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Placement of Fixed Size Diesel Generators in IEEE 12 Bus Radial Distribution System to Improve Voltage Stability

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Abstract: ***Distributed Generation (DG) is small capacity generating units directly associated to the distributed system. With the penetration of distributed generators nearby the consumer load center support to the distribution system will be enhanced. The Distributed Generation involves both Renewable & sustainable sources of energy to engender power in order to appease the ever increasing energy requirement. Suitable location and capacity of DG units will benefit the achievement of active power system network. The voltage profile and Real power line loss and Reactive power line loss reduction can also be improved with suitable location and allocation of DG. This work proposes a new Simulation method for the placement of fixed Size Diesel Generator in IEEE 12 bus radial distribution system stationed on Voltage stability index and Transmission line losses. This index is progressed by acknowledging steady state node voltages cited in Per Unit.***

Keywords: ***Voltage Stability, ABVSI, IEEE 12BUS & MATLAB/SIMULINK***

I. INTRODUCTION

The decentralization of the conventional electrical power system has emerged with more challenges for researchers, academicians and industrialist to develop new intelligent technologies. Distributed generation is an evolving technology to supply the ever increasing demand of electrical power. The term “Dispersed Generation” refers to small capacity electric power generation units which are placed close to the consumers. From the literature survey the proper positioning, capacity and type of DG units maximizes the advantages. The integration of DGs will not only provides technical support to the distribution system, also provides economic benefits. Technical benefits include voltage profile improvement, reduction of real and reactive power line losses, increase in system efficiency, enhancement in reliability of system, Enhanced power factor of the system and hence improving the power quality of the distribution network. The restructuring of existing power system with ever increasing load demand is not required hence it provides economical advantage comprises reduction in power transmission pricing, decrease in transmission and distribution congestion, and enhanced performance of the utilities which are deregulated. Due to the larger integration of non-conventional DGs more environmental benefits like reduction in pollutants emission, noise pollution and fuel saving can be achieved [1-5]. Several researchers, academicians and industrialist have been working to find most appropriate location and sizing of Distributed Generators to avail the maximum benefits [6]. On other hand, failing to place and size the DGs appropriately can have more negative impact on the overall enforcement of distribution network. The negative impacts are increased short circuit MVA level, the voltage rise, poor efficiency and increase in system transmission line losses. Therefore, in order to avail maximum benefit, it is required to obtain suitable location and allocation of Distributed Generating units and its technology. In this context, numerous techniques like Numerical, analytical and heuristic methods are suggested to find the optimal location and size of Distributed Generators with single and multiple objective functions. Distributed Generators capacity varies from a few kilowatts to less than ten Megawatts. Distributed generation resources can be classified into Non-conventional and conventional. Several DG technologies with their size are shown in Table-I.

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Table-I: DG Technologies

Sl. No.	DG Type	Size
1	Micro-Turbines	A few kW to several hundred MW
2	Fuel cells	A few tens of kW to a few MW
3	Photovoltaic cells	A few W to several hundred KW
4	Wind turbines	A few hundred W to a few hundred MW
5	Combustion diesel engines	A few kW to several hundred MW

Many scholars have proposed several intelligent optimization algorithms in recent years to obtain the coordinated optimal DG resources and placement and sizing of capacitor in radial distribution systems to obtain maximum advantages such as Power Stability Index(PSI) based method[8], (FPA) Flower pollination optimization technique [9], (PSO) particle swarm optimization [10, 11], (DPSO) discrete particle swarm optimization [12], (GA) genetic algorithm [13], (TLBO) Teaching Learning based Optimization [14], (ABC) Artificial Bee Colony [15], (CSA) Cuckoo search Algorithm [16], (GSA) Gravitational search algorithm , (MMS) Modified monkey search , (WOA) whale optimization algorithm , (IHA) improved harmony algorithm , (MSA) moth swarm algorithm, (DSA) direct search algorithm , (DEA) differential evolution algorithm , (SA) simulated annealing , (PGSA) Plant growth simulation algorithm , (FRB) fuzzy reasoning , (IBPSO) improved binary particle swarm optimization , and fuzzy-GA have been presented by many authors to deal with the problem of the DG allocation. On the contrary, few derived algorithms are not efficient since the power loss reduction is not minimized effectively. In the proposed work, a new simulation method has been developed to find Suitable location and Maximum number of fixed size diesel generators can be integrated to IEEE 12 bus radial distribution system (RDS) is simulated using MATLAB/SIMULINK software package to reduce the line power losses and to enhance the voltage stability simultaneously.

This paper is organized as follows: The Modeling of diesel generator carried out is shown in section II. The formulation of objective function is shown in section III. In section IV details of IEEE 12 bus test system with simulation procedure are presented. Results are explained in detail in section V followed by the conclusion in section VI.

II. MODELING OF DIESEL GENERATOR

The modern diesel engine based Power generating set involves diesel engine, speed governing system, synchronous generator and Excitation controller. The block diagram of the Whole diesel generator system is shown in Fig.1. The system consists of two closed-loop feedback control system: internal speed feedback control system (Fig. 2) and external excitation feedback control system (Fig. 3). Fig. 4 shows the combination of two closed loops.

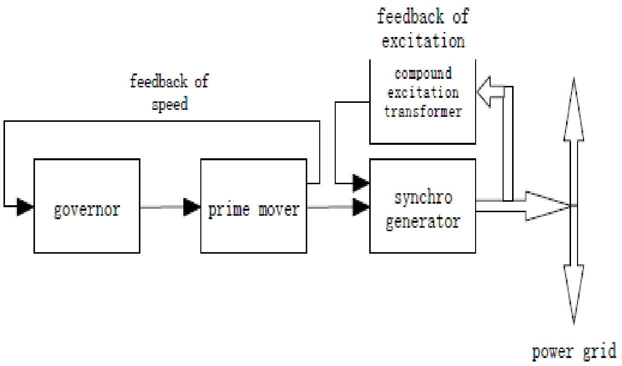

Fig. 1. Block Diagram of diesel generator set

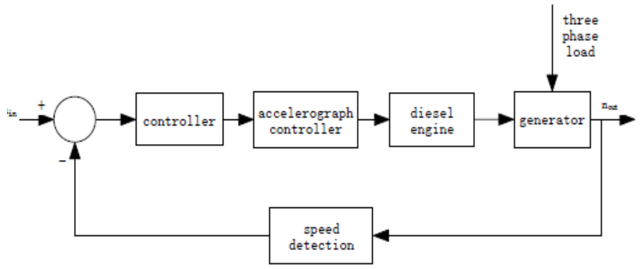

Fig. 2. Block diagram of Diesel engine

In diesel generator Assembly, the main purpose of diesel engine is to provide mechanical energy to the generator. Speed Governor is used to control the speed of engine to obtain desired frequency stable electrical power from the generator. The modeling of diesel engine and governor consists of second order control system blocks as shown as Fig. 5.

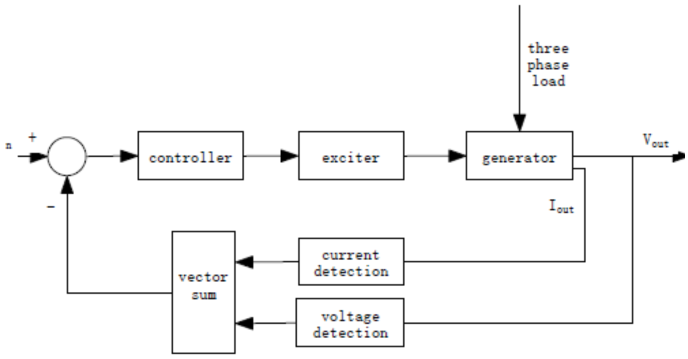

Fig. 3.Block diagram of Exciter

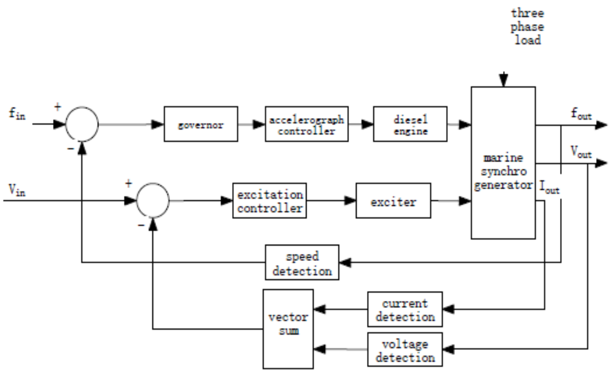

Fig. 4.Block diagram of Speed and Frequency Controller

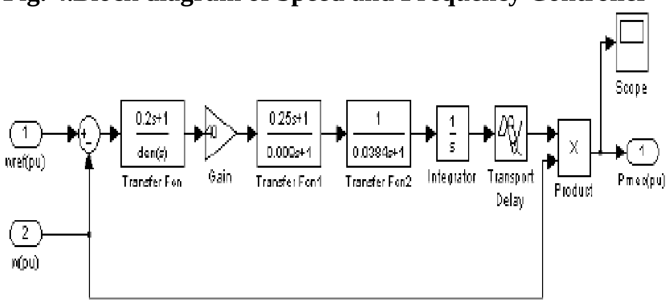

Fig. 5.Block diagram of Governor

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III. PROBLEM FORMULATION

Finding most appropriate location and capacity of distributed generators to be placed in a distribution system involves various parameters. The objective functions and operational constraints to be defined properly to integrate DG unit in order to avail maximum benefit in distribution system.

A. Objective Function & Constraint

For suitable placement and sizing of DG objective function can be single or multiple. The single objective function can be active power loss reduction, reactive power loss reduction, enhancement of voltage magnitude, increment of DG benefits, and enhancement of reliability and minimization of voltage fluctuations. Multi objective functions are attained by combining single objective functions using Correction coefficient factors. The main objective of optimal sizing and placement of DG is to reduce the line power losses and to enhance the voltage stability of distribution system effectively.

i. *Real Power Loss*

The parabolic relation exists in between the number of fixed size DG's and losses, first reduces and then starts increasing, thus the accurate sizing of DG's to obtain minimum losses is essential. The net real power line Loss in a distribution system is given by:

$$P_L = min \sum_{k=1}^{n} R_k |I_k|^2 \quad (1)$$

Where P_L is total network loss, R_k is resistance of k[th] line and k[th] line current absolute is $|I_k|$. n is the total number of lines.

ii. *Voltage Stability Index (VSI)*

A single line diagram of distribution system connected between two nodes is shown in Fig. 6. The steady state voltage stability index at bus j, L_j, is derived as follows (14): The current circulates through the line segment calculated at nodes *i* and *j* is calculated as follows:

$$|I_i|^2 = \frac{P_i^2 + Q_i^2}{V_i} \quad (2)$$

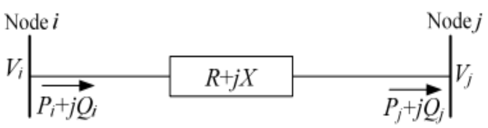

Fig. 6. Distribution line segment connected between two buses

$$|I_j|^2 = \frac{P_j^2 + Q_j^2}{V_i} \quad (3)$$

Where P_i, Q_i, P_j and Q_j are real and reactive power injection at the nodes i and j, V_i and V_j are the voltage at node i and j respectively.

The active and reactive power line losses are expressed in terms of the current flows through the line as follows:

$$P_{Loss} = \frac{P_j^2 + Q_j^2}{V_j^2} R \quad (4)$$

$$Q_{Loss} = \frac{P_j^2 + Q_j^2}{V_j^2} X \quad (5)$$

$$\text{Then, } P_j = P_i - \frac{P_j^2 + Q_j^2}{V_j^2} R \quad (6)$$

$$Q_j = Q_i - \frac{P_j^2 + Q_j^2}{V_j^2} X \quad (7)$$

Where R and X are the resistance and reactance of the branch connecting nodes i and j.

Substitute equantion1, 5 and 6 in 2 yields:

$$\frac{P_i^2 + Q_i^2}{V_i} = \frac{1}{V_j^2}\left[\left(P_j + \frac{P_j^2 + Q_j^2}{V_j^2} R\right)^2 + \left(Q_j + \frac{P_j^2 + Q_j^2}{V_j^2} X\right)^2\right] \quad (8)$$

Rearranging equation (7) gives an expression for the power flow equation at node j:

$$aV_j^4 + bV_j^2 + c = 0 \quad (9)$$

$$\text{Where, } a=1 \quad (9\text{-}1)$$

$$b = 2(P_j R + Q_j X) - V_i^2 \quad (9\text{-}2)$$

$$c = (P_j^2 + Q_j^2)(R^2 + X^2) \quad (9\text{-}3)$$

The solution of the second order equation 8 is obtained as follows:

$$V_j^2 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (10)$$

The visible solution of the terminal voltage at node j is obtained by applying this condition:

$$b^2 - 4ac \geq 0 \quad (11)$$

$$[2(P_j R + Q_j X) - V_i^2]^2 - 4[(P_j^2 + Q_j^2)(R^2 + X^2)] \geq 0 \quad (12)$$

By some manipulation for (12):

$$\frac{1}{V_i^4}[V_i^2(P_j R + Q_j X) + (P_i X - Q_i R)^2] \leq 1 \quad (13)$$

The steady state voltage stability index at bus j is defined

$$L_j = 1/[V_i^4[(P_i X - Q_i R) + V_i^2(P_j R + Q_j X)]] \quad (14)$$

The VSI near to 1 is more stable and bus with VSI deviating from 1should be taken care of. Average Voltage Stability Index (ABVSI) is defined as follows:

$$\text{ABVSI} = \sum_{K=1}^{N} \text{VSI(K)} \quad (15)$$

Where K= bus number & N=Total number of Buses.

IV. TEST SYSTEM

Generally, IEEE 12 bus system is a radial distribution system which is operated in voltage level of 11kV. This IEEE 12 bus RDS has 12 bus and 11 branches. The total reactive and active static loads of the 12 bus test system are 400 Kvar and 435 KW respectively.

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The Fig.7 shows the single line diagram of 12 bus RDS. In Table-II and III, the line and load data of the 12 bus RDS is provided respectively.

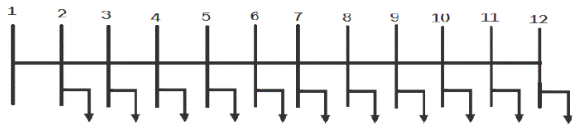

Fig. 7. SLD of IEEE 12 bus RDS

Table -II: Data of Transmission Lines

Line No.	Sending End Bus No.	Receiving End Bus No.	R(Ohms)	X(Ohms)
1	1	2	1.093	0.455
2	2	3	1.184	0.494
3	3	4	2.095	0.873
4	4	5	3.1 88	1.329
5	5	6	1.093	0.455
6	6	7	1.002	0.41 7
7	7	8	4.403	1.21 5
8	8	9	5.642	1.597
9	9	10	2.89	0.81 8
10	10	11	1.514	0.428
11	11	12	1.238	0.351

Table -III: Data of Loads

Bus No.	Real Power Load (KW)	Reactive Power Load (KVAr)
1	0	0
2	60	60
3	40	30
4	55	55
5	30	30
6	20	15
7	55	55
8	45	45
9	40	40
10	35	30
11	40	30
12	15	15

A. Simulation Procedure:

The suitable location and maximum number of Fixed size Distributed generators Can be integrated to the distribution system to improve voltage stability is obtained by using Simulation method. In this work, Modeling of Radial distribution system and Distributed generators is carried out in Matlab/Simulink software package. The steps as followed:

Step 1: Modeling of IEEE 12 Bus radial distribution system in MATLAB/SIMULINK with Static RL loads.
Step 2: Simulate the test system to find Bus voltages, Bus Power flows, VSI at each bus and total line losses and identify the bus which is having Least VSI.
Step 3: At Least VSI Bus Connect 100KVA Diesel Generator and Simulate the test system.
Step 4: Obtain the simulation results and find the Least VSI Bus for the placement of next 100KVA Diesel generator.
Step 5: After the placement of Second diesel generator simulate the test system and record the values of VSI and line Losses.
Step 6: Continue the placement of DG's until the line losses are minimized.
Step 7: Note down the number of DG's placed and their locations
Step 8: Repeat step 3 to step 7 by considering 200KVA, 300KVA 400 KVA & 500KVA Diesel Generators.
Step 9: Compare the Results obtained in each case and obtain the suitable numbers, rating of Diesel Generators to be penetrated to reduce the transmission line power losses and enhancement of Voltage stability effectively.

V. RESULTS & ANALYSIS

The Simulation approach is tested with IEEE 12 bus RDS and the results are tabulated for the base case i.e. without DGs in Table-IV.

Table-IV: Load flow Without DGs

Bus No.	Bus Voltage in P.U	Real Power @ Bus	Reactive Power @ Bus	VSI @ Bus
1	1.0000	426.6007	396.5353	1.0000
2	0.9947	423.5364	395.2597	0.9807
3	0.9897	361.7494	334.8862	0.9612
4	0.9818	319.0809	304.0471	0.9319
5	0.9719	262.4053	249.5028	0.8577
6	0.9689	233.0770	220.7528	0.8821
7	0.9663	213.5059	206.3469	0.8727
8	0.9585	160.1948	154.4548	0.8188
9	0.9512	117.4829	112.7213	0.8209
10	0.9486	80.9619	76.4355	0.8017
11	0.9478	49.4091	40.4233	0.8073
12	0.9476	13.4702	13.4705	0.8059

The total real and reactive power loss of the lines are **18.13KW** and **7.043KVAr** respectively. From the Results it is observed that Least Voltage stability index bus is Bus 10. Hence the best location to primarily place the DG is at bus 10. The Table- V, VI, VII, VIII and IX summaries the various cases to obtain optimal location and size of DGs using different fixed size DGs.

The Table-V summaries the results to obtain Suitable location and number of 100 KVA DGs required for IEEE 12 Bus system. It can be inferred that maximum number of 100KVA DG's can be integrated to the IEEE 12 bus system is SIX , since the losses are least values when six numbers of 100KVA DG's are integrated.

The Table-VI summaries the results to obtain Suitable location and number of 200 KVA DGs required for IEEE 12 Bus system. It can be inferred that maximum number of 200KVA DG's can be integrated to the IEEE 12 bus system is THREE, since the losses are least values when three numbers of 200KVA DG's are integrated.

Table- V: Case A- Summary of Results when 100KVA DGs are integrated

No. of DG's	Location of DG's	Total losses(KW)	Total losses(KVAR)	ABVSI	P_{DG} in KW	Q_{DG} in KVAR	Operating PF of DG's
0	NIL	18.13	7.043	0.8784	NIL	NIL	NIL
1	10	11.72	4.669	0.9000	41.2	58.3	0.5778
2	10,12	8.32	3.380	0.9186	39.83,39.7	45.12, 44.79	0.661, 0.663
3	10,12,8	6.31	2.573	0.9307	39.16, 39.09, 39.9	38.073 ,37.842, 33.688	0.7102 ,0.71848, 0.76418
4	10,12,8,10	5.20	2.136	0.9438	38.31, 38.27, 39.107, 38.31	28.02, 27.94, 27.68, 28.02	0.807, 0.807, 0.816, 0.807
5	10,12,8,10,5	4.48	1.826	0.9504	38.06, 38.03, 38.65, 38.06, 40.08	25.12, 25.08, 24.36, 25.12, 18.80	0.8345, 0.8348, 0.846 0.8345, 0.905
6	10,12,8,10,5,8	4.19	1.691	0.9591	37.5, 37.55, 37.97, 37.566, 39.49, 37.97	20.16, 20.2, 18.65, 20.165, 15.8695, 18.65	0.8810, 0.88, 0.897, 0.881, 0.927, 0.8975
7	10,12,8,10,5,8,9	4.607	1.830	0.9680	36.82, 36.81, 37.27, 36.82, 38.97, 37.27, 36.89	13.81, 13.95, 14.28, 13.81, 13.70, 14.28, 14.21	0.9363, 0.935, 0.9338, 0.9363, 0.943, 0.9338, 0.93314
8	10,12,8,10,5,8,9,5	4.800	1.889	0.9731	36.58, 36.57, 36.95, 36.580, 38.363 36.95, 38.36	11.736, 11.92, 11.80, 11.73, 10.644, 12.03, 10.644	0.9521, 0.95, 0.952, 0.9521, 0.9635, 0.9525, 0.95, 0.9635
9	10,12,8,10,5,8,9,5,7	5.345	2.088	0.9785	36.23 ,36.23 ,36.53, 36.233 ,37.855, 36.538, 36.2825 ,37.85, 37.197	9.27, 9.50, 8.83, 9.278, 8.07, 8.8347, 9.434, 8.07 ,9.56	0.9687 ,0.9672, 0.97199, 0.9687 ,0.978, 0.972, 0.9678, 0.978, 0.9685

Table-VI: Case B- Summary of results when 200KVA DGs are integrated

No. of DG's	Location of DG's	Total line losses(KW)	Total line losses(KVAR)	ABVSI	P_{DG} in KW	Q_{DG} in KVAR	Operating PF of DG's
0	NIL	18.13	7.043	0.878	NIL	NIL	NIL
1	10	8.35	3.386	0.918	79.644	90.1248	0.6622
2	10,12	5.90	2.40	0.95	75.85, 75.66	50.52,47.314	0.832,0.8478
3	10,12,8	5.04	2.01	0.963	73.77,73.66, 75.16	30.9191,28.2, 35.20	0.9222,0.9336, 0.90557
4	10,12,8,5	5.09	1.99	0.9738	72.816,72.722, 73.78,76.70	22.153,19.75, 24.7, 21.9	0.956,0.965, 0.9483,0.9615
5	10,12,8,5,7	6.50	2.52	0.984	71.41,71.32, 72.13,74.71, 73.30	12.9,10.81, 13.35,13.688	0.984,0.9887 ,0.9833,0.987 ,0.983

Table-VII: Case C- Summary of results when 300KVA DGs are integrated

No.of DG's	Location of DG's	Total line losses(KW)	Total line losses(KVAr)	ABVSI	P_{DG} in KW	Q_{DG} in KVAr	Operating PF of DG's
0	NIL	18.13	7.043	0.878	NIL	NIL	NIL
1	10	6.55355	2.6824	0.933	116.56	102.213	0.75186
2	10,8	4.62	1.847	0.96	111.905 113.03	54.577 49.044	0.89881 0.917367
3	10,8,5	5.20	2.029	0.976	109.718 110.2345 113.5936	35.625 26.94 22.60	0.9511 0.9714 0.98

The Table-VII summaries the results to obtain Suitable location and number of 300 KVA DGs required for test system. It can be inferred that maximum number of 300KVA DG's can be integrated to the considered test system is TWO, since the losses are least values when two numbers of 300KVA DG's are integrated.

The Table-VIII summaries the results to obtain Suitable location and number of 400 KVA DGs required for test system. It can be inferred that maximum number of 400KVA DG's can be integrated to considered test system is ONE, since the losses are least values when one 400KVA DG is integrated.

Table-VIII: Case D-Summary of results when 400KVA DGs are integrated

No.of DG's	Location of DG's	Total losses (KW)	Total losses (KVAR)	ABVSI	P_{DG} in KW	Q_{DG} in KVAR	Operating PF of DG's
0	NIL	18.1287	7.0434	0.8784	NIL	NIL	NIL
1	10	5.8235	2.3721	0.9446	151.8598	99.6958	0.8360
2	10,8	6.4113	2.4672	0.9758	143.3476 145.102	31.833 34.333	0.97621 0.97313

Table-IX: Case E-Summary of results when 500KVA DGs are integrated

No. of DG's	Location of DG's	Total losses (KW)	Total losses (KVAR)	ABVSI	P_{DG} in KW	Q_{DG} in KVAR	Operating PF of DG's
0	NIL	18.1287	7.0434	0.8784	NIL	NIL	NIL
1	10	5.967	2.383235251	0.9546	185.183322	86.8459945	0.905381298
2	10,8	6.70	2.591	0.9805	179.0437 186.6738	34.483 28.333	0.98195 0.98867

The Table-IX summaries the results to obtain Suitable location and number of 500 KVA DGs required for IEEE 12 Bus system. It can be inferred that maximum number of 500KVA DG's can be integrated to the IEEE 12 bus system is ONE, since the losses are least values when one 500KVA DG is integrated.

Fig 8. Indicates the variation of Line losses with respect to the increase in Number of Different Size DG's (100-500KVA) penetrated to the considered test system. It can be observed that Line Losses in KW is least when six numbers of 100KVA DG's are integrated to the test system.

The Table-X summaries the Results of % penetration level of DG's, ABVSI, Average DG Power factor & % P loss reduction in each case. The power loss reduction is maximum when 100KVA DG's are integrated. There is real and reactive power loss reduction of 76.89% and 75.99% respectively when 100 KVA DGs are connected to the RDS.

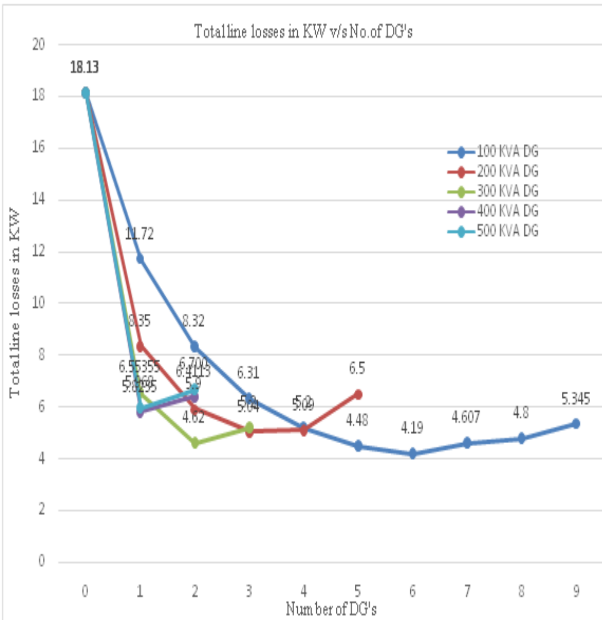

Fig.8: Comparison of losses for various cases

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Table-XI: Comparison of results with new analytic method

Parameters	VSI based Simulation approach		PSI based Search algorithm	
	Before DG Placement	After DG placement	Before DG Placement	After DG placement
Minimum voltage in PU	0.8017	0.9591	0.9438	0.9847
Total line loss in KW	18.13	4.19	20.703	10.6617
Total line loss in KVAr	7.043	1.691	8.037	4.0802
%P loss Reduction	-	76.89	-	48.5
%Q loss reduction	-	75.99	-	49.33
Optimal location	-	10,12,8,5	-	9
PDG in KW	-	228.131	-	239
QDG in KVAR	-	113.708	-	-

Table-XI shows the comparison between proposed methodology and PSI based Search algorithm. In the proposed method the DG penetration required is 228.131KW whereas in new search algorithm method is 239KW. The Proposed method is more effective in reducing Line losses compared to PSI based Search algorithm.

VI. VI. CONCLUSION

This paper presents simulation method to determine Suitable location and Maximum Number of fixed size DGs Can be integrated to the distribution system. This work is majorly concentrated on minimization of power losses and improvement of voltage stability index. From the results it can be concluded that as more number of Diesel Generators are integrated to the system the operating power factor of individual DG increases & Steady state Voltage stability increases. Maximum Number of 100KVA, 200KVA, 300KVA, 400KVA & 500KVA DG's can be integrated to the Considered IEEE 12 Bus test system are 6,3,2,1 & 1 respectively. Out of these standard size DG's minimum Real power line loss can be achieved with 6 Number of 100KVA DG's .Hence instead of integrating higher rating DG's if we integrate lower rating DG's in Larger numbers to the distribution system, line losses can be minimized effectively.

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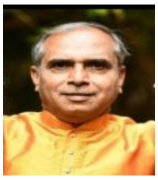

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