol{j}^{th}$ bus voltage; Y_{ij} – Admittance of the line connected between i^{th} and j^{th} buses; Y_{ii}– Self admittance of the line connected to i^{th} bus; P_i – Real power injected into i^{th} bus; Q_i –Reactive power injected into i^{th} bus; I_i-Bus current at i^{th} bus; θ_{ij} – Angle of Y_{ij} the element of Y_{bus}; δ_1 – Voltage angle of i^{th} bus; N - No. of buses; Integer (0 to n)- i, j

Step 1: Initially the magnitude and phase angle of the slack bus voltage is assumed as,

$$V_i^{(0)} = 1.0, \delta_i^{(0)} = 0.0$$

The real and reactive power at bus $\boldsymbol{i}$ were calculated using Eqn. (1).

$$P_i + jQ_i = V_i I_i^* \quad (1)$$

Step 2: The mathematical formulation of the nonlinear algebraic equation of the power flow problem given in Eqn. (2) is solved by using the iterative process.

$$\frac{P_i - jQ_i}{V_i^*} = \left[V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j\right] \quad (2)$$

The current injected into the bus $\boldsymbol{i}$ is expressed in the Eqn. (3)

$$I_i = \left[V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j\right] j \neq i \quad (3)$$

Eqn. 3 can be expressed in terms of the bus admittance matrix, as shown in Eqn. (4)

$$I_i = \left[\sum_{j=0}^{n} Y_{ij} V_i\right] \quad (4)$$

The complex power at bus i is expressed as

$$P_i - jQ_i = V_i^* I_i \quad (5)$$

Step 4: The real and reactive power injected into the $\boldsymbol{i}^{th}$ bus is calculated using Eqns. (6) and (7)

$$P_i = \left[\sum_{j=1}^{n} V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j)\right] \quad (6)$$

$$Q_i = -\left[\sum_{j=1}^{n} V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j)\right] \quad (7)$$

Step 5: The elements of the Jacobian matrix (J_1, J_2, J_3, J_4) are the partial derivatives of Eqns. (6) and (7) and are used to find the change in real and reactive power using Eqn. (8).

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \quad (8)$$

Step 7: For load buses, P_i^l and Q_i^l are calculated by using Eqns. (6) and (7), and change in real power and reactive power are calculated based on scheduled values at load buses.

The difference between scheduled and calculated values of real and reactive power was expressed as

$$\Delta P_i^l = P_i^{sch} - P_i^l \quad (9)$$

$$\Delta Q_i^l = Q_i^{sch} - Q_i^l \quad (10)$$

The above process is continued until if all the ΔP_i^l and ΔQ_i^l are less than the specified limits.

Step 8: The updated voltage magnitudes $(V_i^{(l+1)})$ and phase angles $(\boldsymbol{\delta}_i^{(l+1)})$ are calculated as

$$V_i^{(l+1)} = V_i^l + \Delta V_i^l \quad (11)$$

$$\delta_i^{(l+1)} = \delta_i^l + \Delta \delta_i^l \quad (12)$$

Backwards/Forward Sweep (BFS) Method: This is an iterative approach used for the radial distribution network, to find the power flows and voltage magnitude and its angle at each bus [12-15]. In each iteration, two stages of computation were performed. In this method, the LFA is solved using two sets of recursive equations through iterations. The calculation in the first set of equations is implemented in a backward direction for calculating power flows in the system. The path for calculating the power flow is from the load to the source node. Next, the voltage magnitude and angle values are obtained from the second set of equations. The path for calculating voltage magnitude and angle values is from the source to the load node.

Forward Sweep: The voltage drop is measured in the forward sweep, while the power flow and currents values are updated. Initially, from the first layer to the last segment of the branch, the nodal voltage is gradually updated continuously. The primary purpose of forward calculations is basically to determine the voltage values at each node. Feeder substation is set to the actual value of its voltage. Throughout the forward process, the sufficient power in each branch should be kept constant, as the value of power is determined in the Backward Propagation (BP).

Backward Sweep: The calculation in the backward sweep starts from the last node and moves towards the first node. The power flows, and the current is obtained in BP with an appropriate update in voltage magnitude and phase angle.

The node voltages of the preceding iteration are considered in the backward process for obtaining the modified adequate power flows in each branch. In the backward process, the voltage values obtained in the forward process should be considered constant. Later, the updated power flow values are transmitted along the feeder using a backward path.

The BFS method has three variants which vary from each other, and it is calculated based on electric quantities in backward propagation as follows:

– By using current summation method (KCL), the branch currents are estimated.

– The power flows are measured at each branch by using the power summation method.

– For each node, the driving point admittance is obtained by using the technique of admittance summation.

Simulation of loads is done by the variants calculated in the above process for each iteration. The load calculation is done by using the constant power, constant current and a constant admittance model. In the forward propagation, all the variants are similar, and bus voltages are determined to start from the source node to the last node depending on the backward sweep calculation. To ahead the iteration voltages are updated based on quantities utilized in the backward sweep. Finally, the estimated values of voltages at each node are compared with the values obtained in the previous iteration. If the difference between the updated and old values is $\leq$ 0.0001, then the convergence criterion is satisfied else, the process will be repeated. The basic recursive equations are given in Eqns. (13) and (14) obtained from the single line diagram of a radial distribution system, as depicted in Fig. 1. The power losses and voltage magnitude are estimated from load flow analysis. The real and reactive power is calculated as:

$$P_{h+1} = P_h - P_{loss,h} - P_{Lh+1} \tag{13}$$

$$Q_{h+1} = Q_h - Q_{loss,h} - Q_{Lh+1} \tag{14}$$

P_h indicates real power flowing outside the bus.

Q_h indicates reactive power flowing outside the bus.

P_{Lh+1} indicates load real power of the bus h+1.

Q_{Lh+1} indicates load reactive power of the bus h+1.

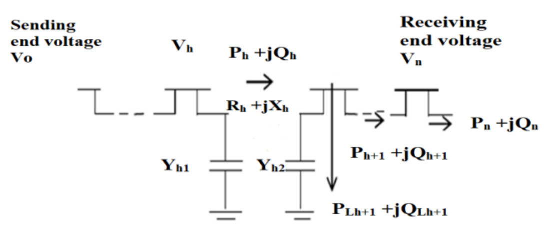

Fig. 1. Single line diagram of the radial distribution system.

Then active and reactive power losses for the line section between buses h and h+1 were calculated using Eqns. (15) and (16).

$$P_{loss}\,(h, h+1) = R_h\, * I_h^2 \tag{15}$$

$$Q_{loss}\,(h, h+1) = X_h\, * I_h^2 \tag{16}$$

where $I_h^2 = \frac{P_h^2 + Q_h^2}{V_h^2}$

The total real and reactive power loss of every section of feeders are determined using Eqns. (17) and (18).

$$P_{totalloss}\,(h, h+1) = \sum_{h=1}^{n} P_{loss}\,(h, h+1) \tag{17}$$

$$Q_{totalloss}\,(h, h+1) = \sum_{h=1}^{n} Q_{loss}\,(h, h+1) \tag{18}$$

Consider branch in-between node ‘h’ and ‘h+1’, and by BP process, effective power flows are evaluated. Therefore, effective real and reactive power was expressed as

$$P_h = P_{h+1} + P_{Lh+1} + R_h\, * I_{h+1}^2 \tag{19}$$

$$Q_h = Q_{h+1} + Q_{Lh+1} + X_h\, * I_{h+1}^2 \tag{20}$$

The voltage and angle values at each node are assessed in the forward propagation process. Let the voltage at node h is $V_h\angle\delta_h$ and voltage at node $h+1$ is $V_{h+1}\angle\delta_{h+1}$. Similarly, the impedance between h and $h+1$ is $Z_h = r_h + jx_h$ then the current in this section is determined using Eqn. (21).

$$I_h = \frac{(V_h\angle\delta_h - V_{h+1}\angle\delta_{h+1})}{(r_h + jx_h)} \tag{21}$$

To determine the voltage and angle values at all nodes, the recursive equations were applied. Initially, the voltage at all nodes is assumed as 1.0 per unit. The backward, forward sweep algorithm provides the complete power flow calculation operation in the system.

Backward Forward Sweep Algorithm:

Step 1: Read the line and bus data of the radial distribution system.

Step 2: Evaluate the real and reactive power injected at each node.

$P_{injected} = P_{generation} - P_{load}$

$Q_{injected} = Q_{generation} - Q_{load}$

Step 3: Set $h = 1$, iteration count and set the maximum number of iterations as N.

Step 4: For convergence criteria, assign $\boldsymbol{\epsilon}$=0.001,

$$\Delta P_{max} = 0, \Delta Q_{max} = 0.$$

Step 5: Evaluate the current injected at node i

$$I_i^h = \left[\left(\frac{S_i}{V_i^{(h-1)}}\right)^* - Y_i V_i^{h-1}\right] \quad i = 1,2,3,\ldots n$$

Step 6: Apply backward sweep and find the branch current using KCL.

Step 7: Apply the forward sweep method to obtain the voltage at each node using KVL.

Step 8: The power injection at node i is determined as

$$S_i^h = \left[V_i^h \left(I_i^h\right)^* - Y_i \left(V_i^h\right)^2\right]$$

Step 9: check convergence if $\Delta P_{max} \leq \varepsilon, \Delta Q_{max} \leq \varepsilon$. then goto step11, else step10.

Step 10: Set $h = h + 1$ and go to step 4.

Step 11: At the Nth iteration, if the process is converged, print the results else goto step3.

Step 12: Stop.

III. PARTICLE SWARM OPTIMIZATION (PSO)

Poli *et al.*, (2007) [16] have introduced the PSO algorithm in the year 1995, it is considered as the vigorous, stochastic optimization procedure based on the manoeuvre and the intelligence accomplished with the swarms. PSO algorithm is mainly related to the population and pretends the social behaviour of the fish schools or bird flock. In [17-20], researchers have used the PSO algorithm to identify the ODGP and sizing of multiple DGs in DS to minimize the losses.

Algorithm for solving DG location problem using PSO

The PSO-based method to solve the optimal placement of DG problem to reduce the total losses takes the subsequent steps:

Step1: Read the input data: Line data, Bus data, voltage Limits.

Step2: Select the parameters of PSO: Randomly generate population Size (pop_size=50), Acceleration Constants (C_1,C_2 =2), Inertia Weight/Weighting Function (W=1),r1,r2 are random numbers (0 and 1).

Step 3: Compute the voltages at each node and real power losses by using the NR method.

Step4: Initialize the Location of the particle(x).

Step5: Population of particles is initialized for finding the location with random positions. At the starting stage set the iteration count k=0

Step6: Initialization of random velocities of the particles.

Step7: Check the power balance constraint and voltage constraint.

Step8: Compute the total power losses and voltage in each bus by means of the objective function Eqn. (22).

Step 9: Estimate the fitness function.

Step10: Discovery the p_best (personal best of particle i) and g_best (global best of the group) values.

Step11: Updating the velocity of each particle as per the equation below:

$$v_i^{k+1} = wv_i^k + c_1\, r_1\left(pbest_i - s_i^k\right) + c_2\, r_2\left(gbest_i - s_i^k\right)$$

velocity(k,:)=w*velocity(k,:)+r1(k,1)*c1.*(p_best(k,:)-x(k,:))+r2(k,1)*c2.*(g_best-x(k,:));

Step12: Check whether the updated velocities are within the limits or not.

Step13: Then the position of each particle will be modified based on the equation below.

$$s_i^{k+1} = s_i^k + v_i^{k+1}$$

x(k,1) = ceil(x(k,1) + velocity(k,1));

Step14: Estimate the new fitness values. If this value is better than the previous value, then allocate the current values as p_best.

Step15: If the criteria are satisfied, goto step 16. Otherwise, the iteration count is set as k=k+1, and move back to step 7.

Step16: The newest g_best is the optimal solution to the problem. The best position is the optimal location of DG, with the minimum loss value and improved voltages profile of the system.

v_i^k : The current velocity of particle *i* at iteration *k*,

v_i^{k+1}: The modified velocity of particle *i*,

s_i^k: The current position of particle *i* at iteration *k*,

s_i^{k+1}: The modified position of particle *i*,

$pbest_i$: The personal best of particle i,

gbest: The global best of the group.

Problem Formulation: The main objective of the DG placement method in the system is to reduce the total system real power loss. Mathematically, the objective function is represented as

$$\text{Minimize } \mathrm{P_{Loss}} = \sum_{m=1}^{N} \text{real power loss}_m \qquad (22)$$

Subject to constraints

Power balance constraints:

$$\sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_{Loss}$$

Voltage constraints: $|V_i|^{min} \leq |V_i| \leq |V_i|^{max}$

Current constraints: $|I_{ij}| \leq |I_{ij}|^{max}$

where $\text{real power loss}_\mathrm{m}$ is distribution power loss at section m, N is total no. of sections, $\mathrm{P_{Loss}}$ is the real power loss in the system, $\mathrm{P_{DGi}}$ is the real power generation DG at bus i and $\mathrm{P_{Di}}$ is the power demand at bus i.

IV. SYSTEM DESCRIPTION

In this paper, the test system considered is Indian Utility 62-bus power system [21-25]. The features of Indian Utility 62-bus power system. It has 16 generators 89 transmission lines with a capacity of 100 MVA at 11kV. The transformer data, load data, line data, bus data, generator data were provided in Table 1, 2, 3 and 4, respectively. In the analysis of this test system, the range of bus voltage considered is from 0.9 p.u. to 1.1 p.u.

Table 1: Transformer data.

From bus	To bus	Tap Setting value (p.u)
1	14	0.9639
14	15	0.9539
4	14	1.0158
13	14	1.0124
12	13	0.9621
14	19	0.9630
14	18	1.0121
14	16	1.0135
48	54	0.9630
48	50	1.0132
48	49	0.9630

Table 2: Indian Utility 62 bus system load data.

Bus no.	Load		Bus no.	Load	
	P (MW)	Q (Mvar)		P (MW)	Q (Mvar)
1	0	0	32	0	0
2	0	0	33	46	25
3	40	10	34	100	70
4	0	0	35	107	33
5	0	0	36	20	5
6	0	0	37	0	0
7	0	0	38	166	22
8	109	78	39	30	5
9	66	23	40	25	5
10	40	10	41	92	91
11	161	93	42	30	25
12	155	79	43	25	5
13	132	46	44	109	17
14	0	0	45	20	4
15	155	63	46	0	0
16	0	0	47	0	0
17	0	0	48	0	0
18	121	46	49	0	0
19	130	70	50	0	0
20	80	70	51	0	0
21	0	0	52	0	0
22	64	50	53	248	78
23	0	0	54	0	0
24	58	34	55	94	29
25	0	0	56	0	0
26	116	52	57	0	0
27	85	35	58	0	0
28	63	8	59	0	0
29	0	0	60	0	0
30	77	41	61	0	0
31	51	25	62	93	23

Table 3: Indian Utility 62 bus system line data.

Line no.	From bus	To bus	Series impedance (p.u)		Half-line charging susceptances (p.u)	MVA rating	Tap Setting
			r	x			
1	1	2	0.00305	0.01560	0.01444	150	1
2	1	4	0.00716	0.03578	0.03397	80	1
3	1	14	0.00548	0.02813	0.10392	180	0.9639
4	1	10	0.01569	0.08061	0.07443	150	1
5	1	9	0.00229	0.01174	0.01084	50	1
6	1	6	0.00411	0.02113	0.01951	100	1
7	2	6	0.00168	0.00861	0.00795	50	1
8	2	3	0.00289	0.01487	0.01373	150	1
9	3	4	0.00381	0.01957	0.01807	100	1
10	4	15	0.00411	0.02113	0.01951	150	1
11	14	15	0.00520	0.02669	0.02464	60	0.9539
12	4	14	0.00411	0.02113	0.01951	150	1.0158
13	13	14	0.001315	0.06754	0.06237	150	1.0124
14	12	13	0.01537	0.07897	0.07292	90	0.9621
15	12	11	0.01905	0.09783	0.09033	50	1
16	11	10	0.00686	0.03522	0.03252	100	1
17	4	5	0.00716	0.03678	0.03397	150	1
18	5	6	0.00575	0.01478	0.00309	90	1
19	6	7	0.00030	0.00157	0.00578	90	1
20	7	8	0.00049	0.00168	0.08612	90	1
21	5	8	0.00575	0.01478	0.00309	100	1
22	11	16	0.01406	0.07223	0.06670	120	1
23	16	17	0.00343	0.01761	0.06504	90	1

24	17	21	0.01850	0.09548	0.08816	150	1
25	21	22	0.01371	0.07043	0.06504	150	1
26	22	23	0.00396	0.02035	0.07516	100	1
27	23	24	0.00305	0.01565	0.01445	240	1
28	23	25	0.00126	0.00650	0.00600	50	1
29	25	28	0.01062	0.05554	0.05037	100	1
30	25	26	0.00941	0.04828	0.04459	150	1
31	25	27	0.01173	0.06026	0.05565	150	1
32	27	29	0.00533	0.02739	0.02529	50	1
33	29	30	0.02058	0.10573	0.09763	50	1
34	20	23	0.02042	0.10573	0.09684	100	1
35	12	20	0.01981	0.10487	0.09395	150	1
36	13	17	0.01563	0.10174	0.07415	100	1
37	14	19	0.00707	0.08030	0.03353	180	0.9630
38	14	18	0.00135	0.03631	0.02558	150	1.0121
39	14	16	0.00396	0.00693	0.01879	90	1.0135
40	24	45	0.01219	0.02035	0.05781	90	1
41	24	41	0.01554	0.06261	0.07371	90	1
42	41	45	0.00335	0.07993	0.01590	90	1
43	40	41	0.00609	0.03130	0.02891	100	1
44	41	42	0.00076	0.00391	0.01445	90	1
45	42	43	0.00914	0.04696	0.04336	50	1
46	42	44	0.01417	0.07278	0.06721	90	1
47	39	42	0.00686	0.03522	0.03252	90	1
48	39	37	0.00229	0.01174	0.01084	100	1
49	38	37	0.01044	0.05361	0.04950	130	1
50	38	34	0.01076	0.05525	0.05102	90	1
51	34	37	0.01990	0.01022	0.09438	150	1
52	34	33	0.01737	0.08922	0.08258	30	1
53	34	35	0.00701	0.03600	0.03324	50	1
54	35	32	0.0036	0.00184	0.06679	150	1
55	33	32	0.01676	0.08609	0.07949	50	1
56	32	31	0.07187	0.09180	0.08477	90	1
57	30	31	0.00992	0.05095	0.04705	50	1
58	40	30	0.00716	0.03678	0.03397	90	1
59	32	36	0.00305	0.01565	0.01445	50	1
60	32	37	0.02200	0.11301	0.10435	50	1
61	32	34	0.00396	0.02035	0.07516	90	1
62	32	46	0.02095	0.10761	0.09937	50	1
63	36	46	0.01828	0.09391	0.08672	50	1
64	37	46	0.00104	0.00536	0.01980	150	1
65	46	44	0.01676	0.08609	0.07949	50	1
66	44	59	0.00884	0.04539	0.04191	150	1
67	59	61	0.00922	0.04735	0.04372	150	1
68	60	61	0.00244	0.01252	0.04625	100	1
69	61	62	0.01499	0.07701	0.07111	100	1
70	62	25	0.01383	0.07106	0.06562	100	1
71	58	61	0.00335	0.01722	0.06359	150	1
72	58	61	0.00411	0.02113	0.01951	150	1
73	55	58	0.00670	0.03443	0.03180	50	1
74	57	58	0.00183	0.00939	0.00867	150	1
75	57	56	0.00152	0.00783	0.00723	100	1
76	56	58	0.00259	0.01330	0.01229	90	1
77	52	61	0.01127	0.05791	0.05348	50	1
78	52	53	0.01132	0.05815	0.05369	100	1
79	51	55	0.01417	0.07278	0.06721	100	1
80	51	53	0.01190	0.06112	0.05644	150	1
81	51	54	0.00407	0.02090	0.01930	50	1
82	48	54	0.01254	0.06441	0.05948	50	0.9630
83	48	50	0.00066	0.00337	0.01242	150	1.0132
84	49	50	0.00670	0.03443	0.03180	90	1
85	49	48	0.00366	0.01878	0.06938	150	0.9630
86	47	48	0.01371	0.07043	0.06504	90	1
87	47	46	0.00792	0.04070	0.03758	150	1
88	60	12	0.01365	0.07012	0.06475	150	1
89	50	12	0.01211	0.06222	0.05745	150	1

Table 4: Bus data.

Bus no.	Bus code	Voltage Mag.	Angle Deg.	Generator				Injected mvar
				MW	Mvar	Q_{min}	Q_{max}	
1	1	1.05	0	192.649	23.554	0	450	0
2	2	1.05	0	190.581	0.00	0	130	0
3	2	1.00	0	0.00	0.00	0	0	0
4	0	1.00	0	0.00	0.00	0	0	0
5	2	1.05	0	255.687	0.00	0	255	0
6	0	1.00	0	0.00	0.00	0	0	0
7	0	1.00	0	0.00	0.00	0	0	0
8	0	1.00	0	0.00	0.00	0	0	0
9	2	1.05	0	78.202	1.218	0	100	0
10	0	1.00	0	0.00	0.00	0	0	0
11	0	1.00	0	0.00	0.00	0	0	0
12	0	1.00	0	0.00	0.00	0	0	0
13	0	1.00	0	0.00	0.00	0	0	0
14	2	1.05	0	171.083	233.905	0	500	0
15	0	1.00	0	0.00	0.00	0	0	0
16	0	1.00	0	0.00	0.00	0	0	0
17	0	1.05	0	190.612	0.00	0	0	0
18	0	1.00	0	0.00	0.00	0	0	0
19	0	1.00	0	0.00	0.00	0	0	0
20	0	1.00	0	0.00	0.00	0	0	0
21	0	1.05	0	0.00	0.00	0	0	0
22	0	1.00	0	0.00	0.00	0	0	0
23	2	1.05	0	151.842	147.932	0	340	0
24	0	1.00	0	0.00	0.00	0	0	0
25	2	1.05	0	250.249	86.526	0	395	0
26	0	1.00	0	0.00	0.00	0	0	0
27	0	1.00	0	0.00	0.00	0	0	0
28	0	1.00	0	0.00	0.00	0	0	0
29	0	1.00	0	0.00	0.00	0	0	0
30	0	1.00	0	0.00	0.00	0	0	0
31	0	1.00	0	0.00	0.00	0	0	0
32	2	1.05	0	106.624	0.00	-100	400	0
33	2	1.05	0	62.380	0.00	0	30	0
34	2	1.05	0	134.508	41	0	41	0
35	0	1.00	0	0.00	0.00	0	0	0
36	0	1.00	0	0.00	0.00	0	0	0
37	2	1.05	0	78.533	0.00	0	87	0
38	0	1.00	0	0.00	0.00	0	0	0
39	0	1.00	0	0.00	0.00	0	0	0
40	0	1.00	0	0.00	0.00	0	0	0
41	0	1.00	0	0.00	0.00	0	0	0
42	0	1.00	0	0.00	0.00	0	0	0
43	0	1.00	0	0.00	0.00	0	0	0
44	0	1.00	0	0.00	0.00	0	0	0
45	0	1.00	0	0.00	0.00	0	0	0
46	0	1.00	0	0.00	0.00	0	0	0
47	0	1.00	0	0.00	0.00	0	0	0
48	0	1.00	0	0.00	0.00	0	0	0
49	2	1.05	0	213.957	0.00	0	80	0
50	2	1.05	0	92.784	0.00	0	200	0
51	2	1.05	0	82.957	41.542	0	245	0
52	2	1.05	0	24.608	35	0	35	0
53	0	1.00	0	0.00	0.00	0	0	0
54	2	1.05	0	72.633	0.00	0	100	0
55	0	1.00	0	0.00	0.00	0	0	0
56	0	1.00	0	0.00	0.00	0	0	0
57	2	1.05	0	219.441	0.00	0	20	0
58	2	1.05	0	339.708	100	100	420	0
59	0	1.00	0	0.00	0.00	0	0	0
60	0	1.00	0	0.00	0.00	0	0	0
61	0	1.00	0	0.00	0.00	0	0	0
62	0	1.00	0	0.00	0.00	0	0	0

V. RESULTS AND DISCUSSION

In this paper, the LFA is carried out for the Indian Utility 62-bus power system through the NR and BFS methods. Results obtained from the above two methods were validated with those obtained in [21, 24]. A total load of this system is 2908.0 MW active power and 1270 MVAR reactive power. Under the base load condition, the active power loss in the system is 68.0664 MW.

Case I: MATLAB R2017A is used here to write the coding to obtain the load flow of the system considered using NR and BFS methods. The LFA is carried out with an accuracy level of 0.00001. The total number of iterations considered here is 50. Fig. 2 shows the convergence graph obtained for the load flow solution of the test system considered under base load condition using the NR method. From the figure, it can be observed that the convergence has occurred at the 10th iteration with a computation time of 14.52 sec. Fig. 3 depicts the node voltages of all the node of this system under base load condition. Fig .4 shows the value of active power loss at each node of the test system under base load condition. From Table 2 it is concluded that all voltages at the node are within limits of 0.9918 – 1.06 p.u as per standards, the difference in voltage magnitude values is almost equal to zero in both methods when compared with CPF method. The system has a weak voltage profile at node 11, 20, 30 and node 31 due to the system hugely loaded, and some of the nodes have no load.

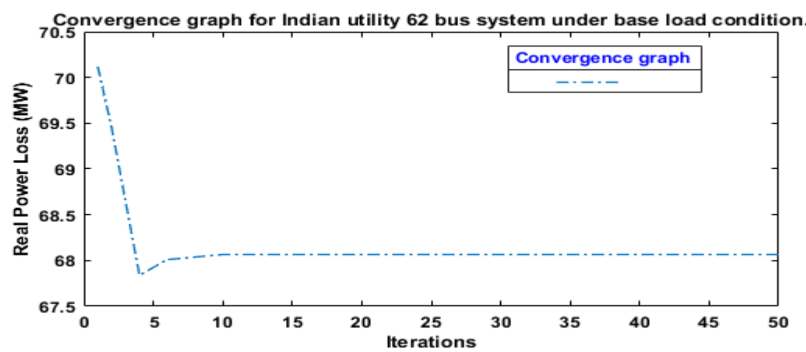

Fig. 2. Convergence graph for Indian utility 62 bus system under base load condition.

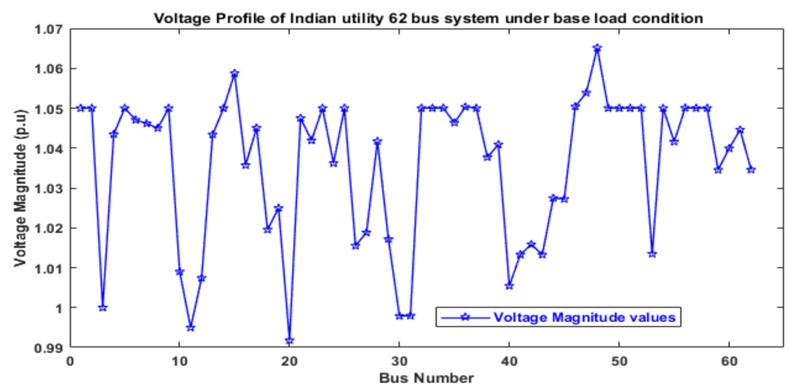

Fig. 3. Voltage Profile of Indian utility 62 bus system under base load condition.

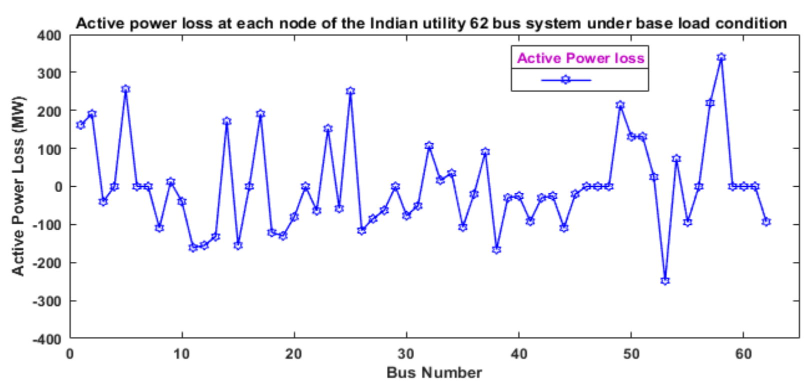

Fig. 4. Active power loss at each node of the Indian utility 62 bus system under base load condition.

Table 5: Comparison of the load flow solution obtained by NR and BFS with CPF for the test system.

Node/ Branch	Voltage magnitude (p.u) [NR method]	Angle (radians) [NR method]	Voltage magnitude (p.u) [BFS method]	Voltage magnitude (p.u) (CPF 21])	Difference Between (NR and CPF [21])	Difference Between (BFS and CPF [21])
1	1.05	0	1.05	1.05	0.00	0.00
2	1.05	0.6714	1.05	1.05	0.00	0.00
3	1	0.3821	1.04	1.0512	-0.05	-0.01
4	1.0434	-0.7195	1.039	1.0566	-0.01	-0.02
5	1.05	1.2389	1.05	1.05	0.00	0.00
6	1.0471	0.654	1.0455	1.0458	0.00	0.00
7	1.0462	0.639	1.045	1.0448	0.00	0.00
8	1.045	0.6303	1.044	1.0435	0.00	0.00
9	1.05	0.0773	1.05	1.05	0.00	0.00
10	1.009	-4.2309	1.006	1.0052	0.00	0.00
11	0.995	-5.3725	0.987	0.9808	0.01	0.01
12	1.0074	-4.847	1.01	1.0266	-0.02	-0.02
13	1.0434	-4.7541	1.045	1.0447	0.00	0.00
14	1.05	-1.9587	1.05	1.05	0.00	0.00
15	1.0588	-2.1414	1.061	1.0622	0.00	0.00
16	1.0357	-2.1435	1.0345	1.0349	0.00	0.00
17	1.0451	-1.7673	1.046	1.05	0.00	0.00
18	1.0195	-4.3076	1.021	1.0343	-0.01	-0.01
19	1.0249	-7.0766	1.0401	1.0722	-0.05	-0.03
20	0.9918	-9.4039	0.992	1.0256	-0.03	-0.03
21	1.0475	-6.237	1.045	1.0442	0.00	0.00
22	1.0419	-9.422	1.045	1.0409	0.00	0.00
23	1.05	-9.7296	1.052	1.05	0.00	0.00
24	1.0362	-11.0798	1.0361	1.0301	0.01	0.01
25	1.05	-9.6976	1.054	1.05	0.00	0.00
26	1.0155	-12.4684	1.017	1.0272	-0.01	-0.01
27	1.0188	-13.1603	1.019	1.0177	0.00	0.00
28	1.0417	-11.5167	1.0408	1.0402	0.00	0.00
29	1.0171	-13.5752	1.0104	1.0005	0.02	0.01
30	0.9979	-15.0629	0.9982	1.0092	-0.01	-0.01
31	0.998	-14.8783	0.9988	1.0143	-0.02	-0.02
32	1.05	-12.4377	1.051	1.05	0.00	0.00
33	1.05	-12.0403	1.05	1.05	0.00	0.00
34	1.05	-12.4162	1.052	1.05	0.00	0.00
35	1.0463	-12.51	1.0468	1.0494	0.00	0.00
36	1.0503	-12.3961	1.051	1.0482	0.00	0.00
37	1.05	-11.5376	1.05	1.05	0.00	0.00
38	1.0377	-14.315	1.038	1.0378	0.00	0.00
39	1.0409	-12.0104	1.0397	1.0399	0.00	0.00
40	1.0054	-14.1962	1.0058	1.0068	0.00	0.00
41	1.0133	-13.025	1.0081	1.0071	0.01	0.00
42	1.0158	-12.9052	1.0102	1.0096	0.01	0.00
43	1.0133	-13.556	1.0123	1.0011	0.01	0.01
44	1.0274	-10.4547	1.0378	1.0218	0.01	0.02
45	1.0272	-11.5802	1.0182	1.0113	0.02	0.01
46	1.0504	-11.1123	1.0502	1.0488	0.00	0.00
47	1.0539	-6.994	1.0432	1.0422	0.01	0.00
48	1.0651	0.1261	1.0658	1.0661	0.00	0.00
49	1.05	1.3301	1.05	1.05	0.00	0.00
50	1.05	0.199	1.05	1.05	0.00	0.00
51	1.05	0.416	1.05	1.05	0.00	0.00
52	1.05	-2.9591	1.052	1.05	0.00	0.00
53	1.0135	-5.0887	1.012	1.0199	-0.01	-0.01
54	1.05	1.0954	1.051	1.05	0.00	0.00
55	1.0416	-0.1644	1.04	1.0347	0.01	0.01
56	1.0501	1.6752	1.0501	1.05	0.00	0.00
57	1.05	1.9611	1.052	1.05	0.00	0.00
58	1.05	1.1926	1.054	1.05	0.00	0.00
59	1.0345	-5.9167	1.034	1.0333	0.00	0.00
60	1.0399	-1.7616	1.0464	1.046	-0.01	0.00
61	1.0446	-1.2152	1.0458	1.0473	0.00	0.00
62	1.0346	-7.4289	1.045	1.0462	-0.01	0.00

Here both NR and BFS methods were applied to obtain the load flow solution for the test system considered, standard Indian utility 62 bus system. Table 5 shows the comparison of the results obtained using NR and BFS with those obtained with CPF method published in [21]. From the table, it can be observed that all node voltages obtained using both the methods are in the range of 0.9918 p.u. – 1.06 p.u., which is referred to as standard limits for voltage magnitude. Also, it can be noted from the table that nodes 11, 20, 30 and 31 have a weak voltage profile, as these nodes are heavily loaded nodes. A comparison of the active power loss and voltage magnitude obtained in the load flow solution carried out at the base loads of the Indian utility 62 bus distribution system using NR and BFS with those obtained using CPF method and Evolutionary based optimal power flow have been tabulated in Table 6 .From Table 5 and 6, it is clear that both the NR and BFS methods have yielded precise load flow solution for the considered test system with less computation time in comparison with other CPF and evolutionary-based methods. Moreover, compared to BFS, NR method can be suggested as the best option for performing load flow solution for the larger distribution systems. Finally, Table 7 shows the active power losses obtained at all the nodes of the considered test system using the NR method.

Case II: This case result determines the optimal location of a DG unit by utilizing the PSO optimization method. The results of the Indian utility 62 test system are shown below. Table 8 shows the voltage magnitude values obtained at all the nodes of the considered test system using the NR method with PSO algorithm before and after installation of DG in the system. Table 9 shows the comparison of total real power losses without and with DG using PSO algorithm. The lowest voltage occurred at the Bus 20 in the case I with of 0.9918 p.u and for the case II lowest voltage occurs at Bus 11 with 0.9928 p.u. The comparison graph in Fig. 5 shows the voltage profile improvement with and without DG using PSO algorithm. From the figure, it is concluded that the voltage profile has improved by placing the DG at the appropriate location using PSO algorithm.Table10 shows that the P_best position for DG allocation and size using a combination of NR method and PSO algorithm. The obtained results from the simulation shows that total Power loss = 56.0006 MW, g_best = 30.0000 (bus number), DG size = 193.9886 MW, if DG placed at g_position the loss have reduced to 12.06 MW and and percentage loss reduction is 17.71%.

Table 6: Summary of results obtained from different methods.

Network	Configuration	Active power losses (MW)	Voltage magnitude Max./Min. (p.u)	Computation Time(sec)
Indian Utility 62 bus distribution system	NR METHOD	68.066	0.9918	14.52
	BFS METHOD	68.124	0.9940	12.15
	Continuous power flow method (CPF) [21]	68.240	0.9808	—
	Evolutionary based optimal power flow [24]	69.569	0.9920	—

Table 7: Active power loss at each node of Indian utility 62 bus distribution using the NR method.

Bus. No.	Power loss Ploss (MW)	Bus. No.	Power loss Ploss (MW)
1	161.6668	32	106.624
2	190.581	33	16.38
3	-40	34	34.508
4	0	35	-107
5	255.687	36	-20
6	0	37	90.533
7	0	38	-166
8	-109	39	-30
9	12.202	40	-25
10	-40	41	-92
11	-161	42	-30
12	-155	43	-25
13	-132	44	-109
14	171.083	45	-20
15	-155	46	0
16	0	47	0
17	190.612	48	0
18	-121	49	213.957
19	-130	50	130.784
20	-80	51	130.957
21	0	52	24.608
22	-64	53	-248
23	151.842	54	72.633
24	-58	55	-94
25	250.249	56	0
26	-116	57	219.441
27	-85	58	339.708
28	-63	59	0
29	0	60	0
30	-77	61	0
31	-51	62	-93
Total power loss=68.066 MW			

Table 8: Voltage magnitude values with and without DG using the combination of the NR method and PSO algorithm.

Bus No.	Case I Without DG	Case II With DG	Bus No.	Case I Without DG	Case II With DG
1	1.05	1.05	32	1.05	1.05
2	1.05	1.05	33	1.05	1.05
3	1	1	34	1.05	1.05
4	1.0434	1.0437	35	1.0463	1.0463
5	1.05	1.05	36	1.0503	1.0503
6	1.0471	1.0469	37	1.05	1.05
7	1.0462	1.046	38	1.0377	1.0377
8	1.045	1.0448	39	1.0409	1.0405
9	1.05	1.05	40	1.0054	1.0042
10	1.009	1.0084	41	1.0133	1.012
11	0.995	0.9928	42	1.0158	1.0144
12	1.0074	0.9982	43	1.0133	1.0118
13	1.0434	1.0359	44	1.0274	1.0223
14	1.05	1.05	45	1.0272	1.0279
15	1.0588	1.0589	46	1.0504	1.0502
16	1.0357	1.0385	47	1.0539	1.0541
17	1.0451	1.0472	48	1.0651	1.0651
18	1.0195	1.0195	49	1.05	1.05
19	1.0249	1.0249	50	1.05	1.05
20	0.9918	0.9874	51	1.05	1.05
21	1.0475	1.0513	52	1.05	1.05
22	1.0419	1.0431	53	1.0135	1.0137
23	1.05	1.05	54	1.05	1.05
24	1.0362	1.036	55	1.0416	1.0412
25	1.05	1.05	56	1.0501	1.0528
26	1.0155	1.0155	57	1.05	1.05
27	1.0188	1.0187	58	1.05	1.05
28	1.0417	1.0417	59	1.0345	1.0276
29	1.0171	1.0168	60	1.0399	1.033
30	0.9979	0.9967	61	1.0446	1.0401
31	0.998	0.9964	62	1.0346	1.0283

Table 9: Comparison of losses with and without DG using PSO algorithm.

Case	Real power losses (MW)	Minimum voltage (p.u)	g_best (bus location)	DG size (MW)
I--Without DG	68.066	0.9918	—	—
II----With DG	56.006	0.9928	30	194.34
Reduced total power losses =12.06 MW and Percentage loss reduction=17.71%				

Table 10: Pbest position for DG allocation and size using PSO.

The personal best of the particle, Pbest		P_best Position
31	133.8701	57.314629
30	149.1957	56.613067
31	170.3747	57.087551
40	289.0476	59.588321
30	182.9841	56.038016
30	282.9562	58.292927
29	176.2611	59.596587
31	162.6127	57.046747
30	170.6845	56.166374
31	96.27905	58.697129
30	144.4701	56.74975
40	214.493	57.453622
30	244.4272	56.743349
30	126.0811	57.415619
40	185.6519	57.392906
31	166.4313	57.060898
30	177.5845	56.08306
30	177.5442	56.083462
31	172.6337	57.108306
30	187.5845	56.013525
30	171.009	56.161806
30	191.5733	56.002583
30	151.9229	56.540537

30	200.5072	56.012572
30	203.5853	56.027006
31	161.4428	57.044716
30	199.316	56.008494
30	240.4266	56.630564
30	195.4071	56.001042
31	147.027	57.109225
30	192.14	56.001802
30	127.4136	57.36015
30	181.1654	56.051219
30	252.1897	56.988227
30	187.5354	56.013719
30	232.5264	56.434796
30	162.2273	56.308177
30	157.3774	56.40935
41	160.9015	59.039451
30	184.4551	56.028799
30	169.0318	56.190639
30	200.2182	56.011505
30	183.3666	56.035494
30	201.353	56.015979
30	**193.9886**	**56.000589**
31	166.0908	57.059169
30	188.0975	56.011583
40	215.995	57.468683
30	219.73	56.194183
31	135.7904	57.275827

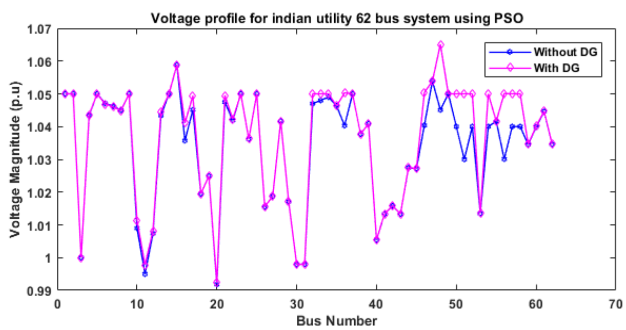

Fig. 5. Voltage profile improvement with and without DG.

VI. CONCLUSION

In this paper, the performance and application of the NR and BFS methods for the load flow analysis of the Indian utility 62 bus distribution system have been discussed and analyzed. This paper also presents an LFA programming with a combination of NR method and the PSO algorithm to find out the optimal location of a DG unit for voltage profile improvement and minimizing power loss of the system. A comparison is made for the node voltage magnitude and total active power losses obtained for the test system using both NR and BFS methods with those obtained and published using CPF and Evolutionary based optimal power flow methods.

From the comparison made, it can be concluded that the NR method yields a better solution in terms of accuracy and computation time. Hence NR method can be recommended for the load flow analysis of large distribution system.BFS method is also mostly applied LFA program for the real distribution system to find the power losses. The power loss for Indian utility 62-bus system obtained from both methods is almost same NR method P_L=68.066 MW and BFS method P_L=68.124 MW.

The proposed PSO algorithm identified the g_best location for optimal DG placement, to improve the voltage profile at all buses and to minimize total power losses. The obtained results show that bus number 30 is the best location for DG placement to improve the voltage profile and reduce the total power loss of 12.06 MW and percentage loss reduction is 17.71%. Further, the solutions obtained here can be utilized to study the security, planning and reconfiguration of the system. This heuristics algorithm is easy to implemented and can obtain a non-dominant solution in a single run process.

VII. FUTURE SCOPE

The current work offers a way for network reconfiguration problem considering DGs for minimization of losses and voltage profile improvement for real distribution systems by using different heuristics and hybrid metaheuristics algorithm. Combination of PSO algorithm and other heuristic algorithms yield better results in solving network reconfiguration problem and also for installation of DG at the optimal location with optimal size.

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Conflict of Interest. The authors declare that there are no known conflicts of interest associated with this publication of this paper.

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