Analyzing the Impact of Multiple Distributed Generations on Distribution System Performance

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Abstract—**The distribution system has got primary concern for dispatching load without any technical problems. For this, the conventional methodologies of compensation face difficulties in improving system security by minimizing severity. The state of a system depends on the system configuration, for this, in this work, radial and weakly meshed distribution system are considered. The load flow methodology presented in this work is based on the compensating factors and minimizes the computational burden. This methodology is extended to solve load flow problem for the weakly meshed distribution systems. The technological advancements in compensating system parameters can enhance the system performance. Usually, various kinds of distributed generations (DGs) are available to compensate node voltage and power flow in transmission lines by injecting active and reactive powers at the node where it is connected. Further, the system performance is enhanced with optimal placement i.e., location and as well as size of multiple DG units. The complete analysis is presented for Radial-33 node and Radial-69 node test systems with supporting graphical and numerical results.**

Index Terms—**Distribution systems, BFS algorithm, DG modeling, effect of multiple DG units.**

I. INTRODUCTION

A distribution system is a system which distributes power from higher level to lower level. The generation of electrical power in a power station will be in a range of 11-25 kV. For long distances, to transmit power, it is stepped up to 400kV or 220kV based on the requirement. The transmission network with large number of voltages carries the power. When the large voltage lines run for hundreds of kilometers, they deliver power to the power pool known as a grid. If the grid relates to transmission network of 132kV lines, which terminate it to a substation and the voltage will be stepped-down to 11kV or 33kV. A feeder can be used an underground cable or an overhead line. In urban areas based on the density of customers, a11kV feeder can feed up to a length of 3km. Whereas in rural areas it can be up to a length of 20km.

Power development and power supply of the transmission and distribution system are built to feed in both the commercial and domestic loads. The transmission and distribution of networks were rapidly expanded. The extension of the high voltage transmission system has been made based on the system studies and load flow of both the transmission and the distribution systems. The radial networks will dominate the development of distribute system. Because of radial nature several problems were emerged, the power is supplied through a radial link which feeds from 132kV and below. The radial link may be disturbed by any faults at any stage through the area. For example, rusted pole can be replaced, the line can be reconductored etc., when the section can be shut down in the line, which effects the supply of the power to the feeding areas.

- Voltage regulation: the transmission and distribution voltage can be regulated up to ±5 % or ±10 % based on the voltage. At the time of high voltages and large amount of power in radial link, sudden voltage drop may occur. Whereas at the time of low voltages shunt capacitors were used as load compensator in the network which leads to high voltages.
- Inadequacy: The growth of the network will become non-systematic planning if the long-term requirement is not considered in many parts of transmission and distribution network. This inadequacy can get frequency tripping and high technical losses.
- Developing of low-tension lines: The low-tension lines automatically developed by distribution networks with inadequate capacity of transformer all over the country. Which leads to high losses, sudden voltage drops, unreliability in supply.

Lack of maintenance properly and equipment quality resulting high amounts of technical losses in the distribution side. High level of commercial losses may also occur due to revenue collection, poor billing, and theft of power. That is why it is very important to have an attention to improve efficiency of the distribution system.

II. ELECTRICAL DISTRIBUTION SYSTEMS

- Distribution sub-station: It is a type of electric power system which transmits power from transmission side to distribution side in a particular area.
- Feeders: It is a conductor that connects power distribution area and distribution sub-station. In feeder current will remain constant in the entire system without any tapping's in it. The considerations of the feeder depend on the capacity of it to carry current.
- Distribution transformers: It is a step-down transformer of which both the primary and secondary are connected in star and delta form respectively. Another name of distribution transformer is service transformer. In 1-Φ system the output voltage of distribution transformer is230 V and in 3- Φ system it is 440V.
- Distributor: It is also called as a conductor. The tapings are considered from the distributor for supplying power to the consumers. After completion of this taping at several places, the current will not be uniform in its length.
- Service mains: It is a cable that connects consumer meter and distributor.

Distribution systems can be classified into to two categories.

1) Primary distribution system: The electrical energy is transmitted from generation stations to various substations through transmission lines from 33kV to 220kV. A primary distribution system's voltage level is higher than the utilization level. In many cases, a 3-Φ three wire system of voltage level of range 3.3kV, 6.6kV, 11kV are used. The supply of power to most of the consumers like commercial complexes or industries is done by primary distribution system.

2) Secondary distribution system: The voltage is stepped down to 400 volts at this substation. According to scheme of connections it is classified into 3 types

- Radial system
- Ring main system
- Interconnected system

A secondary distribution system's voltage level is at the utilization level. A primary distribution is up to a transformer and this secondary is used to convert 11kV to 415V. Then this power is supplied directly to small scale units. Most probably, the primary winding and secondary winding of the transformer is connected in delta and star connection respectively. That is why a 3-Φ, four wire secondary system is used in the secondary distribution system. 1-Φ supply is considered by anyone phase with one neutral terminal, which provides a 230V or 120V of voltage magnitude. For some small-scale industries 3-Φ supply is used. The consumer like industries, mills, etc 3- Φ supply is used by terminals of R,B,Y, and N terminals as per below figure.

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Radial distribution system

To illustrate the procedure to determine the nodes beyond the branch, a sample radial distribution system is considered and is shown in Fig.1.

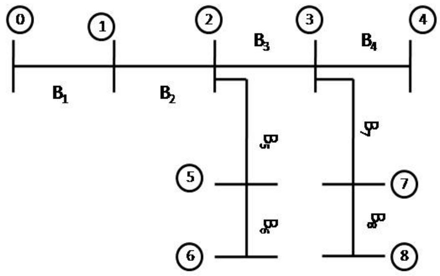

Fig.1 Radial distribution system for illustration

A numbering scheme for node and branches is given in Fig.1. The substation node is numbered as the node '0'. Starting from it, the nodes of the main feeder are numbered. The first lateral from the source node of the main feeder is chosen, and its nodes are numbered following the end node number of main feeder, similarly the node numbers of the next lateral are numbered following the end node of the previous lateral and so on until all the laterals are completed. The receiving end node numbers are given as the branch numbers.

III. Literature Review

Power flow distribution system of AC-MTDC can resolved by the proposed algorithm as it is effective, fast and flexible.[1]The speed of the PLF analysis needs to improved to adjust to the distribution models, operational needs also are to be improved by new time-series approaches. Sophiscated data collection plays an important role in improving the accuracy of the input variables. [2] A generalised network modelling has been identified to define tap-invariant and decoupled sequence networks along with the zero-sequence network integrity at any transformer configuration. The computational accuracy and efficiency of the methodology is verified.[3] The simulation results showed that the harmonic voltage distributions are reconstructed accurately (magnitude and phase angle). The iterative approach also carried the background harmonic interaction relevance. The incomplete CAT (ICAT) was based on a probabilistic HLF formulation.[4] The proposed technique's effectiveness has been demonstrated. The proposed faster, robust and computational in comparison to the conventional systems.[5] The Probabilistic load flow techniques are proposed in this paper. By developing the program, the probabilistic Voltage profiles at all nodes or buses are predicted. To show the study of Photo voltaic power penetration a practical case is also discussed and can be installed without changing the Voltage constraints into a Distribution network. [6] Location and load model of non-line modal loads have been taken into consideration due to the discrepancies seen in them. PHLF algorithm has been formulated to justify the superior capabilities of the method. Results have been correlated and Monte Carlo(MCS) method had been applies to the node system IEEE37 to prove its effectiveness. [7]

A new algorithm is proposed to reduce the overheads in handling flows without requiring flow rates. The average FCT flows are reduced to 47% by using a data centre FDALB over ECMP which achieves higher scalability comparing to load balancing of the state-of-art in this mechanism. [8]To determine the marginal price a new approach of optima power flow is used along with nodal prices to minimize the operation cost of the system. To get these prices it uses marginal loss coefficients and the compared results are residential, commercial, and industrial load patterns by considering the seasonal variations. [9]In this article, PLF is enhanced based on LHS to achieve calculations more accurately. To predict the arbitrary distributions of an integrated system, a method of non-parametric estimation is proposed. To deal with the correlation parameter Nataf transformation is introduced. The superiority of these approaches are applied in permutation procedures of LHS method and the demonstration of the results can be obtained. [10]

This manuscript aims at an integrated approach for Dwarf Mongoose optimization and loss sensitivity factor. The size and optimal location of DG for reducing the power loss and improvement of voltage profile is identified. [11]In order to identify the capacity of the DG and the optimum location, CMBHHO is utilized. This is implemented on Simulink platform in MATLAB and the results are analyzed with techniques like LSA,GSA,ALO,HAS,RGA,FWA,PSO*, and TBLO*.[12] The size and optimal location of DG is analyzed and voltage stability index is also considered to get an objective function. By comparing the results with PSO and GA methods in RDS the proposed approach has been shown superior values. The performance and analysis is carried out by considering IEEE 69 and 33 buses as the test system. [13]The types of loads used in this distribution system are linear and non-linear type, also load growth is considered. A 31-bus system is considered to get the effectiveness of this algorithm. It is shown that the green house gas emissions are reduced due to renewable energy resources. [14]In this paper, constant power load model, real power DG units and other voltage dependent load models like residential, commercial, and industrial are considered. The effectiveness of this algorithm is tested and validated on a 38 and 69-node radial distribution system. [15]

The proposed MICP model is to find the global optimal solution and two perform the different conditions of a 69-bus radial distribution system. The sensitivity analysis is conducted and the results are compared to approve its usefulness and effectiveness.[16] Different multi-objective algorithms are compared to get power loss sensitivity factor and opposition based differential evolution. By this method there might be improvement of loss mitigation, power loss and voltage profile. [17]This method proven to be effective when results were compared from results obtained for three distinct platforms – IEEE-PES data, MATLAB/Simulink and Open DSS. EO algorithm has proven its effectiveness by working at the minimal power loss and better voltage profile. [18] Two search strategies of pattern-based global optimal flows are developed to develop the near or global optimal solutions. By using three test systems the proposed algorithms performance is validated for different applications. The search strategies efficiency is improved and optimality of solutions can be verified. [19]By using loss sensitivity factor and by considering different network parameters, the analysis was carried out in the Radial Distribution Network. By ArithmeticOptimization Algorithm the EVCS optimal placement has been resolved. [20]

IV. MATHEMATICAL MODELING OF BACKWARD AND FORWARD SWEEP (BFS) ALGORITHM

The step-by-step procedure to be following to solve load flow problem is described as follows. For this procedure, the sending and receiving end nodes are represented with ‘s’ and ‘r’ notations. Also, ‘N’ and ‘nl’ represents the total number of nodes and lines in a specified radial distribution system.

Step1: Calculating load current

As described earlier, using KCL, the current drawn from the receiving end node ‘r’ of each of the distribution line can be calculated using respective active ‘P_r^{Load}’ and reactive ‘Q_r^{Load}’ loads, magnitude ‘Vr’ and angle ‘δr’ of the voltage at the node. The expression for this is

$$I_r^{\text{Load}} = \left(\frac{S_r^{\text{Load}}}{\overline{V_r}}\right)^* = \frac{P_r^{\text{Load}} - jQ_r^{\text{Load}}}{V_r\angle -\delta_r}; \forall r = 2,3,\ldots..N \quad (2.1)$$

Step2: Calculating total node current

The final current at each of the nodes can be calculated by adding currents of load calculated in step 1 of backward sweeping procedure. The node currents are calculated towards substation node starting from end node by following back sweeping methodology. The expression used for calculating current at ‘nq’ number nodes starting from end node ‘q’ in a lateral of given network is

$$I_{sr} = I_r^{\text{Load}} r = s+1,\ldots.q; \quad s = 1,2,3,\ldots nq \quad (2.2)$$

Step3: Calculating voltage drop in lines

After evaluating node currents, the voltage drop in line connected between nodes ‘s’ and ‘r’ having impedance ‘$Z_{sr} = R_{sr} + jX_{sr}$’ of the networks is

$$VD_{sr} = I_{sr} \times Z_{sr}; \quad \text{sr} = 1,2,3,\ldots\text{nl} \quad (2.3)$$

Step4: Calculating node voltage

After evaluating voltage drops in lines, the voltage at receiving end node ‘r’ can be evaluated using forward sweeping procedure. In this procedure, the receiving end node voltage is calculated by subtracting voltage drop from the send end node voltage. The mathematical expression used is

$$V_r = V_s - VD_{sr}; \quad s = 1,2,3,\ldots N \quad (2.4)$$

Step5: Calculation of power losses

In this, the power losses of a line connected between nodes ‘s’ and ‘r’ can be expressed as

$$P_{sr} = \overline{I}_{sr}^2 \times R_{sr} \& Q_{sr} = \overline{I}_{sr}^2 \times X_{sr} \quad (2.5)$$

Algorithm and flowchart for load flow solution

The following algorithm followed to solve load flow problem for radial distribution system.

- Step 1: Read distribution system data i.e., line resistance and reactance data, active and reactive load data.
- Step 2: Give number to the nodes as per the procedure explained in section 2.3.
- Step 3: Identify end nodes for both the main feeder and laterals.
- Step 4: Calculate node current using the Eqn (2.1).
- Step 5: Calculate the total node current using Eqn (2.2).
- Step 6: Calculate voltage drop using Eqn (2.3).
- Step 7: Calculate node voltage and there by the losses using Eqns (2.4) to (2.5).

V. MODELING OF DISTRIBUTED GENERATION

Generating stations are unable to cope with the demand to generate and transmit power on an economical and dependable scale. Distributed Generation (DG) plays a vital role in backing up the system in a reliable manner. Due to the proximal placement of DG to the consumer the chances of reactive power losses are reduced thereby increasing the system efficiency. Contrary to the belief that this placement improves efficiency it affects the system. To assess the optimal location of DG a voltage stability index (VSI) has been proposed. The location of the DG is decided based on the values derived from VSI. This study analyses the performance of individual DG's In this thesis, all types of DGs are placed individually to study the performance analysis of the system in by voltage profile improvement to reduce real and reactive power loss.

It is necessary to analyse the effect of single or multiple DG units towards the system performance. The analysis is carried out with a novel approach for simultaneous placement of optimum sizing of DG in optimal location.

Need of compensation

DG can be defined as "electric power generation within distribution networks or on the customer side of the network" [41]. Most commercially available DG technologies are wind power, solar photovoltaic, solar thermal systems, biomass, and small-scale hydro power. Appropriate location and sizing of DG units in distribution system improves the voltage profile, supplies peak load demand, minimizes line loadings, reactive power requirement, reduces the system power losses. But improper allocation and higher penetration of DG units in the distribution system leads to increase in power losses and reduces the reliability of the power system. Therefore, the incorporation of DG units in the power distribution system should be planned considering both technical and economic factors. Technical factors include: the reduction of losses, line loadings, voltage profile improvement. Economic factors include: optimal investment cost of DG units.

Reasons for widespread use of distributed generation is summed up as

- It is easier to find sites for small generators.
- Latest technology has made available plants ranging in capacities from 10 KW to 15 MW.
- Some technologies have been perfected and are widely practiced (gas turbines, internal combustion engines), others are finding wider applications in recent years (wind, solar energy) and some particularly promising technologies are currently being experimented or even launched (fuel cell, solar panels integrated into buildings).
- DG units are closer to customers so that Transmission and Distribution (T&D) costs are ignored or reduced.
- Combined Heat and Power (CHP) groups do not require large and expensive heat networks.
- Natural gas, often used as fuel in DG stations is distributed almost everywhere and stable prices are expected for it.
- Usually, DG plants require shorter installation times and the investment risks are not so high.
- DG offers great values as it provides a flexible way to choose wide ranges of combining cost and reliability.

The main objectives of DG units are:

i. To provide a continuous power supply to the load.
ii. To provide power where main grid cannot supply electric power.
iii. Provide for load growth with enhanced stability and with minimum growth of the transmission system.
iv. Make greater use of renewable energy sources.
v. Increase energy efficiency and reduce power transmission losses.
vi. Reduce pollution and greenhouse gas emissions.
vii. Increase the availability of high-power quality for sensitive loads.

There may be four types of DGs [42]:

- Type 1: only inject real power.
- Type 2: only inject reactive power.
- Type 3: inject both real and reactive power.
- Type 4: inject real power but consume reactive power.

Load flow in the presence of DGs

To study the effect of DG on a given system, it is necessary to solve load flow problem in the presence of DG. To perform this, backward and forward sweep (BFS) radial distribution load flow algorithm explained in section 2.4 is followed. But, to get an effect of DG, the current injected into the node given in Eqn (2.1) can be modified as

For Type-1 DG:

$$\bar{I}_n = \frac{P_n - P_{DG} - jQ_n}{(\bar{V}_n)^*}; n = \text{ dg node} \tag{3.1}$$

For Type-2 DG:

$$\bar{I}_n = \frac{P_n - j(Q_n - Q_{DG})}{(\bar{V}_n)^*}; n = \text{ dg node} \tag{3.2}$$

For Type-3 DG:

$$\bar{I}_n = \frac{P_n - P_{DG} - j(Q_n - Q_{DG})}{(\bar{V}_n)^*}; n = \text{ dg node} \tag{3.3}$$

For Type-4 DG:

$$\bar{I}_n = \frac{P_n - P_{DG} - j(Q_n + Q_{DG})}{(\bar{V}_n)^*}; n = \text{ dg node} \tag{3.4}$$

The objective of the work is completely relating to the TPL minimization. This is having significant impact by injecting active power into the system from the point of connection. Due to this, the local active load is supplied and hence, the active power drawn from the substation is being reduced. Due to this reason, Type-1, and Type-3 DGs are considered in this work.

VI. Optimal Location

The proposed location identification strategy of considered Type-1 and Type-3 DGs in radial distribution system is by compensating the respective active and reactive power at each node by their respective active and reactive load at that node one at a time, except the source node, the total active power losses in each case are computed using Eqn. (2.5) and the results are tabulated.

Power Loss Index

The power loss index (PLI) are calculated as

$$PLI(k) = \frac{LOSS\_REDUCTION(k) - min\_LOSS\_REDUCTION}{(max\_REDUCTION - min\_REDUCTION)} \qquad (3.5)$$

The best location of nodes for DG placement is identified by the PLI values obtained.

Where, LOSS_REDUCTION (k)is the Loss reduction with and without placement of DG at node k, max_REDUCTION is the maximum reduced loss in all the branches, min_REDUCTION is the minimum reduced loss in all the branches.

Computation procedure

The algorithmic steps of locating the DGs in each radial distribution is given below

Step 1: Read the system line and load data i.e the line resistance and reactance and the active and reactive power loads at each node.

Step 2: Calculate the total active power loss by running the load flow for base case system.

Step 3: At each node the active and reactive load is compensated by injecting the active and reactive powers of DGs which is equal to load reactive power, and then run the load flows for calculating the total active power losses in each case.

Step 4: Calculate the reduction in total active power losses in each case.

Step 5: Calculate the PLI using eq. (3.5)

Step 6: Arrange the calculated PLI values in descending order.

Step 7: Identify the optimal number of DG(s) for a given system, at first, one DG is installed in highest PLI valued node.

Step 8: This procedure is repeated with two DGs in top two locations and so on.

Step 9: Finally, identify the optimal number of DGs based on the TPL values.

Step 10: Stop.

VII. Results and Analysis

This section presents the results and analysis with regards to the effect of different types of DG units on system performance. For this, standard 33-node and 69 node test systems are considered. The entire analysis is performed by developing MATLAB code on a computing system with 4 GB RAM and intel i7 processor.

In order to highlight the impact of compensator(s), the analysis is divided in to three cases.

- Case-1: Base case results (without DG)
- Case-2: Optimal location identification procedure
- Case-3: Effect of single and multiple DG unit(s)

Test system-1 (RDS-33 node system)

The 33- node system consists of 33 nodes and 32 distribution lines with load of 3695 kW and 2300 kVAr. The data is taken from [43]. The effect of proposed methodology is tested for the considered three cases as follows:

Case-1: Base case results (without DG)

In this case, the load flow problem is solved using existing and proposed load flow methodologies and obtained results are tabulated in Table.4.1. From this table, it is observed that, the voltage profile of the proposed methodology is slightly higher when compared to the existing methodology. This is due to the updating of system parameters locally as well as globally without considering any simplifications. The variation of voltage magnitude is shown in Fig.4.1.

Table.4.1 Bus voltage results of case-1 for 33-node system

Node No	Existing method [43]		Proposed Method	
	Voltage Magnitude (p.u.)	Voltage Angle (deg)	Voltage Magnitude (p.u.)	Voltage Angle (deg)
1	1	0	1	0
2	0.997	0.0148	0.997394	0.012626
3	0.983	0.0985	0.985124	0.086201
4	0.9755	0.1658	0.978804	0.144949
5	0.9682	0.2341	0.972559	0.204239
6	0.9498	0.1446	0.956996	0.132839
7	0.9463	-0.0872	0.95404	-0.05577
8	0.9415	-0.0539	0.950016	-0.02249
9	0.9352	-0.1312	0.944819	-0.0775
10	0.9294	-0.198	0.940011	-0.12368
11	0.9286	-0.1914	0.939306	-0.11702
12	0.9271	-0.1812	0.938079	-0.10633
13	0.921	-0.2778	0.933071	-0.17389

14	0.9187	-0.3585	0.931213	-0.23435
15	0.9173	-0.3976	0.930085	-0.26201
16	0.916	-0.4223	0.928928	-0.28138
17	0.914	-0.5017	0.927212	-0.34582
18	0.9134	-0.512	0.926699	-0.35382
19	0.9965	0.0039	0.996874	0.002018
20	0.9929	-0.0636	0.993354	-0.06371
21	0.9922	-0.0831	0.992661	-0.08273
22	0.9916	-0.1036	0.992034	-0.10273
23	0.9794	0.0673	0.981744	0.057271
24	0.9727	-0.022	0.975454	-0.02591
25	0.9694	-0.0662	0.97232	-0.06699
26	0.9479	0.1858	0.955354	0.166334
27	0.9453	0.2443	0.953172	0.214013
28	0.9339	0.3386	0.943435	0.285267
29	0.9257	0.4249	0.93644	0.351835
30	0.9222	0.5338	0.933415	0.440816
31	0.918	0.4534	0.929872	0.369911
32	0.9171	0.4312	0.929092	0.350555
33	0.9168	0.4237	0.928851	0.344061

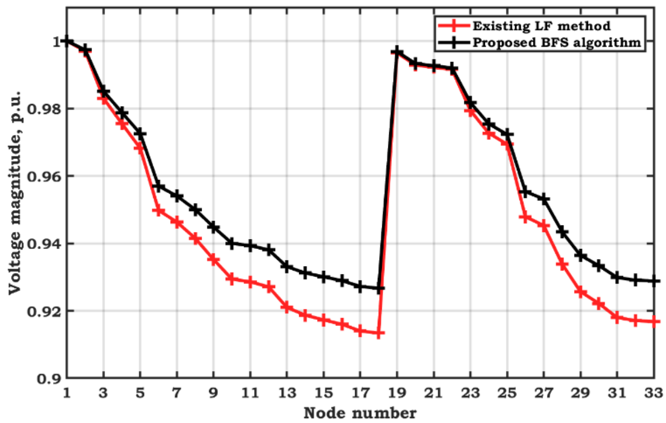

Fig.4.1 Variation of voltage magnitude in case-1 for 33 node system

Similarly, the active and reactive power losses in each of the branches for the existing and proposed load flow methodologies are tabulated in Table.4.2 and the corresponding real power loss variation in all the branches is shown in Fig.4.2. From this table, it is noticed that, the power flow through some of the lines has been altered due to the variation of voltage magnitude and there by the power losses in those branches. This leads to the variation of total active and reactive power losses.

Table.4.2 Line power loss results of case-1 for 33-node system

Branch No	Sending Node	Receiving Node	Existing method [43]		Proposed Method	
			P_{loss} (KW)	Q_{loss} (KVAr)	P_{loss} (KW)	Q_{loss} (KVAr)
1	1	2	12.1927	6.2154	11.9153	6.073961
2	2	3	51.5711	26.2668	50.2615	25.59972
3	3	4	19.7934	10.0806	19.146	9.750857
4	4	5	18.5931	9.4697	17.95985	9.147226
5	5	6	38.0256	32.8256	36.70842	31.68847
6	6	7	1.9131	6.3238	1.813457	5.994482
7	7	8	4.8342	1.5976	4.543083	1.501376
8	8	9	4.1773	3.0012	3.87369	2.78304
9	9	10	3.5575	2.5216	3.283174	2.327154
10	10	11	0.5531	0.1829	0.50762	0.16783
11	11	12	0.8802	0.2911	0.802705	0.265424
12	12	13	2.6638	2.0958	2.404703	1.891984
13	13	14	0.7286	0.959	0.64905	0.854334
14	14	15	0.3569	0.3176	0.302396	0.269138
15	15	16	0.2813	0.2054	0.273371	0.199635
16	16	17	0.2515	0.3358	0.244323	0.326206

17	17	18	0.0531	0.0416	0.051587	0.040452
18	2	19	0.161	0.1536	0.160818	0.153463
19	19	20	0.8322	0.7498	0.831441	0.749192
20	20	21	0.1008	0.1177	0.100668	0.117606
21	21	22	0.0436	0.0577	0.043595	0.057641
22	3	23	3.1812	2.1737	3.163098	2.16131
23	23	24	5.1432	4.0613	5.113413	4.037774
24	24	25	1.2873	1.0073	1.279614	1.001269
25	6	26	2.594	1.3213	2.533667	1.290548
26	26	27	3.3211	1.6909	3.242487	1.650907
27	27	28	11.2766	9.9424	11.00548	9.703324
28	28	29	7.818	6.8108	7.628354	6.645641
29	29	30	3.8881	1.9805	3.793018	1.93201
30	30	31	1.5928	1.5742	1.552183	1.534024
31	31	32	0.2131	0.2484	0.207622	0.241992
32	32	33	0.0132	0.0205	0.012823	0.019938
Total Power Loss			**201.8927**	**134.6416**	**195.4085**	**130.1779**

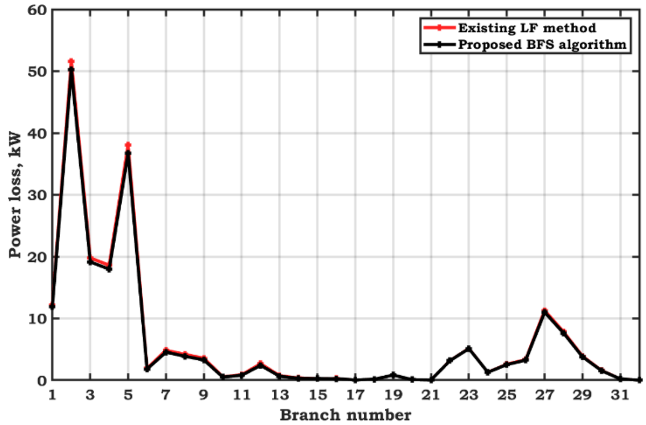

Fig.4.2 Variation of power losses in case-1 for 33 node system

Similarly, the consolidated results for this case are tabulated in Table.4.3. From this table, it is identified that, due to the effectiveness of the proposed load flow methodology, the total active power losses are decreased when compared to the existing load flow methodology. Similarly, with the proposed method, the low voltage node is identified to be 18, which is farther from the source node. It is also observed that, due to the reduced complexity of mathematics and minimized number of mathematical computations in the proposed method, computational time taken is reduced when compared to existing load flow method.

Table.4.3 Consolidated load flow results in case-1 for 33 node system

Description	**Existing radial load flow method [43]**	**Proposed BFS method**
Total active power losses (kW)	201.8927	195.4085
Minimum voltage node	18	18
Minimum voltage (p.u)	0.9134	0.926699
Number of Iterations	12	8
Convergence time, sec	25.3746	18.2736

Case-2: Optimal location identification procedure

In this case, to identify the effect of DGs on system performance, the optimal locations to install DGs are identified using power loss index (PLI) analysis. For this, PLI values are evaluated at each of the node using the procedure given in section 3.5 and are arranged in descending order. Then, one DG is installed in highest PLI valued location and the DG settings (maximum of 80% total active load on a given system) and total power losses are evaluated using the procedure given in section 2.5. This process is repeated for two, three DG locations and the total power losses are evaluated. Finally, the number of locations which yields minimum power losses are considered as the optimum number of DG locations. The descending ordered PLI values at the system nodes are tabulated in Table.4.4. From this table, it is identified that, the top three highest PLI valued nodes are 30, 32 and 8. The variation of PLI values is shown in Fig.4.3.

Table.4.4 Power loss index values of case-2 for 33-node system

S. No	**Node No**	**PLI value**
1	30	1.000000
2	32	0.951469
3	8	0.365888

S. No	Node No	PLI value
4	7	0.348797
5	14	0.347223
6	31	0.311913
7	29	0.292294
8	24	0.231799
9	25	0.230196
10	33	0.181112
11	18	0.165854
12	13	0.15007
13	12	0.14367
14	11	0.122283
15	4	0.119128
16	16	0.083864
17	17	0.083572
18	27	0.081578
19	10	0.080092
20	26	0.077954
21	9	0.074834
22	28	0.073827
23	6	0.058907
24	5	0.056248
25	23	0.050883
26	15	0.04016
27	3	0.036502
28	2	0.006445
29	20	0.005298
30	21	0.004999
31	22	0.00436
32	19	0.003284

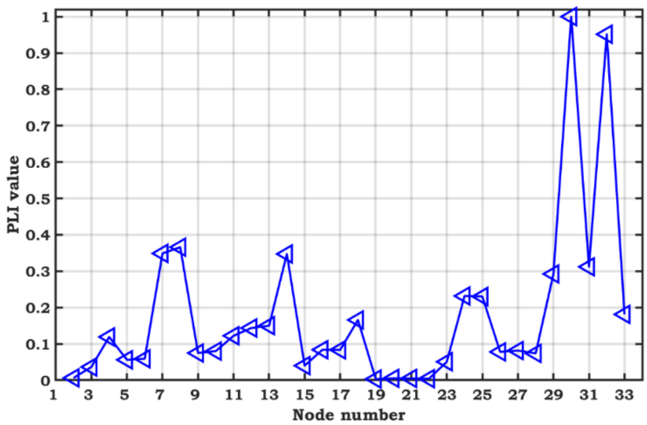

Fig.4.3 Variation of PLI values in case-2 for 33 node system

Case-3: Effect of single and multiple DG unit(s)

For this case, the DG size is fixed at 80% of total active load presented in Table.4.5. Further, the analysis with DG is performed with these sizes.

Table.4.5 DG sizes for 33-node system

S. No	Node Number	kW		kVAr	
		Active load	DG active Power	Reactive load	DG reactive Power
1	30	200	160	600	480
2	32	210	168	100	80
3	8	200	160	100	80

The detailed summary of the test results for single and multiple DG unit's placement are tabulated in Table.4.6. From this table, it is observed that, 45.3099 kW losses are reduced with three Type-1 DGs and 86.3004 kW losses are reduced with three Type-3 DGs when compared to without DGs. It is also observed that, minimum voltage magnitude is obtained at node 18 because that node is far away from the substation. And, the number of iterations and convergence time taken is increased due to increased mathematical computations in the presence of DGs.

Table.4.6 Summary of test results for DG placement of 33-node RDS

Description	Without DG	With Type-1 DG			With Type-3 DG		
DG locations	-	30	30, 32	30, 32, 8	30	30, 32	30, 32, 8
TPL (kW)	195.4085	178.4281	161.8046	150.0986	143.9401	123.6419	109.1081
Vmin_node	18	18	18	18	18	18	18
Vmin (p.u)	0.926699	0.92848	0.93032	0.932934	0.932011	0.934532	0.938118
Number of Iterations	8	9	9	9	9	9	9
Convergence time, sec	18.2736	19.4981	19.8635	19.9738	20.1792	20.6728	21.2001

In this case, the load flow problem is solved with single and multiple Type-1 and Type-3 DG units using proposed BFS load flow algorithm and obtained variation of voltage magnitude is shown in Fig.4.4. From this variation, it is observed that, the voltage profile of the proposed methodology is enhanced in the presence of Type-3 DG when compared to Type-1 DG and without DG. And, the voltage profile is further enhanced with multiple Type-3 DG units when compared to single DG units. This is due to the injection of sufficient active and reactive power in to the system from point of connection.

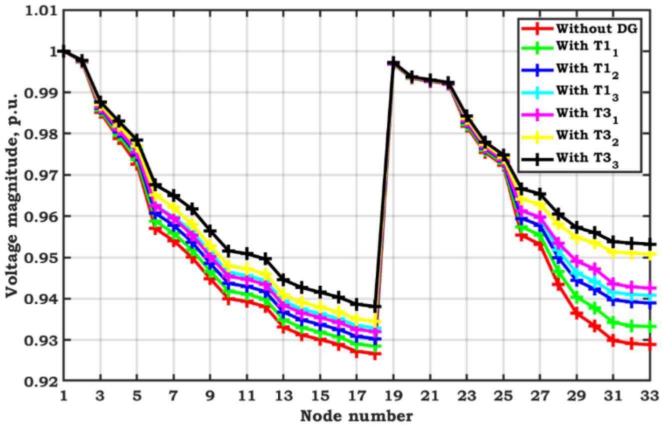

Fig.4.4 Variation of voltage magnitude in case-3 for 33 node system

Similarly, the active and reactive power losses in each of the branches with single and multiple Type-1 and Type-3 DG units using proposed BFS load flow algorithm and the corresponding real power loss variation in all the branches is shown in Fig.4.5. From this result, it is noticed that, the power flow through the lines which are connected nearer to DG connected nodes is increased due to the power injections by DG units and there by the power losses in those branches are decreased. This leads to the variation of total active and reactive power losses.

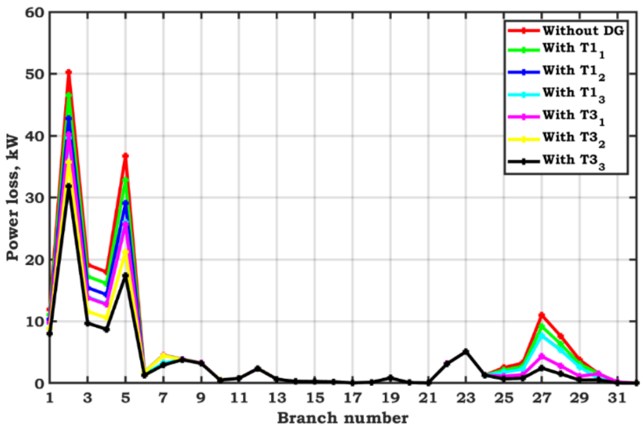

Fig.4.5 Variation of power losses in case-3 for 33 node system

VIII. Conclusions

In this paper, a new load flow formulation to solve load flow problem for radial distribution systems has been presented. This methodology works based on the backward and forward sweep methodology and there by the computational time has been decreased when compared to existing methods. Later, the effect of DGs on system performance has been analyzed to enhance voltage magnitude at the node where DG is connected. for this, the optimal location has been identified using developed PLI analysis. Further, the effect of multiple DGs on system performance has been analyzed by placing them in optimal locations obtained from PLI analysis. From these results, it has been noticed that, the losses are considerably reduced in the presence of multiple DG units when compared to single DG unit. Also, it has been identified that, Type-3 DG impact is more when compared to Type-1 DG units.

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