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Novel Technique for Optimal Placement and Sizing of DG in 3-Phase Unbalanced Radial Secondary Distribution System

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***Abstract:** The optimum position and volume of the Distributed Generation to be planned in the unbalanced radial distribution network (URDN) is critical to minimize power losses. Incorrect size and location may enhance the power losses and voltage regulation. This paper investigates the operations of the distribution system and aims to develop a new technique to solve the problem of placement and sizing distributed generation to minimize power loss, improving the profile of voltage. A Novel Sensitivity Analysis is used to estimate the optimal position and volume of DG units to be installed in a URDN. The proposed technique is validated on the 25 bus test system to illustrate and evaluate the correctness. The results are confronted with the results of distinct methods available in the literature. The performance of the proposed method is considered to be better in terms of the quality of the solutions than the other classical techniques..*

***Keywords—** Distributed Generation, unbalanced radial distribution network, optimum DG location, and capacity.*

I. INTRODUCTION

There are many techniques available to minimize the losses, such as placement of DG, placement of capacitor, load management, Reconfiguration of Network, and so on. DG technology attracts more attention because of the global concerned about the energy crisis and advancements in Technology. Most of these algorithms are based on artificial intelligence and heuristic techniques.

Ravi Teja Bhimarasetti, Ashwani Kumar [1] proposed a simple and efficient method to minimize the losses related to the real component of current by keeping the optimal size of DG at the appropriate bus. This approach first recognized the DG capacity at all busses by optimizing the equation for saving losses. The bus where the maximum loss saving can be considered as an optimum location and the DG size at this optimum location is the optimum size. A useful technique for finding the best site and DG size by using the variational algorithm and voltage index analysis to minimize the losses is proposed [2] by Thiruveedula Ramana, Ganesh.V, Sivanagaraju.S. V.V.S.N. Murthy, A Kumar [3] presents a strategy which is based on united power loss sensitivity for DG capacity, Novel approach for DG site.

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The proposed method implemented on two kinds of DG, one is operating at upf, and the other is at 0.9 power factor lagging and can justify that there is a significant decrease in power losses. The voltage regulation also enhanced by including a DG operated at 0.9 pf lag than DG at upf.

A novel algorithm presented in [4] is based on the framework of the diagonal band copula method. In this Monte Carlo method is employed to evaluate an hourly or seasonal model for type-I DG, type-III DG, and the system demand. Furthermore, a supervised BB-BC algorithm proposed to precisely determining the optimum location of the DG in the unbalanced distribution network to reduce the energy losses. A solution for the effect of DG on real power losses for consumers connected to the radial distribution system depends on the exact allocation of losses in [5], a new algorithm proposed for DG location and sizing. The algorithm is based on a PSI to identify the most sensitive bus and minimum power losses. The exact loss allocation plan is based on branch current flow and guarantees that every customer only has designated losses at branches for which current it provides. For minimizing the losses and enhancement of bus voltages in the distribution network by optimally placed DSTATCOM and DG, and the proposed scheme suggested that both DSTATCOM and DG at the same bus as present in the literature. By placing DSTATCOM improves only voltage profiles, and the reduction in the losses is very less and installing the DG causes losses reduced significantly, but voltage profile improvement is minimal. Optimum capacitor size and position is to find by using the Index Vector method different types of loading conditions, and two kinds of load unbalances are considered to investigate their impact on optimum capacitor size and position as per literature. Metaheuristic techniques can be used to optimize the location and size of DG and kVAR allocation for minimizing the losses in the unbalanced radial distribution system. A novel nature-influenced Ant Lion optimization technique, which is based on the hunting nature of ant lions is used to find the optimum size of DG. They concluded that DG running at 0.9 pf gives more reliable results. A new Bus voltage deviation technique, which is a precise and straightforward approach to place multiple DGs in a radial unbalanced distribution network for optimal location and size to enhance the voltage regulation and minimizing the losses. Hybrid optimization that combines GSA and GAMS optimization to integrate renewable DGs and reconfigure to reduce losses and boost voltage profile. The unpredictability of DG generation and load has been taken into account.

GA technique proved to be the slowest while GSA the fastest. Multi-stage decision problem is solved for Optimal DGs using Reinforcement Learning, elephant herding optimization, WOA-SSA algorithm, and IPSO algorithm for reducing the losses in the system were proposed in [7].

II. OPTIMAL LOCATION AND SIZE OF DG USING NOVEL METHOD

After executing the three phase load flow solution [6] on URDS for this paper, two types of DG's are considered. Type-I happened to be photo voltaic (PV) generation and type-III happened to be a DG which combines type-I and type-III(capacitor) [7].

Let us consider

$$TAPL = Total\ Active\ Power\ Losses.$$

$$TQPL = Total\ Reactive\ Power\ Losses$$

The copper losses in an unbalanced distribution system associated with both real and reactive part of line current are obtained by [1]

$$ST_{Loss} = \sum_{k=1}^{n-1}[R_{aak}(I_{ark}^2 + I_{aik}^2) + R_{bbk}(I_{brk}^2 + I_{bik}^2) + RcckIcrk2+Icik2+Rabk-IarkIbrk-IaikIbik+3IarkIbik -3IaikIbrk+Rbck-IbrkIcrk-IbikIcik+3IbrkIcik-3Ibik Icrk+Rcak-IcrkIark-IcikIaik+3IcrkIaik-3IcikIark] ---------(1)$$

Where I_{ark}, I_{brk}, and I_{crk}, are the active component of the current in a,b, and c phases.I_{aik}, I_{bik}, and I_{cik}, are the reactive component of the current in a,b and c phases.

Total Active Power loss can be divided into two components: because of the real part of the line current is $TAPL_a$, and the imaginary part of the line current is $TAPL_r$.

Total Active Power loss due to the real part of current can be minimized by placing the DG at appropriate locations. When Type-I DG is connected at bus 'g', the DG current flows towards the source bus and the respective branches currents reduce, but, the currents in the rest of the branches remain unchanged. Let β be the set of lines from origin node to the g[th] bus. Then the current of all lines belongs to β will be altered. Type-I DG can only supply the real part of current. Therefore, real power loss associated with the real part of line current will be changed after installing the DG.

Total Active power loss associated with real component of current is

$$TAPL_a = \sum_{k=1}^{n-1}[R_{aak}I_{ark}^2 + R_{bbk}I_{brk}^2 + R_{cck}I_{crk}^2 + R_{abk}\left(-I_{ark}I_{brk} + 3IarkIbik-3IaikIbrk + R_{bck}\left(-I_{brk}I_{crk} + \sqrt{3}I_{brk}I_{cik} - \sqrt{3}I_{bik}I_{crk}\right) + R_{cak}\left(-I_{crk}I_{ark} + \sqrt{3}I_{crk}I_{aik} - 3IcikIark\right] ----------(2)$$

By deploying DG at bus 'g', modified currents of branches in set β are

$$I_{ark(new)} = I_{ark} + G.I_{DGa}$$
$$I_{brk(new)} = I_{brk} + G.I_{DGb}$$
$$I_{crk(new)} = I_{crk} + G.I_{DGc}$$

Where G=1; if branch ∈ β

= 0; otherwise.

The real power loss with deployment of DG can be obtained as,

$$\begin{aligned} TAPL_a^{DG} = \sum_{\substack{k=1\\k\in\beta}}^{n-1} [& R_{aak}(I_{ark} + I_{DGa})^2 + R_{bbk}(I_{brk} + I_{DGb})^2 \\ & + R_{cck}(I_{crk} + I_{DGc})^2 \\ & + R_{abk}\{-(I_{ark} + I_{DGa})(I_{brk} + I_{DGb}) \\ & + \sqrt{3}(I_{ark} + I_{DGa})I_{bik} - \sqrt{3}I_{aik}(I_{brk} \\ & + I_{DGb})\} \\ & + R_{bck}\{-(I_{brk} + I_{DGb})(I_{crk} + I_{DGc}) \\ & + \sqrt{3}(I_{brk} + I_{DGb})I_{cik} - \sqrt{3}I_{bik}(I_{crk} \\ & + I_{DGc})\} \\ & + R_{cak}\{-(I_{crk} + I_{DGc})(I_{ark} + I_{DGa}) \\ & + \sqrt{3}(I_{crk} + I_{DGc})I_{aik} - \sqrt{3}I_{cik}(I_{ark} \\ & + I_{DGa})\} \\ & + \sum_{\substack{k=1\\k\notin\beta}}^{n-1}[R_{aak}(I_{ark})^2 + R_{bbk}(I_{brk})^2 \\ & + R_{cck}(I_{crk})^2 + R_{abk}\{-(I_{ark})(I_{brk}) \\ & + \sqrt{3}(I_{ark})I_{bik} - \sqrt{3}I_{aik}(I_{brk})\} \\ & + R_{bck}\{-(I_{brk})(I_{crk}) + \sqrt{3}(I_{brk})I_{cik} \\ & - \sqrt{3}I_{bik}(I_{crk})\} \\ & + R_{cak}\{-(I_{crk})(I_{ark}) + \sqrt{3}(I_{crk})I_{aik} \\ & - \sqrt{3}I_{cik}(I_{ark})\}\,] --------(3) \end{aligned}$$

The loss saving $TAPL_{save}$ is the difference between eqns. 2 & 3 and is given by

$$TAPL_{Save} = -\sum_{\substack{k=1\\k\in\beta}}^{n-1}[R_{aak}(I_{DGa}^2 + 2I_{ark}I_{DGa}) + R_{bbk}(I_{DGb}^2 + 2I_{brk}I_{DGb}) + R_{cck}(I_{DGc}^2 + 2I_{crk}I_{DGc}) + R_{ab}\{-(I_{ark}I_{DGb} + I_{brk}I_{DGa} + I_{DGa}I_{DGb}) - \sqrt{3}I_{aik}I_{DGb} + 3IbikIDGa + R_{bc}\{-(I_{brk}I_{DGc} + I_{crk}I_{DGb} + I_{DGb}I_{DGc}) - \sqrt{3}I_{bik}I_{DGc} + 3IcikIDGb + R_{ca}\{-(I_{crk}I_{DGa} + I_{ark}I_{DGc} + I_{DGa}I_{DGc}) - \sqrt{3}I_{cik}I_{DGa} + 3IaikIDGc] ----------(4)$$

The required current to be generated by DG can be obtained by differentiating the eqn. 4 and is given in eqn.5.

β is the branches set connected between source bus and the bus connected by DG.

$$\begin{bmatrix} I_{DGa} \\ I_{DGb} \\ I_{DGc} \end{bmatrix} = \sum_{\substack{k=1\\k\in\beta}}^{n-1} \begin{bmatrix} 2R_{aak} & -R_{abk} & -R_{ack} \\ -R_{bak} & 2R_{bbk} & -R_{bck} \\ -R_{cak} & -R_{cbk} & 2R_{cck} \end{bmatrix}^{-1} * \sum_{\substack{k=1\\k\in\beta}}^{n-1} \begin{bmatrix} -2R_{aak}I_{ark} + R_{abk}I_{brk} + R_{ack}I_{crk} \\ -\sqrt{3}R_{abk}I_{bik} + \sqrt{3}R_{ack}I_{cik} \\ R_{bak}I_{ark} - 2R_{bbk}I_{brk} + R_{bck}I_{crk} \\ -\sqrt{3}R_{bck}I_{cik} + \sqrt{3}R_{bak}I_{aik} \\ R_{cak}I_{ark} + R_{cbk}I_{brk} - 2R_{cck}I_{crk} \\ -\sqrt{3}R_{cak}I_{aik} + \sqrt{3}R_{cbk}I_{bik} \end{bmatrix} ---(5)$$

The Appropriate DG size is,

$$P_{DGa} = I_{DGa} * |V_a| \;\; ---------(6)$$

$$P_{DGb} = P_{DGc} = P_{DGa} \;\; ---------(7)$$

Here $|V_a|$ is the phase-A voltage magnitude at the gth bus. Calculate the loss saving for all buses by using the eqn.4. The bus having peak loss saving can be treated as an appropriate bus for deploying the DG, and the capacity is the optimum DG capacity.

III. ECONOMIC ANALYSIS

The cost of energy losses and cost component of DG power has been calculated based on the mathematical model represented as

The cost of annual energy loss (TCL) is given by [15]

$$TCL = (Total\ Power\ Loss) * (x + y * loss\ facotr * 8760 --------(8)$$

$$Where\ x = Annaual\ cost\ of\ power\ loss\ \$/\mathrm{kW},$$

$$y = Annual\ cost\ of\ energy\ \$/\mathrm{kWh}.$$

$$Loss\ factor = k1 * load\ factor + (1 - k1) * load\ factor^2 ----- \qquad (9)$$

The values of the coefficients for finding Loss factor are:

$k1 = 0.2,$

$Load\ Factor = 0.47,$

$x = 57.6923\ \$/\mathrm{kW}$ &

$y = 0.00961538\ \$/\mathrm{kWh}.$

DG cost for active power is given by

$$cost(pdg) = a * pdg^2 + b * pdg + c\ \$/\mathrm{MWh} --(10)$$

Where a, b & c *are the cost coefficients and are taken as*

$a = 0,$

$b = 20$ &

$c = 250$

IV. ALGORITHM

Step 1: Read Line and load data of the test system.
Step 2: Calculate the bus voltages, branch currents, and losses by running the power flow without placing the DG.
Step 3: Calculate the cost of the power losses.
Step 4: Choose a bus and calculate the current delivered by DG by using the eqn. 5 to obtain minimum losses.
Step 5: By using DG currents and eqn.4, determine the loss saving. Find the DG size by utilising the eqns. 6 & 7.
Step 6: Repeat steps 4 & 5 for every bus present in the network except slack bus.
Step 7: The bus at which the power loss saving is maximum is the candidate bus to place the DG.
Step 8: Run the power flow by pacing the DG.
Step 9: Calculate the cost of power losses obtained in step 8 by using eqn. 8 and also find the cost of DG by using eqn. 10

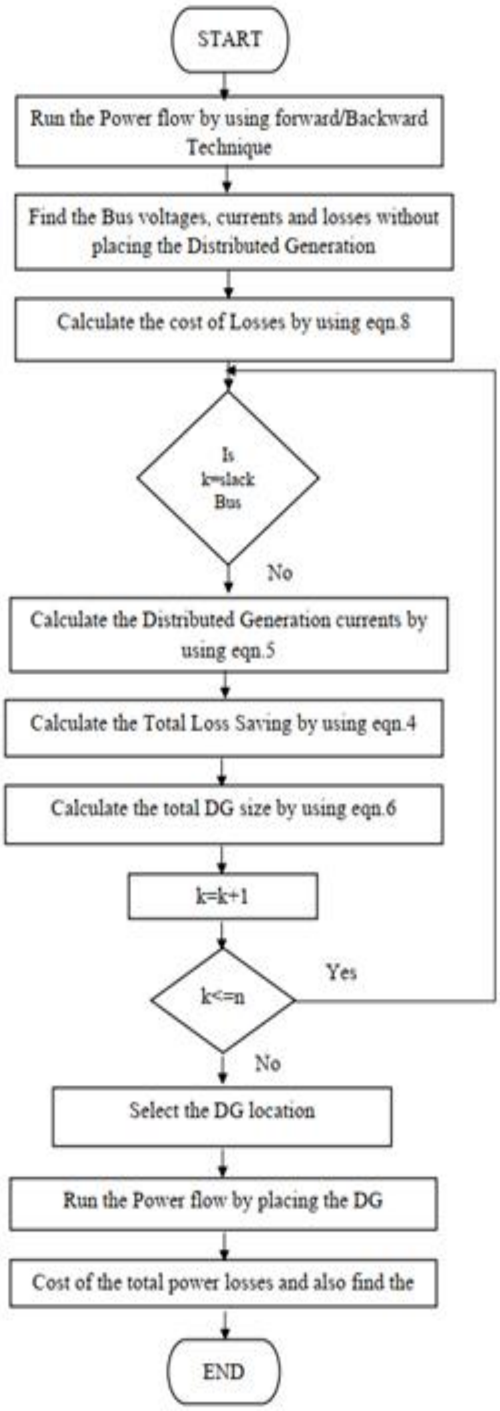

Fig.1.Flowchart for optimal sizing and placement of DG.

V. RESULTS AND DISCUSSIONS

The suggested approach has been validated on 25 bus [1] URDN that its load is star-connected load, and the load patterns are constant power (PQ), constant current (I), and constant impedance (Z). Simulations were carried out regardless of the transformer and regulator. The results of 25 bus system are compared with the method mentioned in [1] at normal loading conditions.

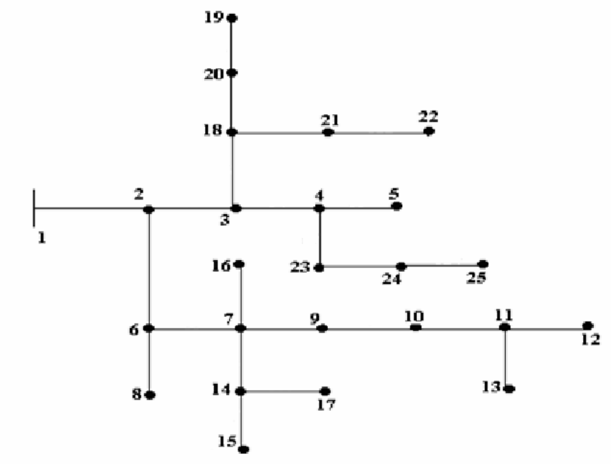

Fig.2 Single line diagram of 25-bus System

Fig.2. Shows the line diagram of 25 bus system [1]. The 25 bus system has 24 branches. The total active power load in each phase is 1073.3,1083.3 & 1083.3 kW. The whole reactive power load each phase is 792, 801 & 800 kVAr. For 25 bus system without deploying DG, the active and reactive power losses are 149.9420 kW and 167.1490 kVAr, respectively.

With Type-I DG

The active & reactive power losses with the deployment of Type-I DG were 79.4616 kW and 86.0321 kVAr, respectively. A comparison of results is tabulated in Table I and Fig. 3,4 & 5 shows a,b & c phase voltage profile under Normal load condition without DG and with type-I DG, respectively. The optimum location for the 25 bus system is found to be 7. The size of the Type-I DG is obtained as 656.91 kW. The magnitudes of minimum voltages in a,b & c phases before installing DG are 0.9284,0.9284,0.9366, and after installing DG are 0.9527,0.9532,0.9557 occurs at the bus no 12.

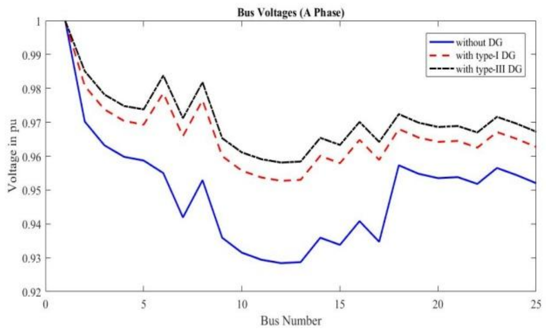

Fig.3 Voltage profile (A Phase) of 25-bus System

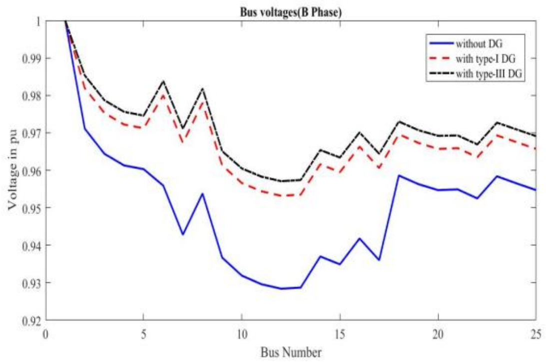

Fig.4 Voltage profile (B Phase) of 25-bus System

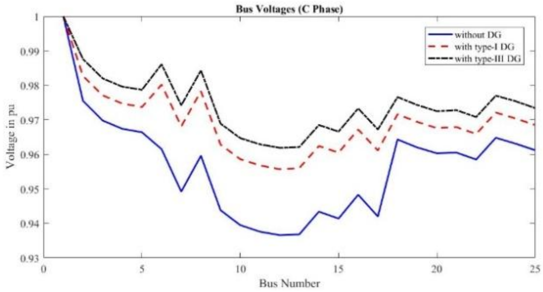

Fig.5 Voltage profile (C Phase) of 25-bus System

With Type-III DG

The active & reactive power losses with the deployment of Type-III DG were 43.5151 kW and 43.8673 kVAr, respectively. A comparison of results is tabulated in Table II and Fig. 3,4 & 5 shows a,b & c phase voltage profile under Normal load condition without DG and with type-III DG, respectively. The optimum location for the 25 bus system is found to be 6. The size of the Type-III DG is obtained as 693.0756+j519.8067 kVA. The magnitudes of minimum voltages in a,b & c phases before installing DG are 0.9284,0.9284,0.9366, and after installing DG are 0.9717, 0.9714, 0.9746 occurs at the bus no 12.

VI. CONCLUSION

In this paper, a Novel Sensitivity Analysis is proposed to pre-determine the optimum location and size of DG units in the unbalanced radial secondary distribution system to decrease the system active power losses and enhance voltage regulation. In addition, a simplified way of evaluating the load flow technique is used. The proposed method was tested on 25 bus URSDS. The results showed that an improvement in the voltage regulation and real power losses because of the DG placement. It is observed that more reduction in losses is seen with type-III DG.With type-I ,Real losses are reduced by 47.53,46.67 & 46.79 % and reactive losses are reduced by 48.96,48.05 & 48.54 % in phases a,b & c respectively . With type-III losses are reduced by 71.78,71.35 & 69.47 % and reactive losses are reduced by 73.92,73.50 & 73.83 % in phases a,b & c respectively. Results obtained are compared with the results available in the literature. The algorithm proposed can be used to any practical distribution network.

TABLE I Comparison Of Results for a 25-bus system with Type-I DG

Description	**Without DG**			**With Type-I DG (Proposed Method)**			**With Type-I DG [1]**		
	Ph-A	***Ph-B***	***Ph-C***	***Ph-A***	***Ph-B***	***Ph-C***	***Ph-A***	***Ph-B***	***Ph-C***
Real Power Loss (kW)	43.59	45.64	34.32	27.6528	29.5499	22.2589	27.8813	29.3626	22.3349
% Real Power Loss Reduction	-	-	-	36.56	35.25	35.14	36.03739	35.66477	34.92162
Reactive Power Loss (kVAr)	49.99	45.58	48.58	29.7067	27.6769	28.6485	30.2769	27.9116	29.1619
% Reactive Power Loss Reduction	-	-	-	40.57	39.28	41.03	39.43409	38.76349	39.97139
Total Real Power Loss (kW)	123.55			79.46			79.5789		
Total Reactive Power Loss (kVAr)	144.15			86.03			87.3506		
Minimum Voltage(Per Unit)	0.9371	0.9381	0.9442	0.9617	0.9627	0.9649	0.9605	0.9611	0.9629
DG Location	-	-	-	7			7		
DG Size	-	-	-	656.93			647.916		
Energy losses cost ($)				6396.15			6405.722		
Cost of DG ($/MW h)	-	-	-	13.39			13.21		

TABLE II Comparison Of Results for a 25-bus system with Type-III DG

Description	With Type-III DG (Proposed Method)			With Type-I DG [Ref 2]		
	Ph-A	*Ph-B*	*Ph-C*	*Ph-A*	*Ph-B*	*Ph-C*
Real Power Loss (kW)	14.8717	15.8743	12.7691	32.01	33.39	25.04
% Real Power Loss Reduction	71.78	71.35	69.47	39.39	39.77	40.18
Reactive Power Loss (kVAr)	15.1797	14.1184	14.5692	37.08	33.66	35.40
%Reactive Power Loss Reduction	73.92	73.50	73.83	36.42	36.83	36.43
Total Real Power Loss (kW)	43.5151			90.39		
Total Reactive Power Loss (kVAr)	43.8673			106.14		
Minimum Voltage(Per Unit)	0.9717	0.9714	0.9746	0.9504	0.9511	0.9557
DG Location	7			7		
DG Size(kW)	693.0756+j519.8067			215 @ 0.85 p.f		
Energy losses cost ($)	3502.757			7275.9627		
Cost of DG ($/MW h)	14.11			4.55		

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