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Effect of change in number and power factor of DG on optimal allocation for minimal actual power loss in RDS

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Abstract

Due to its remarkable techno-economic advantages, Distributed Generator (DG) penetration is growing drastically. To minimize the power losses and enhance the voltage profile, determining the precise size & position of DG is critical. The proposed paper compares the effect of variations in the number & power factor of DG on its optimal allocation in the Radial Distribution System (RDS) for minimizing the active power loss & enhancing the voltage profile using Grey Wolf Optimization (GWO) algorithm. The Direct Load Flow (DLF) approach is applied to address the system's power flow. Under altering DG parameters, the proposed method computes and compares appropriate DG allocation in standard IEEE 33 & 69 bus RDS.

*Keywords:*Radial Distribution System (RDS), Distributed Generation (DG), Voltage Profile, Power Factor (pf), Grey Wolf Optimization (GWO), Optimal Placement, Optimal Sizing

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This paper was earlier presented at the SDCEE-2021: 1st International Online Conference on Sustainable Development in Civil and Electrical Engineering, National Institute of Technology Kurukshetra, Kurukshetra, India, December 17-19, 2021 and substantially improved for this Special Issue. Guest Editors: (i) Dr. Sri Niwas Singh, Professor (HAG), Department of Electrical Engineering, Indian Institute of Technology Kanpur, 208016 (U.P.) India, Director, ABV-Indian Institute of Information Technology & Management Gwalior; (ii) Dr. Ashwani Kumar, SMIEEE, Fellow IE (I), Fellow IETE (I), LMISTE, LMSCIEI, Professor and Head, Department of Electrical Engineering, NIT Kurukshetra Haryana, India. Dr. Kumar has 27 years teaching experience and an industrial experience of 2 years, 8 months.

1. Introduction

The energy crisis is an essential issue in the Present world as fossil fuel deposits are depleting at a tremendous pace due to the ever-increasing demand for power. Recent reductions in coal supplies have resulted in predicted power outages and ultimately blackouts. As fossil fuels are a significant source of power, there is a need to find new ways for energy production. Therefore, there is a need to switch to Renewable Energy which provides a cleaner and everlasting energysource (Maradin, 2021). Further, the Paris Accord binds the governments to reduce the emission to net-zero. This affects the countries' National Policies to maximize the use of Renewable sources of energy. DG is the onsite generation of energy, which consists of tiny generators placed near the load end, circumventing the need for network expansion in order to meet the demands of new regions and loads. In India, after The Electricity Act of 2003, which deregulated the power market leading to the entry of private players into the energy business, thus initiating competition paving the way for the introduction of new technologies and methods for improving power quality within the economic constraints to attract consumers. Installation of DG has effects on various parameters, it reduces the electrical system losses, which in turn increases the efficiency, can be used for ancillary service support, improves voltage profile leading to better reliability and power quality. DG's integrated into the distribution system range from small (several kilowatts) to medium (a few megawatts). Renewable sources like wind, solar, hydro-thermal, geothermal can be used as DG. In some cases, non-renewable technologies like diesel natural gas are also used. Out of these, solar and wind are most prominent in the market due to the ease of availability and green energy sources. DG integration can boost the performance of the radial system, but its improper allocation can lead to adverse effects. Although integrating renewable energy sources reduces pollution by reducing greenhouse gas emissions but results in a more complex system. Much work has already been done, and a lot more is under progress regarding the placement of DG in the RDS. Many academics have proposed various optimization strategies to meet various distribution system objectives, including as analytical methods(Gabr et al., n.d.) (Delhi Technological University & Institute of Electrical and Electronics Engineers, n.d.)and more recently, heuristic methods like Genetic Algorithm (GA)(Gopu et al., 2021), Ant Colony Optimization (ACO)(Godha Dagade et al., 2020), Grasshopper Optimization(Ghavifekr et al., 2021), FlowerPollination(Dhivya& Arul, 2021),Particle Swarm Optimization (PSO)(Karunarathne et al., 2020)(P. Prakash, 2021)(Saidah&Masrufun, 2020)(Vempalle& Dhal, 2021), Bat algorithm(Koundinya et al., 2021), Black widow optimization(Samal et al., 2021), Whale Optimization(D. B. Prakash &Lakshminarayana, 2018), Ant Lion Optimization(ALO)(Roy et al., 2020),sine cosine algorithm(SCA)(Chayakulkheeree& Ang, n.d.)(Selim et al., 2021).GWO is utilized in this paper as an alternative optimization approach. Previous research has proposed the optimal allocation of DG, but this paper investigates and compares the effect of changing the pf and increasing the quantity of DG on the optimal allocation.

2. Types of DG

Based on its terminal features in terms of real power (P) & reactive power (Q) providing capabilities, DG may be divided into

Type A: DG is solely capable of injecting P consisting of convertor/inverter-integrated photovoltaic, microturbine, and fuel cell power sources

$$S_{DGA} = \sqrt{(P_g + P_{DGA})^2 + (Q_g)^2} \quad (1)$$

Type B: DG is solely capable of injecting Q consisting of synchronous compensators, i.e., gas turbines.

$$S_{DGB} = \sqrt{(P_g)^2 + (Q_g + Q_{DGB})^2} \quad (2)$$

Type C: DG with the ability to infuse both P and Q mainly synchronous-machine-based DG units (cogeneration, gas turbine, etc.)

$$S_{DGC} = \sqrt{(P_g + P_{DGC})^2 + (Q_g + Q_{DGC})^2} \quad (3)$$

Type D: DG can infuse P but deplete Q comprising mainly of wind farm induction generators.

$$S_{DGD} = \sqrt{(P_g + P_{DGD})^2 + (Q_g - Q_{DGD})^2} \quad (4)$$

where P_{DGA}, P_{DGC} and P_{DGD} are the active power injected by DG & Q_{DGB} and Q_{DGC} are the reactive power injection whereas Q_{DGD} represents the reactive power demand by the DG.

3. Problem Statement

3.1 Objective Function:
Minimize:

$$P_{loss} = \sum_{i=1}^{n} |I_i|^2 R_i \quad (5)$$

Constraints

Voltage constraint: To maintain the system's power quality, the voltage at each node must continue to operate within reasonable bounds.

$$V_{min} \leq V_n \leq V_{max} \quad (6)$$

where V_{min}& V_{max} are the lower and upper limits, V_n the voltage of n^{th} node and N the total nodes in the network.

Thermal Constraint: The network's branch currents must all be well within the conductor's maximum thermal capacity.

$$I_m \leq I_{rated} \quad (7)$$

where I_m and I_{rated} is the m^{th} branch and maximum allowable branch current respectively

DG capacity constraint: Every integrated DG unit's total active power generation must be less than the network's total active power consumption; otherwise, power would flow back.

$$0 \leq \sum_{i=1}^{n} P_{DG_i} \leq \sum_{i=1}^{n} P_{L_i} \quad (8)$$

where P_{DGi} the active power injection and P_{Li} the load connected to the i^{th} node.

3.2Load Flow Analysis: The distribution system is predominantly radial or weakly meshed with unbalanced loading due to the ever-changing load demand of various consumers, an immense number of nodes and branches, as well as resistance and reactance valuing large spans of the spectrum. The high R/X ratio causes high power losses in the system. Due to the above-stated features, traditional load-flow methods like Gauss-Seidel & Newton-Raphson fail to render the performance and robustness criteria and the assumptions of fast-decoupled NR method are invalid in distribution system. As a result, forward and backward sweep, as well as DLF method, are the most common load-flow approaches adopted in the distribution network. In this work, DLF technique(Teng, 2003) has been used to perform the load-flow analysis saving profuse time and befitting for online application.

4.Grey Wolf Optimization

In 2014, SyedaliMirjalili et al.(Mirjalili et al., 2014), presented a novel population-based meta-heuristic optimization method called “Grey Wolf Optimizer” (GWO). The inspiration behind this algorithm is the hunting mechanism & social hierarchy of the pack of grey wolves. The pack have stringent social dominant hierarchy where the alphas are leaders and primarily responsible for decision-making and are imposed on the pack. Although the alpha is not the strongest member of the pack, he is the greatest at controlling it. The betas, the best candidate for replacing alphas, are second to alphas assisting them in making decisions by reinforcing the alpha's order across the pack, as well as providing feedback to the alpha. The omegas are the lowest in the power pyramid and have to follow the rest and the remaining wolves are the deltas which submit to alpha and betas but dominate the omegas. Along with social hierarchy, wolves engage in collective hunting, which entails tracking, pursuing, surrounding, and eventually attacking exhausted victims.

Optimal placement of DGs:
Input Data**:** Bus Data
Output: Optimal allocation
Initialization:
1.DLF
Loop Process
2.Run GWO till Maxiter reached
3. Search agents—Randomly generated
Position of wolves—initialized
4. Objective Function-Calculate P_{loss} by calling DLF
5. If (P_{loss} violates constraints) — Discard Solution
6. else — Update position of wolves
7. If (Obtained position better than previous run) — Discard previous solution
8. else — Rerun GWO

4. Simulation Results

The differences in the characteristics that are compared among the two techniques taking GA as base case, as shown in Table 1 have a minute difference in values, but the average time taken for computation of the same set of values is considerable for a test case with a limited number of iterations and program runs. The authors observe that the computation time for GWO technique is much less compared to PSO & GA for the IEEE-33 bus test RDS with 600 iterations on a single run with comparable accuracy.

Table 1. Comparison of various Optimization.

Method	Results	Avg. Time
GA	2590.287 [6]	29.816 sec
PSO	2590.217 [6]	7.937 sec
GWO	2590.252 [6]	4.67 sec

4.1 Effect on Voltage Profile & Power Losses of IEEE 33 bus RDS

In the instance of IEEE 33 bus RDS, the total load drawn from the substation is 3715 kW and 2300 kVAR. According to the load-flow study done using DLF on the test system without installing DG, the total active power loss amounts to 210.98 kW while the total reactive power is 143.02 kVAR, with the minimum voltage being 0.90378 p.u at the bus no. 18.

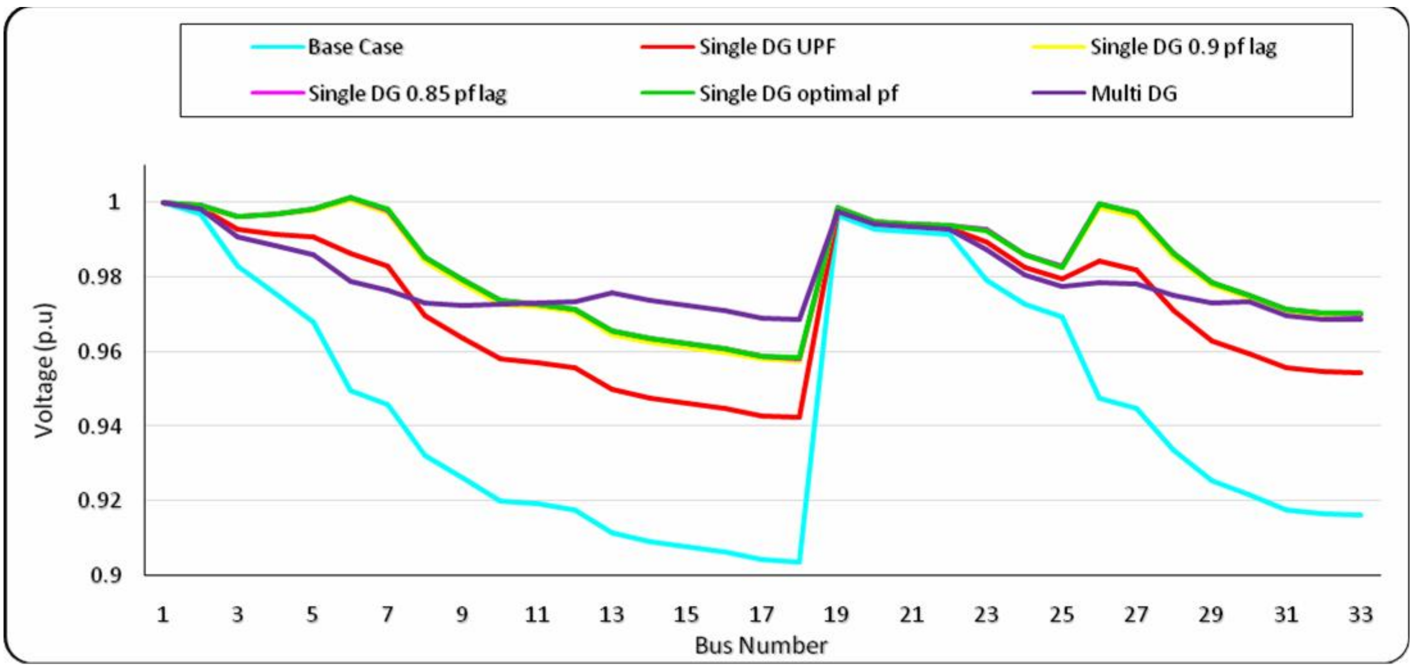

Figure 1. Variation of Voltage Profile in IEEE 33 bus RDS with implementation of various DGs.

Voltage Profile: Figure 1. represents the effect of the change in the number & power-factor of DG on the voltage profile, utilizing the aforementioned optimization approach and conducting the load flow analysis; the new voltage profile on the application of DG at the ideal position and the size determined shows the minimum value after DG implementation is more significant than the base case and keeps improving on increasing number of DGs and as the pf moves to its optimal value of 0.82378 pf lag.

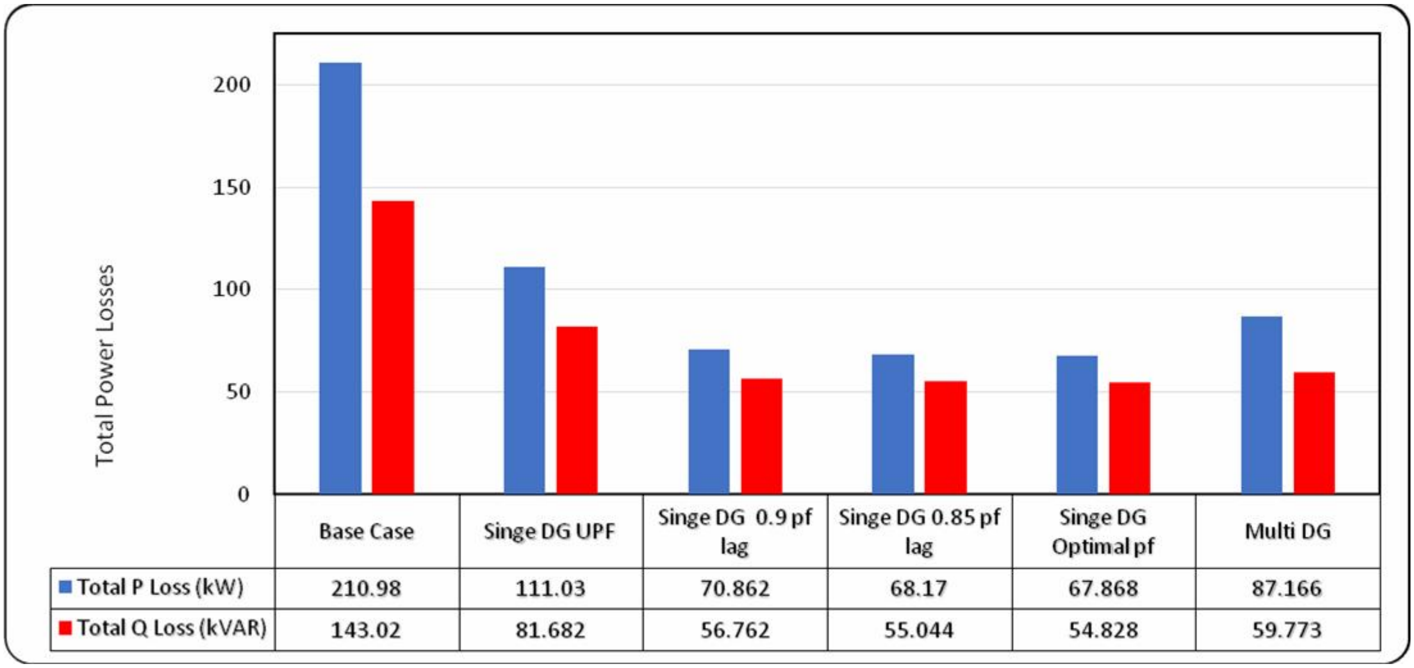

Figure 2. Variation in Total Power Losses of IEEE 33 bus RDS with implementation of various DGs.

*Power Losses:*Figure 2. indicates the decrease in the total active and reactive power losses on implementing of various DGs with the total power loss saving of 99.95 kW, 140.12 kW, 142.81 kW, 143.12 kW when implementing single DG at Unity power factor (UPF), 0.9 pf lag, 0.85 pf lag, optimal value of 0.82378 pf lag respectively & 123.82 kW on the implementation of multiple DG at UPF. Table 2 represents the variation of parameters on DG allocation.

Table 2. Effect of various Type of DGs on IEEE 33 bus RDS.

Parameters	DG Allocation Size (Location) (kVA)	Total P_{loss} (kW)	Total Q_{loss} (kVAR)	%P_{loss} Reduction	% Q_{loss} Reduction	Min Voltage p.u (Bus)
Base Case	-	210.982	143.022	-	-	0.9038 (18)
SingleDG UPF	2590.252 (6)	111.03	81.682	47.37%	42.88%	0.9424 (18)
Single DG 0.9 lag	3073.499 (6)	70.862	57.762	66.41%	60.31%	0.9575 (18)
Single DG 0.85 lag	3103.022 (6)	68.169	55.044	67.69%	61.51%	0.9584 (18)
Single DG Optimal pf	3106.561 (6)	67.868	54.828	67.83%	61.67%	0.9584 (18)
Multi DG	851.525 (13) 1157.576 (30)	87.166	59.773	58.68%	58.31%	0.9685(33)

4.2 Effect on Voltage Profile & Power Losses of IEEE 69 bus RDS

In the instance of IEEE 69 bus RDS, the total load drawn from the substation is 3802.6 kW and 2694.6 kVAR. According to the load-flow study done using DLF on the test system without installing DG, the total active power loss amounts to 224.9887 kW while the total reactive power is 102.17 kVAR, with the minimum voltage being 0.90919 p.u at the bus no. 65.

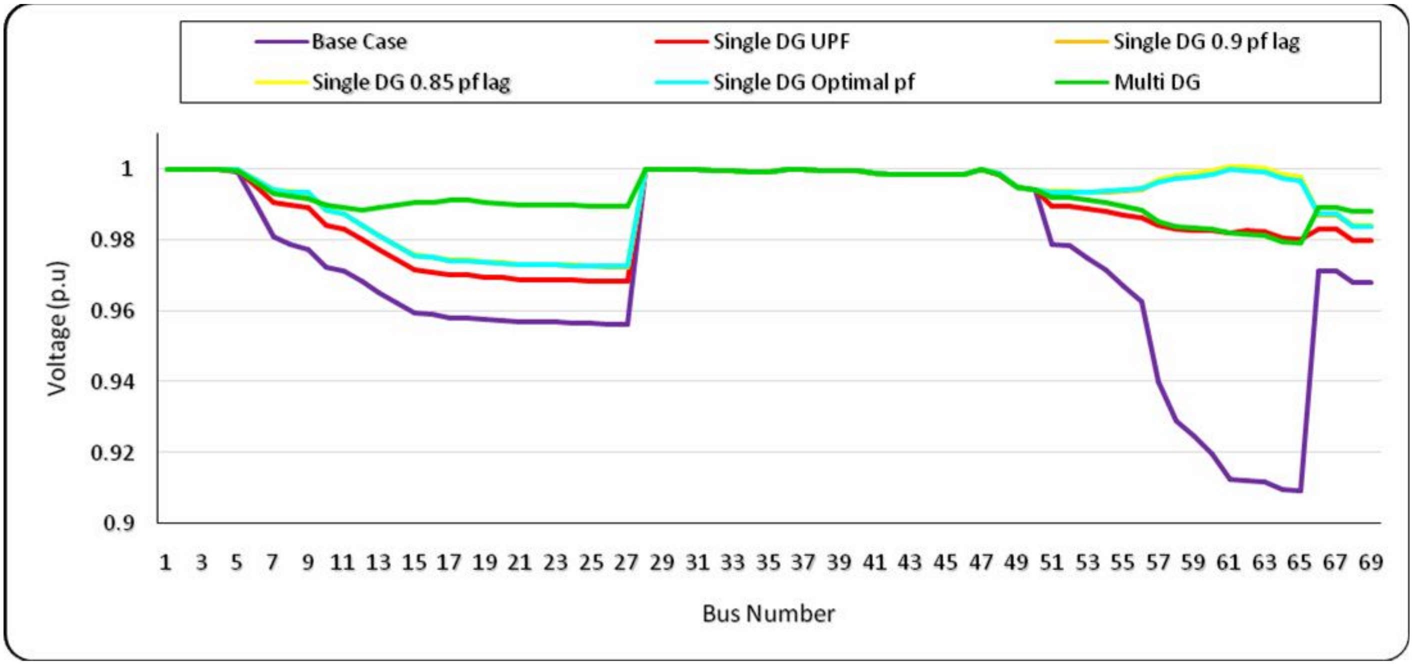

Figure 3. Variation in Voltage Profile of IEEE 69 bus RDS with implementation of various DGs.

Voltage Profile: Figure 3. represents the effect of the change in the number & power-factor of DG on the voltage profile, utilizing the aforementioned optimization approach and conducting the load flow analysis; the new voltage profile on the application of DG at the ideal position and the size determined shows the minimum value after DG implementation is more significant than the base case and keeps improving on increasing number of DGs and as the pf moves to its optimal value of 0.81496 pf lag.

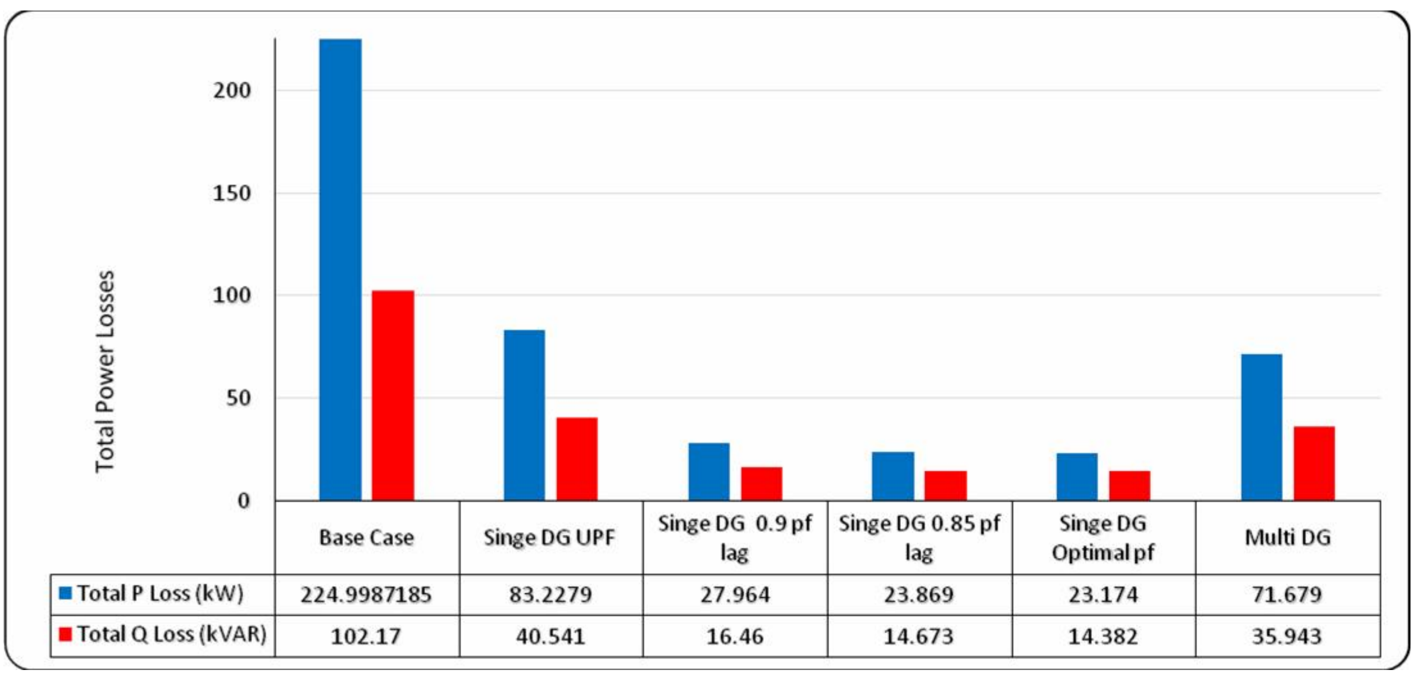

Figure 4. Variation in Total Power Losses of IEEE 69 bus RDS with implementation of various DGs.

*Power Losses:*Figure 4. indicates the decrease in the total active and reactive power losses on implementing of DGs with the total power loss saving being 141.77 kW, 197.03 kW, 201.13 kW, 201.824 kW when implementing single DG at UPF, 0.9 pf lag, 0.85 pf lag, and optimal value of 0.81496 pf lag & 153.32 kW when implementing multiple DG at UPF. Table 3 represents the variation of parameters on DG allocation.

Table 3. Effect of various Type of DGs on IEEE 69 bus RDS.

Parameters	DG Allocation Size (Location) (kVA)	Total P_{loss} (kW)	Total Q_{loss} (kVAR)	%P_{loss} Reduction	% Q_{loss} Reduction	Min Voltage p.u (Bus)
Base Case	-	224.998	102.166	-	-	0.9092 (65)
Single DG UPF	1872.823 (61)	83.228	40.541	63.01%	60.32%	0.9683 (27)
Single DG 0.9 lag	2217.441 (61)	27.964	16.46	87.57%	83.89%	0.9724 (27)
Single DG 0.85 lag	2240.445 (61)	23.869	14.673	89.29%	85.64%	0.9726 (27)
Single DG Optimal pf	2244.142 (61)	23.174	14.382	89.70%	85.92%	0.9725 (27)
Multi DG	531.523 (17) 1781.579 (61)	71.679	35.943	68.14%	64.82%	0.9789 (65)

4. Conclusions

In this paper power loss minimization is achieved with the deployment of DG by either increasing the number or tweaking the pf of DG thereby reducing the cost of energy along with significant improvements to the voltage profile. This enhances the system's efficiency, reliability and quality of power. The authors conclude that altering the pf from unity to the optimum value reduces power losses more prominently than increasing the number of DGs. On the other hand, increasing the number of DGs rather than altering the pf improves voltage profile significantly better. As a result, a trade-off must be made between the two DG variants, which can be extremely useful for deploying DGs in RDS according to the requirements. The authors find that the computation time for the GWO approach is significantly smaller than that of the PSO and GA techniques with equivalent accuracy. This approach may be used to realistic load models with DGs and FACTS controllers as well as practical systems that can save a significant amount of time and storage space.

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