Optimal Placement of Distributed Generations and Capacitor Placement with Varying Load Models

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Abstract

For optimal location and sizing of Distributed Generations (DG) and Capacitors in radial distribution network (RDN), constant power load model has been used in majority of cases. In real neatwork, there are the loads which change their real and reactive power drawl based on the voltage available at their terminal. Also, considering only one fixed loading conditions for ascertaining the locations of DGs and capacitors are not suffice. In this paper, the impact of different load models and varying loading conditions are comprehensively analysed to assess the impact of DGs and capacitor placement in RDN in order to observe the full benefits of improved voltage profile and reduction in losses. Golden Selection Search Method has been used for the determination of location and sizing, keeping the constraints on bus voltage magnitudes.

Keywords: *Distributed Generation, Capacitor Placement, Golden Selection Search, Static Load Models*

I. INTRODUCTION

Electrical distribution network usually consists of feeders configured radially. The radial feeders of distribution network have higher R/X ratio in comparison to that of transmission network and the numbers of connections on the low voltage side of these feeders are increasing substantially. Hence, the energy losses and voltage drops in the different branches of the radial feeders have been reported significantly which is a major concern for any utility around the world. The restructuring of electricity markets, environmental concerns and the heavy investment in building new transmission lines are all influencing factors which promote more penetration of Distributed Generation (DG) units in radial distribution network. It has been shown that DGs are one of the most cost-effective and an economical solution to solve the problems of radial distribution network (RDN) [1-2].

DGs are small power generating units ranging from few kW to several MW and they are connected at distribution side directly to supply the local load demand. Due to only few kW generation requirements from DGs, the generation from renewable energy based power generation units can be integrated in the systems which may serve the purpose of both sustainable and efficient energy. The full potential of DGs in RDN can be explored for loss minimization, voltage profile improvement, stability enhancement etc. by determining their optimal location and capacity as well as their mode of operation [2].

Many researchers proposed several methods such as analytical method [3-7] for optimal location and sizing of DG unit for minimizing total real power losses in distribution systems. Authors have also suggested different approaches in [8-12] for an objective of voltage stability enhancement of system. In [13] authors have addressed both objectives of voltage stability enhancement and power loss minimization. An extensive literature review on several challenges in RDN and their possible solutions are reviewed in [14] by considering different issues of power losses, voltage profile improvement and voltage stability enhancement after the placement of DGs and capacitors.
Reactive power compensation by shunt capacitor banks (SCBs) to the RDN can also be beneficial solution for performance improvement of distribution system [15]. The reactive power support from SCBs is one of the best suggested solutions for minimizing the losses together with other benefits; such as efficient utilization of equipment, relieving overloaded of system components and enhancing

the life cycle of the equipment [16]. To achieve the full benefits from SCBs optimal location and sizing are very vital to determine otherwise too much compensation at wrong site may worsen the problem.

Many methods have been reported in literature to take the advantages from SCBs by placing them properly in the system. Recently, researchers have suggested several algorithms and techniques to find the appropriate locations and optimal sizes of shunt capacitors with different objectives. Many techniques such as Genetic Algorithm (GA) [17-19], Particle Swarm Optimization (PSO) [20-23], Cuckoo search algorithm (CSA) [24-26], Teaching Learning Based Optimization (TLBO) [27], Flower Pollination Algorithm (FPA) [28, 29], and Oppositional Krill herd algorithm (OKH) [30], mixed integer nonlinear programming (MINLP) [31] and other classical methods are discussed in [32-34]. Enhancement of loading capacity of distribution system through optimal placement and sizing of multiple DGs is presented in [35] by considering the effect of load growth. PSO with constriction factor approach is used for the optimization process. Simultaneous placement of DGs and capacitors is presented in [36] with intersect mutation differential evolution (IMDE) to optimally locate and to determine the size of DGs and capacitors with objectives to minimize the power loss and loss expenses keeping constraints on bus voltage and line currents.

Placement of DGs such as inverter-based distributed generation (like photovoltaic and fuel cells) considering total harmonic distortion (THD) constraint according to IEEE 519 standard along with generalized objectives is presented in [37] with new biogeography-based optimization (BBO) algorithm. Authors in [38] addressed the capacitor placement considering power quality problem with the use of penalty free GA. Multi objective PSO (MOPSO) considering load uncertainty modelled using fuzzy data theory in distribution systems is outlined in [39] to optimally place DGs and SCBs simultaneously. Hybrid method based on Imperialist Competitive Algorithm (ICA) and genetic algorithm (GA) is successfully applied in [40] for DGs and SCBs for loss minimization, voltage stability enhancement and for load balancing in RDN. Effect of load models on optimal location and sizing of DG resources is presented in [41] and comparison for power loss, active and reactive power drawl from main substation and MVA support obtained after DG resources installation for different type of loads models have been outlined. Recently, a new approach of Loss Sensitivity Factor (LSF) and Voltage Stability Index (VSI) are implemented in [42] to determine the optimal location for installation of capacitor banks using Bacterial Foraging optimization algorithm (BFOA) where loading condition is varied from light load (50%) to peak load (160%) with a step size of 1% and optimization procedure is followed to entire period.

The problem of optimal placement and sizing of DGs and capacitor have always been a popular problem for the researcher. The recent literature review in this area has revealed its importance in the present distribution system resources planning. The majority research papers in this area has attempted to propose new optimization method that can result in minimum losses, improved voltage profiles of all nodes and for improved utilization of the resources after considering only constant power load. In this paper, the problem of optimal placement of DG and capacitors have addressed separately by implementing Golden Selection Search in the presence of different load combination to ascertain the optimal location of DG and capacitors. The voltage dependency of the loads may definitely alter the location of DG and SCB to enjoy their full benefits. Hence, comprehensive analysis has been carried out to determine the impact of these varying load models on distribution network after the placement of DGs and SCB.

II. LOAD MODELS IN DISTRIBUTION NETWORK

Optimal location of DG and capacitor planning in RDN may have different result corresponding to different load models. The optimal location determined for DGs and/or SCB may completely ineffective and in some cases it may worsen the performance of RDN. The voltage dependency of load models is given in [41] to represent residential, industrial, and commercial loads. The load models can be mathematically represented as

$$P_i = P_{0i}\left|V_i\right|^{\alpha}$$
$$Q_i = Q_{0i}\left|V_i\right|^{\beta} \quad (1)$$

P_{0i} and Q_{0i} are base active and reactive power load, respectively, at node i. For constant load, industrial, residential and commercial load representation, the coefficient values are chosen as per Table I. In the practical realistic situation, loads are not explicitly residential, commercial and industrial; rather, load class mix may be seen by RDN.

TABLE I Load types and Exponent Values

Load Type	Α	β
Constant Power (CP)	0	0
Industrial Load (IL)	0.18	6.000
Residential Load (RL)	0.92	4.04
Commercial Load (CL)	1.51	3.40

III. PROBLEM FORMULATION AND PROPOSED METHODOLOGY TO ASSESS RDN PERFORMANCE

In this paper, the objectives are to evaluate the performance of RDN after the optimal placement of Distributed generation and capacitors. For the distributed generation, the different types have been identified based on their reactive power capability generation. The DGs using synchronous generator operating in voltage control mode and capable to supply both active and reactive power is the best DG option to reduce the power losses and enhance the voltage stability of RDN [13]-[14]. Hence, in this work, DG based on synchronous generator is adopted. The objective function to achieve the goal of keeping node voltage within a strict band, the objective functions are defined in (2)-(5). The DG and Capacitors are place on each bus individually and their sizes are varied from 0% to 100% in step size of 1% of load power. For finding out the optimal size and location of DGs and the shunt capacitors, Grid Search method is used [5, 43]. The complete flow chart of the Grid Search method is shown in Fig. 1 where presence for only DG is given, this methodology is applicable for the placement of capacitors as well.

To minimize $f\left(P_{dg}\right) = P_{loss}$ (2)

$\left|V_i\right| \leq 1 + 0.05\,pu \quad i = 1, 2, ..., \mathrm{n}$

Subject to $0 \leq P_{dg} \leq \sum P_{load}$ (3)

To minimize $f\left(Q_{sc}\right) = P_{loss}$ (4)

$\left|V_i\right| \leq 1 + 0.05\,pu \quad i = 1, 2, ..., \mathrm{n}$

Subject to

$0 \leq Q_{sc} \leq Q_{gslack}$ (5)

In Fig. 1, i bus number, n total number of buses, optsize(i) optimum size of DG at bus i, optploss(i) total power losses with optimum size of DG at bus i,

DG_U upper bound of the search interval of DG

DG_L lower bound of the interval

Δ interval at each iteration step

S_1 and S_2 points within the interval where $S_1 < S_2$

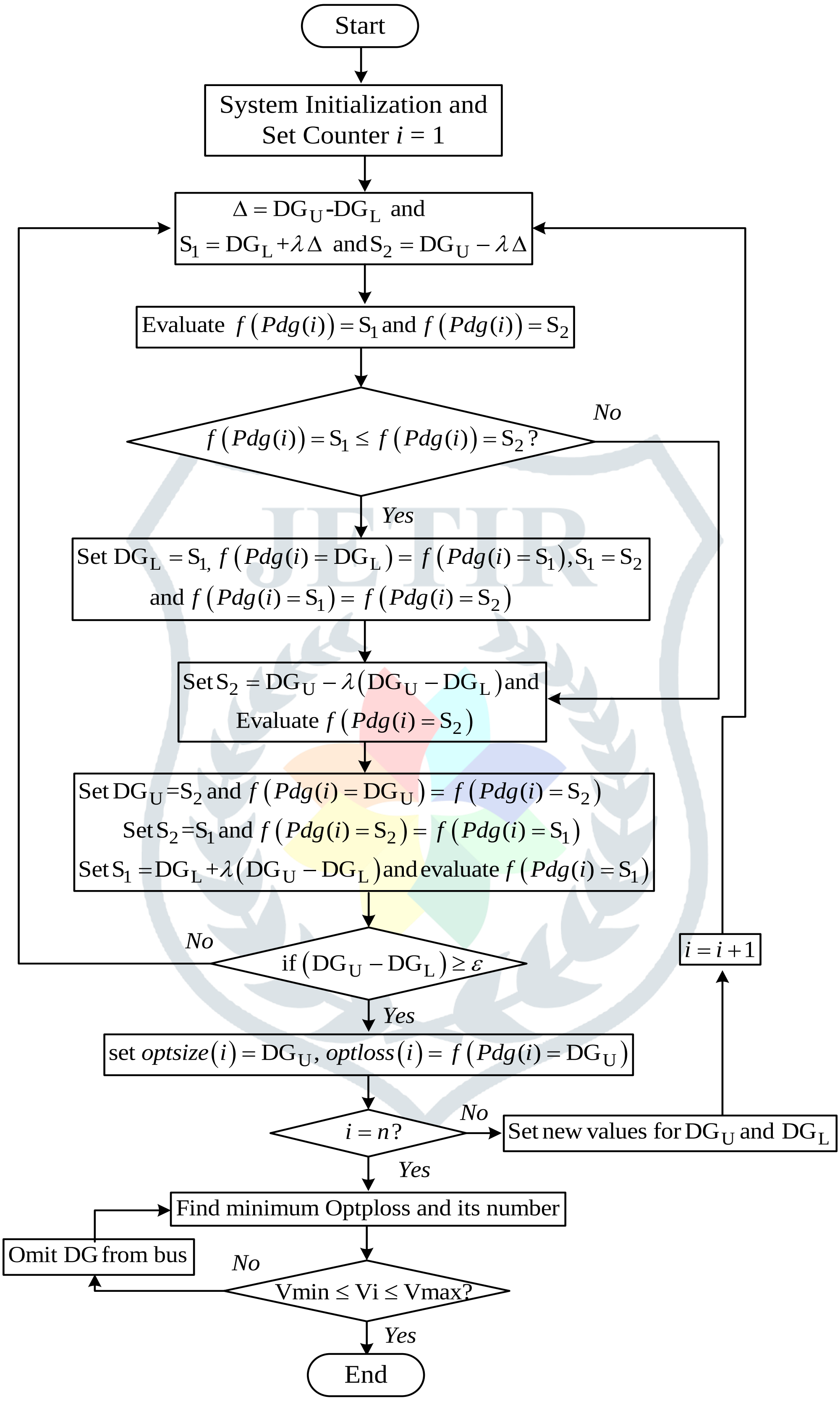

Fig. 1 Golden Selection Search for determination of optimal DG location

IV. SIMULATION RESULTS AND DISCUSSION

The test system used in this paper is 69 nodes radial distribution network which is considered to be medium sized network [27]. The load on each node is modified by the eq. (1) and the values given in Table I to have different load models. Moreover, the case studies are carried out with varying loading conditions of 30%, 70%, 100% and 120 % of that of the base load for each load model category. The impact of placement of DGs and capacitor are evaluated and compared for each load model and varying loading conditions to find which option is the best suited to improve the RDN performance.

Fig. 2 and Fig. 3 show the bus voltage profile of the 69 nodes RDN with the placement of DG and capacitor individually. The bus 61 is found to be optimal for the placement of both DG and capacitor. The sizing of both DG and capacitors have changed significantly due to changes in loading conditions as well as load models. Table II gives the sizing of DG and capacitors for these variations. In Fig.2 and Fig.3, bus voltage profile corresponds to that profile which is obtained after the placement of DG and capacitor at bus 61 with the optimal size as indicated in Table II.

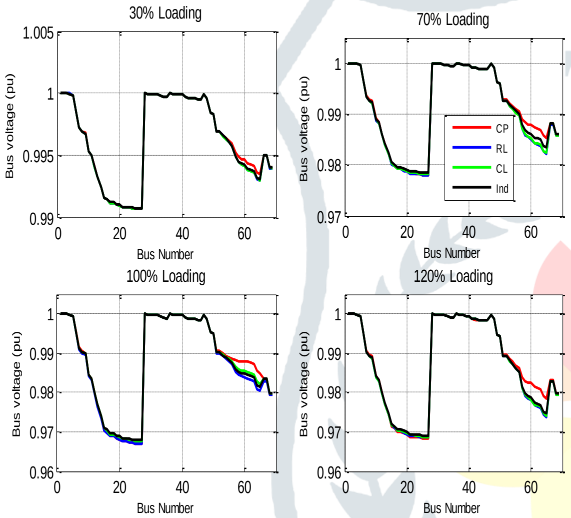

Fig. 2 Bus voltage profile after the optimal placement of DG

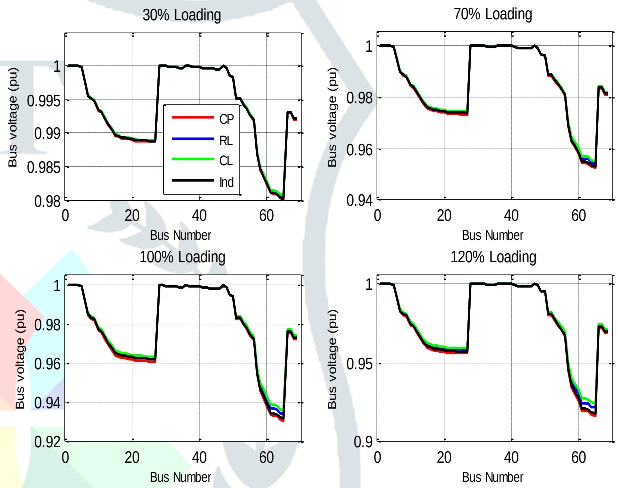

Fig. 3 Bus voltage profile after the optimal placement of capacitor

Table II: Optimal Sizing of DG and Capacitor

Loading	Sizing Comparison				Loading	Commercial Load		Industrial Load	
	Constant Power		Residential Load			DG	Cap	DG	Cap
	DG	Cap	DG	Cap	30%	0.3638	0.5247	0.3476	0.5247
30%	0.388	0.5475	0.3638	0.5247	70%	0.7733	1.1977	0.7167	1.171
70%	0.9242	1.3041	0.7545	1.171	100%	1.0239	1.6349	0.9161	1.6349
100%	1.3203	1.863	0.997	1.6349	120%	0.679	2.0531	0.6224	2.0531
120%	0.9619	2.2356	0.6602	2.0988	30%	0.3638	0.5247	0.3476	0.5247

The effects of load models on bus voltages are not much apparent for the nodes nearer to substation bus, but the buses at the tail ends are significantly affected in case of DG placement as compared to capacitor placement. The reduction in the bus voltage is very high in case of capacitor placement which is compared separately in Fig. 4 to have clear insight of DG placement benefits.

Table III gives the aggregate voltage deviation index (AVDI) for all the cases. AVDI is obtained after aggregating the deviation of bus voltages from the nominal value of 1 pu. It is observed that AVDI greatly differs with different loading conditions. AVDI also gives the indication that with the different load models, bus voltage profile gets affected. The impact of DG is more for all load models under all loading condition as compared to capacitor placement which can be noticeable from Fig. 4. One of the most common reasons could be the only reactive power generation capacity by capacitors. Hence, the active loads at the buses rely only on the substation power which flows all over longer path of the feeders and results in larger voltage drop. The changes in bus voltage profile for the varying load conditions are shown in Fig. 5. For this case study, the base case loading is increased/decreased by 30%, 70% and 120%. It is obvious that for the stressed loading condition, the voltage drops at the larger proportion. Placement of multiple DGs/Capacitors can be the solution to restrict this further decline in voltage profile. The similar responses have been obtained with DG with somewhat more improved voltage profile, but it is not shown here.

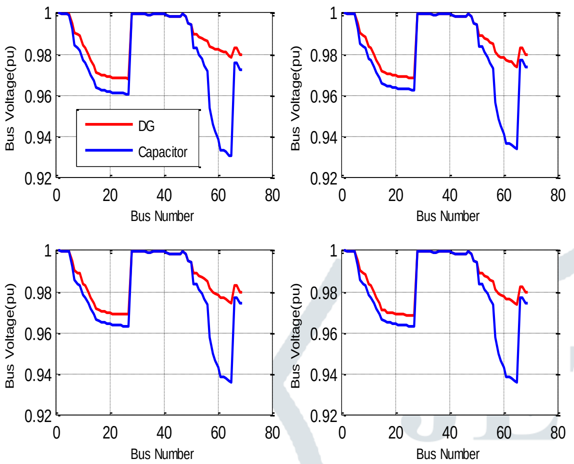

Fig. 4 Comparison of bus voltage profile improvement after placement of DG and capacitor

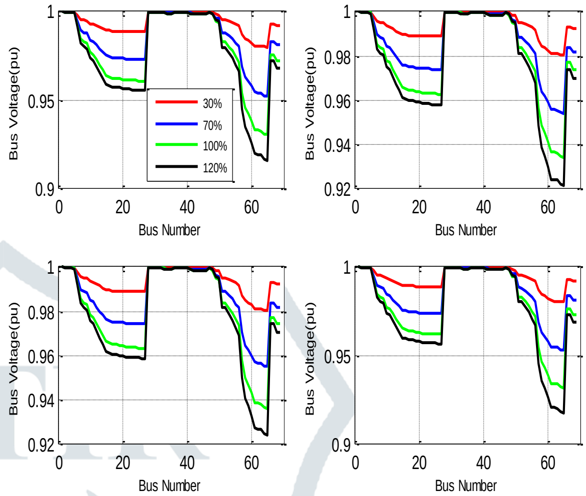

Fig. 5 Comparison of bus voltage profile with capacitor placement for different loading conditions

Fig. 6 shows the active power losses after the placement of DG and capacitor. The losses are increased with the increment in loading for both the cases. DG has again resulted in promising solutions for minimizing the active power losses in RDN. The comprehensive studies have been carried out to see the impact of sizing of DG and capacitor on losses reduction. The effect of optimal DG sizing on individual buses is shown in Fig. 7. In this analysis, on each bus, the DG is placed individually and its size is varied in the capacity from 0% to 100 % of maximum load demand.

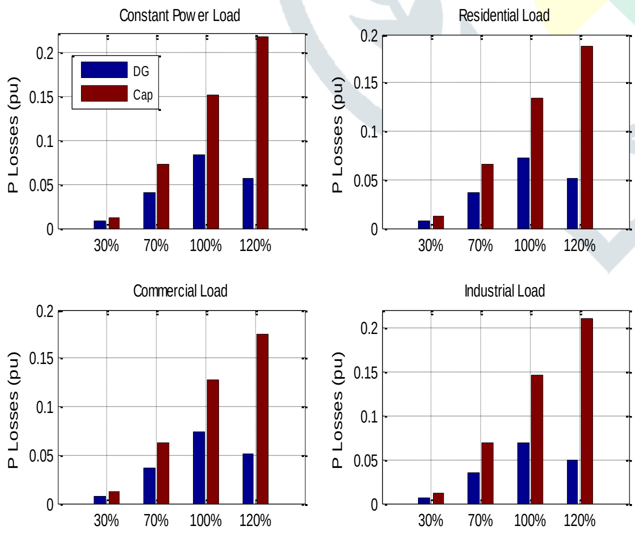

Fig. 6 Comparison between DG and Capacitor for active power losses reduction

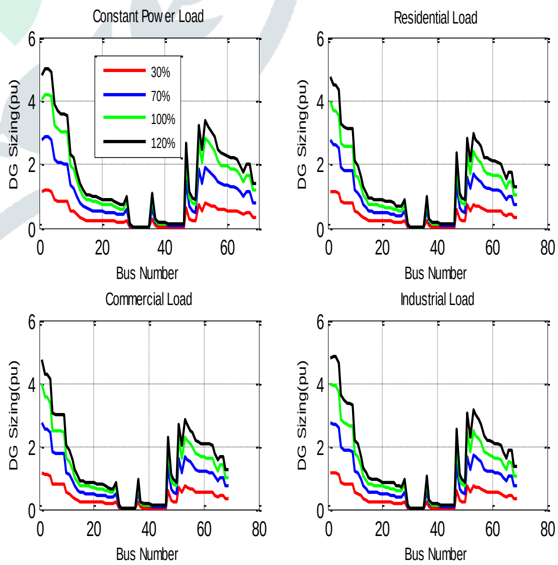

Fig. 7 Optimal Sizing of DG at individual buses for different loading conditions

V. CONCLUSION

The impacts of DG and capacitor placement in RDN at different location and with different sizing have been analyzed comprehensively. The exhaustive case studies have been carried out considering varying load conditions which is a more realistic situation. It is observed that, the varying loading condition does not alter the optimal location of DG and/or capacitor. Another case studies with different load models reveal that sizing of DG and/or capacitor are greatly affected for different load models. The sizing of DG and capacitor play vital role for minimization of voltage deviation and active power losses which are also significantly depend on load models. The cases studies suggest to consider the impact of combination of load models to ascertain the location and sizing of DG and capacitor in RDN.

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