

# Optimal allocation of solar and wind distributed generation using particle swarm optimization technique

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## ABSTRACT

Power demand in the current days is increasing more and more where the conventional power generation systems are failing to meet these power demands due to less availability of non-renewable resources. Hence, many of the researchers are working on the distributed generation (DG) by using renewable resources like wind and solar. The penetration towards wind, solar DG faced challenging situations during power generation due to uncertainty in the wind speed and solar radiation. Recent studies have predicted that the combination of both solar and wind can lead to better performance. However, the sizing and placement of DG systems is necessary to achieve efficiency otherwise the systems may lead to adverse effects in distribution networks. This paper introduced the solar DG, wind DG and hybrid (solar and wind) DG system. The particle swarm optimization technique is used to size and place the DG because of its parallel search capability. Also, the combination of wind-solar DG gives better DG sizing in the respective DG location. The voltage profile of these DG systems has shown better results for the efficient power system. In comparison to conventional DG systems, the suggested hybrid DG system is capable of minimizing power loss and maintaining voltage profile.

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## 1. INTRODUCTION

The development and implementation of distributed generation technology (DG-T) allows power to be generated according to the load side of the consumer. The consumer is connected with the power grid or the multi-generation system including solar or wind and other forms of the renewable power generation systems. The problem of these distributed generators placement in the grid system is an essential requirement for a balanced consumption of the energy as per the optimal proximity. In another word, the DG-T is a low scale or dimension power generation mechanism at lower voltage to facilitate the electric power in the closer proximity of the consumer as compared to the base power generation system. There are various terminologies used for such systems few to name it includes: i) distributed resources of energy (DRE), ii) load side power generator (LSPG), and iii) distributed or decentralized energy generators (DEG). The common power generation sources include wind, solar, diesel and gas along with micro-turbines and engines [1].

The implementation of electricity generation technologies near the end user load point is known as distributed generation (DG) [1], [2]. The power generation systems may be of some modular technologies or renewable energy-based system is used as DG [3]. The DG system will be a perfect replacement for a traditional power generation system only if it provides a low cost, highly reliable and secure alternative. The

very important advantage of DG system-based power consumption society is to meet the goal of green energy [4]. The capacity ranges from 10 to 1,000 MW for DG-based power production systems [5]. It is critical to locate the DG system ideally in relation to its size in order to maximize the DG system's utility. The placement or localization of DG has direct impact of location of installation, the climatic condition of the location, the available resources, and size.

Various research works have given different techniques to have better DG placement and sizing. Magadam and Kulkarni [6] address the issue of multiple DG placement and sizing with the goal of minimizing power loss while staying within a safe voltage range. The solution for the DG placement uses fuzzy logic. The model validation takes place on IEEE 33 bus system. The fuzzy logic works well in case of uncertainty but within the defined rule set that limits its scope if the uncertainty is beyond the defined rule set. The use of swarm-based optimization models brings parallelism into the search space so that the time complexity reduces. One of the solutions [7] employs a particle swarm optimization (PSO)-based optimization strategy to reduce loss and facilitate optimal DG placement. The DG placement is a multivariate optimization problem, where methods like harmony search are being utilized over IEEE 33-bus that results minimization of the power loss [8]. The minimization of load consumption by maintaining a threshold voltage is the core objective of a popular energy saving scheme, namely the integration of DG and conservation voltage reduction (CVR). In order to investigate the interaction between DG and CVR, an optimization model on 37-bus distribution system is formulated and solved using stochastic method of average approximation algorithm and the energy consumption is minimized [9].

The DG allocation problem is most prevalent in distribution systems of medium and small size. In order to overcome the problem of allocation, an effective Chu-Beasley genetic algorithms is employed in the study of three different bus systems, including the 10, 34, and 70-bus. The performance analysis shows a better location for DG placement, reduced active power losses, and increased voltage level [10]. Though the genetic algorithms provide the best solution, it has a memory overhead due to its iterative nature. The power demand for the various industries, research areas, commercial aspects is growing at a higher pace by which the fulfilment of power distribution in current trend has become a major concern. Hence, many of the DG systems are facing problems with power quality which needs an optimization mechanism. In this regard, Haddad and Akkar [11] introduced a sequential quadratic programming (SQP) mechanism which is composed of a 3-phase 4-wire distribution network for parallel synchronization of voltage enhancement and voltage unbalancing. The SQP mechanism retains its power quality even at higher rate of power generation. The author has not addressed the impact of voltage non-linearity, system losses under weak transmission networks in the DG. Hocine and Djamel [12] have come up with solutions for the enhancement of system stability as well loss reduction mechanism i.e., fast voltage stability index (FVSI) distribution [12]. The distribution losses due to active and reactive power during DG and capacitor placement have not been addressed. The solution to improve active and reactive power compensation is described in [13] where the PSO method is used and on the IEEE 33 bus system, it has been validated.

The compensatory technique's drawback is that it results in an increase in demand range and DG installation while maintaining a sophisticated and reliable power system. A genetic algorithm is adopted by the author in the referred work is to establish the optimal distribution and achieve the higher power quality and minimize the system losses [14]. Similarly, the problem of DG allocation with respect to system flexibility, an adaptive protection mechanism is presented in [15]. This method aids in the reduction of power losses and by properly allocating DGs improves voltage performance. The voltage nonlinearity has been addressed in [16] where inertia weight PSO technique which is beneficial in enhancing the DG performance and offers higher penetration level towards renewable energy sources. The system performance analysis suggests that it has better convergence speed that helps to enhance the system economy and ecology. The nonlinearity or unexpected power demands can lead to system failure, and it can lead to poor power quality, hence Prakash [17] has presented a collaborative DG system that composes wind and solar energy systems. The DG system works on the basis of three-point estimate that offers optimal and probabilistic load flow. However, power losses during allocation of DG are not addressed with this collaborative DG system. The investigational analysis on the losses due to DG allocation and power system sizing has been addressed in [18] where fuzzy logic scheme is introduced to analyze the power losses. The performance of both the IEEE 69 bus system and the IEEE 33 bus system is analyzed, with the fuzzy logic scheme-based DG system having lower power losses. Sarwar *et al.* [19] had offered numerous DG allocation methodologies such as marginal price and price locational difference, total congestion rent revenue, and total savings as a means of achieving optimal DG placement. These approaches are implemented and tested over IEEE 14 bus system and their performance is analyzed.

Biogeography based optimization (BBO) methodology is used to have optimal placement of DG and capacitor [20], which addresses system losses and minimization through both power active and reactive method of compensation. The performance of BBO based techniques is analyzed with PSO based technique

over IEEE 13 node system. The concerns of non-optimal DG placement led to power system losses as it exhibits steady state parameter. To address this issue and offer optimal DG allocation, Lukianenko *et al.* [21] had presented Monte Carlo mathematical model for available IEEE standard test system. The work comes up with the notion of cooperating both DG and PSO in a radial distribution system [22]. The collaborative system is analyzed for power losses and voltage profile linearity over IEEE 33 and 69 bus system. The appropriate location of a DG system in the power system is critical for managing the voltage level and minimizing power losses. Such work is found in [23] where Monte Carlo method is used over IEEE-bus system comprising of 14 nodes. The islanding problem in the power system leads to system failure which needs to be addressed for better distribution of the power. Narayanan *et al.* [24] have addressed the islanding problem by presenting the 2-stage genetic algorithm approach. The approach is validated over IEEE 33 and 69 bus system and found that it helps to achieve faster convergence in results. The hierarchical method to rank the alternative solutions (technique for order of preference by similarity to ideal solution or TOPSIS) for the thermal power plant system is presented by Fu *et al.* [25] which the technical, economic, and environmental contexts are taken into account. The outcomes suggest that the IEEE 24 bus system with 10-generators and 38 power lines can offer efficient performance. However, TOPSIS approach has not addressed the reduction of power losses and DG placement issues with the mathematical model.

If the DG place is not chosen optimally, then there will be many operational deficiencies that may lead to power losses, hence the cost will be higher. Therefore, the optimal DG placement is a very essential requirement to get quality power with fewer harmonic in lower cost reliably and securely. This manuscript provides the swarm optimization concept for solar, wind DG placement and sizing. The manuscript is divided into various sections as follows: section 2 contains the problem statement, section 3 contains the proposed renewable generation systems, section 4 contains the results analysis, and section 5 contains the conclusion.

Due to urbanization, demand for electricity has been increasing more rapidly in recent days where the traditional power generation or supply units are failing to meet these demands. Also, it is a very challenging task to meet clean, stable, and efficient power generation with endangering fossil fuels. Hence, various research attempts were made towards power generation through renewable resources i.e., wind and solar. The focus is given on these resources-based DG. However, the penetration towards wind, solar DG faced challenging situations during power generation due to uncertainty in the wind speed, solar radiations that leads to unstable power generation. Recent studies have predicted that the combination of both solar and wind can bring stability to the DG. However, in order to attain efficiency, DG systems must be properly sized and placed; otherwise, the systems may have negative consequences on distribution networks. The consideration of the optimization algorithms can bring proper sizing and placement of DG. According to current studies, solar and wind DGs are constructed individually, and research combining both solar and wind DGs is uncommon. Also, the implementations of optimization algorithms over the combined DG systems are very less. Thus, there is a need for a system that can offer efficient sizing and placement of DG.

## 2. PROPOSED RENEWABLE DISTRIBUTED GENERATION SYSTEMS

This manuscript describes the different forms of DG system design using wind, solar and integrated (solar and wind) DG. The DG's appropriate placement is critical for improving power quality and reducing power loss while meeting demand. As a result, the suggested DG systems use a PSO-based algorithm. The objective functions are addressed further down.

Based on power supply and user demand, the active power losses should be minimized, and voltage stability can be maximized for effective DG placement and sizing. For the N-bus system, the active power losses can be reduced by using (1):

$$f_{\text{loss}} = \sum_{i=1}^{N-1} m_i \times R_i \left( \frac{P_i^2 + Q_i^2}{V_i^2} \right) \quad (1)$$

where  $m$  is line,  $R_i$  is branch resistance,  $V_i$  is voltage magnitude,  $P_i$  is active power, and  $Q_i$  is reactive power at bus  $i$ . The voltage stability index ( $V_{\text{stab}, m}$ ) is used for power flow solution [26] and is represented in (2):

$$V_{\text{stab}, m} = \frac{4[(P_j R_{ij} + Q_j X_{ij})V_i^2 + (P_j X_{ij} - Q_j R_{ij})]}{V_i^4} \quad (2)$$

where  $m$  is line,  $R_i$  is branch resistance,  $X$  is reactance,  $i$  is sending bus, and  $j$  is receiving bus.

For a stable system, voltage stability at each of the branches must be less than 1. However, if the system is made up of crash buses, the voltage stability may be compromised. Hence, the voltage stability is analyzed within voltage stability index ( $V_{\text{stab}, m}$ ) and 1. The maximum  $V_{\text{stab}}$  is represented in (3):

$$fV_{stab} = \max\{V_{stab,1}, V_{stab,2}, V_{stab,3}, \dots, V_{stab,N}\} \quad (3)$$

where,  $f$  indicates the dual objective function to reduce the losses and improve voltage stability. The optimization function of  $f$  can be given by using the weight coefficient approach and it is represented in (4).

$$\min f = a \times w_1 \left( \frac{f_{ploss}}{ploss_{init}} \right) + a \times w_2 \left( \frac{f_{Vstab}}{V_{stab_{init}}} \right) \quad (4)$$

In (4), power loss (real) and voltage stability index considered initially is represented as  $ploss_{init}$  and  $V_{stab_{init}}$ , respectively. The variables  $a$  and  $b$  are respective penalty factors for the active power loss and voltage (static) stability index, and it is represented in (5).

$$a = \left\{ \begin{array}{ll} \text{if } \frac{f_{ploss}}{ploss_{init}} \geq 1, & a = N \\ \text{else} & a = 1 \end{array} \right\} \text{ and } b = \left\{ \begin{array}{ll} \text{if } \frac{f_{Vstab}}{V_{stab_{init}}} \geq 1, & b = N \\ \text{else} & b = 1 \end{array} \right\} \quad (5)$$

The equation suggests that the greater level of optimization in the real power losses than the initial value of no DG system, then  $a = \text{bigpositive\_value } (N)$  enhances objective function  $f$  value i.e., optimal solution else  $a = 1$ . Similarly, the value of  $b$  is updated.

The weighting factors  $w_1$  and  $w_2$  are meant with active power loss and voltage (static) stability index, respectively. Generally, the addition of these to factor  $w_1 + w_2 = 1$ . Also, if ( $w_1 = 1$ ) and ( $w_2 = 0$ ), then the single objective optimization is referred as real power loss else voltage stability index.

The following constraints [27] are addressed during the optimization process i.e., power equality, voltage, active power loss, DG size.

- Power equality constraint: the power equality constraints can be expressed using (6),

$$\begin{aligned} P_{gi} - P_{di} - V_i \times \sum_{j=1}^{N_{bus}} V_j Y_{ij} \cos\{\theta_{ij} + \delta_j - \delta_i\} \\ Q_{gi} - Q_{di} - V_i \times \sum_{j=1}^{N_{bus}} V_j Y_{ij} \sin\{\theta_{ij} + \delta_j - \delta_i\} \end{aligned} \quad (6)$$

where  $i$  is number of buses  $1, 2 \dots N_{bus}$ ,  $P_{gi}$  is power generated(real) at  $i^{th}$  bus,  $Q_{gi}$  is power generated (reactive) at  $i^{th}$  bus,  $P_{di}$  and  $Q_{di}$  are the power demands at  $i^{th}$  bus,  $V_i$  is voltage at  $i^{th}$  bus,  $V_j$  is voltage at  $j^{th}$  bus,  $Y_{ij}$  and  $\theta_{ij}$  is complex value of admittance of branch connecting the bus  $i$  and  $j$ . And this (6) is equated to zero.

- Voltage constraint: the magnitude of voltage  $V_i$  needs to be lie between maximum ( $V_{max}$ ) and minimum voltage ( $V_{min}$ ). The range of voltage constraints: ( $V_{max} \leq V_i \leq V_{min}$ ).
- Active power loss: once the DG is installed, active power losses are required to be less than or equal to the losses before the DG is included in the system considered (no DG).
- DG size: the DG size should not be too high or too small with respect to the load demand. Also, the size of DG should not be taken as zero or more than total power (active) demand.

### 3.1. Solar DG modeling

The maximum power output of photovoltaics (PV) array modules can be computed as given in (7).

$$P_{pv} = N_s N_p P_{md} \quad (7)$$

$P_{md}$  is the PV module maximum power defined in (7),  $N_s$  is the series connected PV modules,  $N_p$  is the number of parallel connected PV modules. Maximum module power is as defined in (8) where  $V_{oc}$  represents voltage at the output terminals of the PV module during open circuit while  $I_{sc}$  denotes current during short circuit of the PV module. Fill factor ( $FF$ ) in (4) is the light sensitive area in the solar panel.

$$P_{md} = FF \times V_{oc} \times I_{sc} \quad (8)$$

$$V_{oc} = \frac{V_{Noc}}{1 + C_2 \times \ln\left(\frac{G_N}{G_A}\right)} \times \left(\frac{T_N}{T_A}\right)^{C_1} \quad (9)$$

$$I_{sc} = I_{Nsc} \left(\frac{G_A}{G_N}\right)^{C_3} \quad (10)$$

$$FF = \left(1 - \frac{R_s}{\frac{V_{oc}}{I_{sc}}}\right) \times \frac{\left\{ \frac{V_{oc}}{q} - \ln \left( \frac{V_{oc}}{nKT} + 0.72 \right) \right\}}{1 + V_{oc} \frac{1}{nKT/q}} \quad (11)$$

Where  $G_N$  and  $G_A$  are the nominal and actual solar irradiation of the module;  $T_N$  and  $T_A$  are module's nominal and actual temperature, respectively;  $V_{Noc}$  and  $I_{NSC}$  are PV module's nominal open circuit voltage and short circuit current;  $R_s$  is the module's series resistance;  $c_1$ ,  $c_2$ , and  $c_3$  are different constants which indicates non-linear relationship between photo-current, cell temperature, and solar irradiance;  $n$  is module's density factor ( $n = 1.5$ );  $T$  is the temperature of module (in Kelvin);  $K$  is Boltzmann constant ( $1.38 \times 10^{23}$  J/K); and  $q$  is the charge of electron ( $1.6 \times 10^{19}$  C).

### 3.2. Wind DG modeling

Wind energy conversion systems (WECS) are classified into two types based on their rotational speed: fixed speed and variable speed. A direct grid coupled induction generator makes up the fixed speed wind turbine generating units (WTGU). Variable speed WECS is commonly utilized, with real power production varying with wind speed [28]. Power generated for different ranges of wind energy is defined in (12).

$$P_w = \begin{cases} 0 & V_w < V_{cin} \text{ or } V_w > V_{cout} \\ P_{rated}(V_w - V_{cin}) / (V_N - V_{cin}) & V_{cin} \leq V_w \leq V_N \\ P_{rated} & V_N \leq V_w \leq V_{cout} \end{cases} \quad (12)$$

The wind speed range for which WECS generates power is between the nominal wind speed  $V_N$ , and the cut-out wind speed ( $V_{cout}$ ). Average wind speed  $V_w$  lies between cut in speed and average speed. Rated wind power generator given the average wind speed, power coefficient is as given in the (13).

$$P_{rated} = 0.5 \rho A v_w^3 C_p \quad (13)$$

The equation defines the rated wind generation power ( $P_{rated}$ ) with power coefficient  $C_p$  density of air,  $\rho$  area occupied by rotor  $A$ . The wind energy generation is modeled using these equations.

### 3.3. PSO approach

PSO is a variational evolutionary algorithm for solving optimization problems. This strategy is focused mainly on population and interaction of various members of the population, which was inspired by organism movement that includes flock of birds or a school of fish. The PSO method [29] involves updating the particle's velocities and locations, as shown in (14) and (15):

$$V_{k+1}^i = wv_k^i + C_1r_1(p_{best}^i - x_k^i) + C_2r_2(gbest_k - x_k^i) \quad (14)$$

$$x_{k+1}^i = x_k^i + v_{k+1}^i \quad (15)$$

Where  $k$  is article count,  $i$  is iteration count  $r_1$ ;  $C_1, C_2$  are learning factors;  $r_1, r_2$  are random numbers from 0 to 1;  $x$  is the new particle;  $V$  is velocity; and  $w$  is inertia.

The flow of the algorithm is given below. Using a PSO-based method, the best location and scale of the DG problem minimizes the cost and real power loss.

Step 1: Line data (line resistance and reactance) and bus data (with loads connected) with bus voltage limitations are collected as input data.

Step 2: Line loss is calculated using the distribution load flow.

Step 3: Initialize  $k = 0$  for counter to generate.

Step 4: Generate an erratic population with random positions and velocities.

Step 5: Make  $C=2$  the bus count.

Step 6: Using (1), compute the total loss for each particle.

Step 7: Verify the voltage restrictions on the bus. When the limit is exceeded, the particle becomes infeasible.

Step 8: Considering each particle, the obtained value is compared to the best value of individual particle. So, this value is referred as current  $P_{best}$  and update the related particle position if the value is smaller than  $P_{best}$ .

Step 9: The particle connected with the lowest personal best is selected ( $P_{best}$ ), and this  $P_{best}$  is updated as the global  $gbest$ .

- Step 10: The velocity and position of the particle are estimated and (14) and (15) were used to update, respectively.
- Step 11: If the bus's count reaches the maximum, proceed to step 12. Otherwise, return to step 6 and initialize bus count  $C=C+1$ .
- Step 12: Proceed to Step 13 if the generator bus number reaches its limit. Otherwise, return to step 4 and set generation index  $K=K+1$ .
- Step 13: The best solutions are found.

### 3. RESULTS AND ANALYSIS

MATLAB is used to analyze the proposed renewable DG systems over the IEEE 33 bus infrastructure as shown in Figure 1. There are 32 lines in the bus system, 33 loads, and end nodes 18, 22, 25, and 33. The voltage levels on these buses are 12.66 kV, with a rated megavolt-ampere (MVA) of 100.

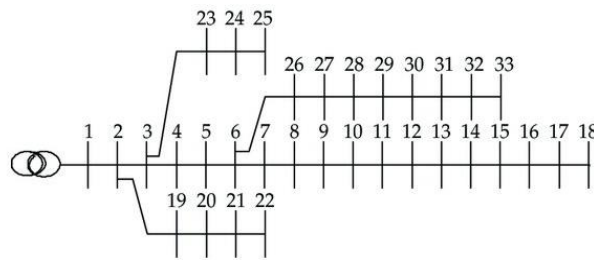


Figure 1. IEEE 33 bus systems

The load and line database are used for the 33-bus system and extracted respective active power (P), reactive power (Q), resistance (R), and reactance (X). Using rated MVA and kV, base impedance (Zb) is calculated and then per unit value of the R, X, P, and Q is calculated using Zb. The obtained results of power loss (active and reactive), DG location, power generated by solar, wind, solar-wind DG are tabulated in Table 1. Table 1 shows that the active and reactive power losses in solar DG are lower than those in wind DG. The solar DG has a capacity of 1,190 kW at optimal bus site 29, whereas the wind DG has a capacity of 470 kW at the 17<sup>th</sup> bus. Also, the combination of wind-solar DG gives better DG sizing in the respective DG location. Figure 2 shows the voltage profile of the solar DG at different bus. The maximum voltage profile is observed on bus 18 and minimum on bus 17.

Table 1. DG types and its performance results

Type of DG/Result	Solar DG	Wind DG	Solar-Wind
Active power loss	$1.57 \times 10^2$ kW	$1.89 \times 10^2$ kW	$1.26 \times 10^2$ kW
Reactive power loss	$1.05 \times 10^2$ kVAR	$1.21 \times 10^2$ kVAR	$8.34 \times 10^2$ kVAR
DG location	29	17	29 & 17
DG sizing	1190 kW	470 kW	1660 kW

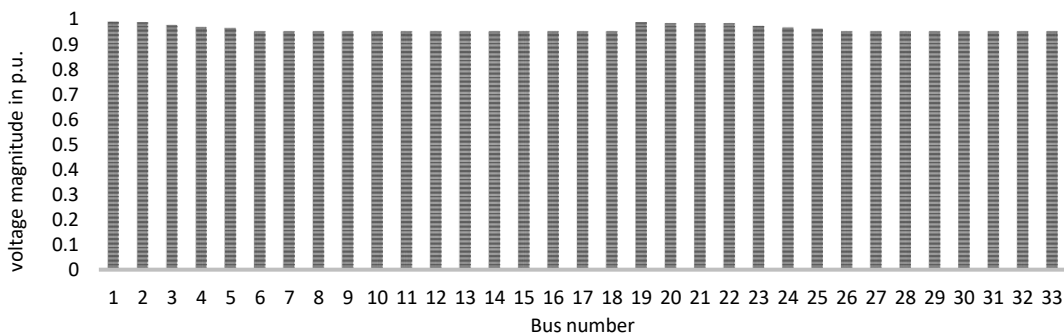


Figure 2. Voltage profile of solar DG at different bus number

Figure 3 shows the voltage profile of wind DG at different buses. The maximum voltage profile is observed at bus 18 and minimum at bus 33. Figure 4 shows the voltage profile of combined solar-wind DG at different buses where maximum voltage profile is observed at bus 18 and minimum at bus 33.

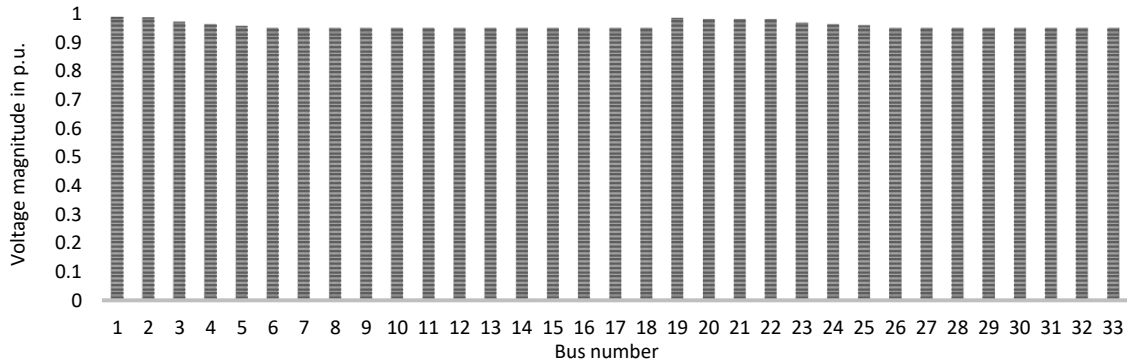


Figure 3. Voltage profile of wind DG at different bus number

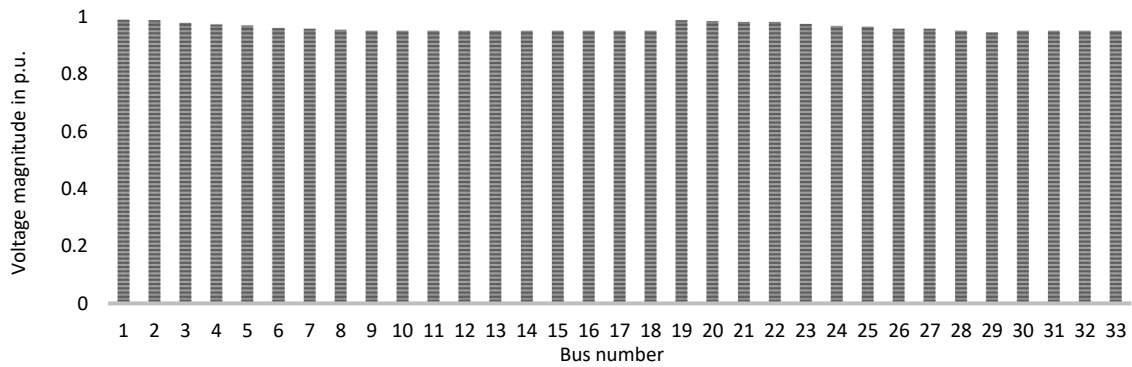


Figure 4. Voltage profile of solar-wind DG at different bus number

The performance analysis of the proposed system is given in Table 2 where existing system is considered (approach: hybrid grey wolf optimizer) with average active power loss and voltage profile [30]. From the analysis, it is observed that the proposed PSO algorithm is able to minimize the power loss and maintain the voltage profile in the proposed DG systems than the existing approach [30]. The hybrid (solar wind) DG reduces the active losses than the individual solar or wind DG system.

Table 2. Analysis for comparison of present and previous work

Method	Parameter/DG type	Solar	Wind	Solar-Wind
Sambaih <i>et al.</i> [30]	Average power loss in kW	16.6	24.02	16.17
	Average voltage magnitude in p.u.	0.98	0.96	0.98
Proposed technique	Average power loss in kW	9.54	11.50	7.66
	Average voltage magnitude in p.u.	0.94	0.94	0.95

#### 4. CONCLUSION

This paper introduced the solar DG, wind DG and combined (solar and wind) DG system to make distributed system more reliable. The sizing and placement of the DG is performed by using the PSO technique as it is simple in implementation, offers robust controlling at better computational complexity and high parallel search capability. The DG systems are tested on IEEE 33 bus system where it is observed that the size of the solar DG is 1190 kW at optimal bus location 29 while wind DG exhibits 470 kW DG size located at 17<sup>th</sup> bus. Also, the hybrid wind-solar DG gives better DG sizing (allocation) in the respective DG location. A better voltage improvement is observed with hybrid DG systems. The hybrid (solar wind) DG reduces the active power losses than the individual solar or wind DG system.

## REFERENCES




- [1] M. Huneault and F. D. Galiana, "A survey of the optimal power flow literature," *IEEE Transactions on Power Systems*, vol. 6, no. 2, pp. 762–770, May 1991, doi: 10.1109/59.76723.
- [2] K. Zehar and S. Sayah, "Optimal power flow with environmental constraint using a fast successive linear programming algorithm: Application to the algerian power system," *Energy Conversion and Management*, vol. 49, no. 11, pp. 3362–3366, Nov. 2008, doi: 10.1016/j.enconman.2007.10.033.
- [3] M. Shahidehpour and V. Ramesh, *Nonlinear programming algorithms and decomposition strategies for OPF*. In *IEEE/PES tutorial on optimal power flow*. IEEE: New York, NY, USA, 1996.
- [4] J. S. Lipowski and C. Charalambous, "Solution of optimal load flow problem by modified recursive quadratic-programming method," *IEE Proceedings C Generation, Transmission and Distribution*, vol. 128, no. 5, pp. 288–294, 1981, doi: 10.1049/ip-c.1981.0048.
- [5] F. Capitanescu, M. Glavic, D. Ernst, and L. Wehenkel, "Interior-point based algorithms for the solution of optimal power flow problems," *Electric Power Systems Research*, vol. 77, no. 5–6, pp. 508–517, Apr. 2007, doi: 10.1016/j.epsr.2006.05.003.
- [6] R. B. Magadam and D. B. Kulkarni, "Optimal placement and sizing of multiple distributed generators using fuzzy logic," in *2019 Fifth International Conference on Electrical Energy Systems (ICEES)*, Feb. 2019, pp. 1–6, doi: 10.1109/ICEES.2019.8719240.
- [7] K. Zou, A. P. Agalgaonkar, K. M. Muttaqi, and S. Perera, "Voltage support by distributed generation units and shunt capacitors in distribution systems," in *2009 IEEE Power & Energy Society General Meeting*, Jul. 2009, pp. 1–8, doi: 10.1109/PES.2009.5275628.
- [8] V. Kona and R. Kollu, "A multi-objective approach for Dg and capacitor placement using harmony search algorithm," in *2017 Ninth International Conference on Advanced Computing (ICoAC)*, Dec. 2017, pp. 320–325, doi: 10.1109/ICoAC.2017.8441380.
- [9] Z. Wang, B. Chen, J. Wang, and M. M. Begovic, "Stochastic DG placement for conservation voltage reduction based on multiple replications procedure," *IEEE Transactions on Power Delivery*, vol. 30, no. 3, pp. 1039–1047, Jun. 2015, doi: 10.1109/TPWRD.2014.2331275.
- [10] I. F. Prado and L. P. Garces, "Chu-Beasley genetic algorithm applied to the allocation of distributed generation," in *2013 IEEE PES Conference on Innovative Smart Grid Technologies (ISGT Latin America)*, Apr. 2013, pp. 1–7, doi: 10.1109/ISGT-LA.2013.6554425.
- [11] S. Q. G. Haddad and H. A. R. Akkar, "Intelligent swarm algorithms for optimizing nonlinear sliding mode controller for robot manipulator," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 5, pp. 3943–3955, Oct. 2021, doi: 10.11591/ijece.v11i5.pp3943-3955.
- [12] S. Hocine and L. Djamel, "Optimal number and location of UPFC devices to enhance voltage profile and minimizing losses in electrical power systems," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 5, pp. 3981–3992, Oct. 2019, doi: 10.11591/ijece.v9i5.pp3981-3992.
- [13] S. Kansal, V. Kumar, and B. Tyagi, "Composite active and reactive power compensation of distribution networks," in *2012 IEEE 7th International Conference on Industrial and Information Systems (ICIIS)*, Aug. 2012, pp. 1–6, doi: 10.1109/ICIInfS.2012.6304764.
- [14] M. Jahromi, E. Farjah, and M. Zolghadri, "Mitigating voltage sag by optimal allocation of distributed generation using genetic algorithm," in *2007 9th International Conference on Electrical Power Quality and Utilisation*, Oct. 2007, pp. 1–6, doi: 10.1109/EPQU.2007.4424197.
- [15] S. M. Brahma and A. A. Girgis, "Development of adaptive protection scheme for distribution systems with high penetration of distributed generation," *IEEE Transactions on Power Delivery*, vol. 19, no. 1, pp. 56–63, Jan. 2004, doi: 10.1109/TPWRD.2003.820204.
- [16] L. Jiang and Q. Yang, "Maximizing DG penetration in power distribution networks based on cost/benefit analysis," in *2016 35th Chinese Control Conference (CCC)*, Jul. 2016, pp. 2872–2877, doi: 10.1109/ChiCC.2016.7553800.
- [17] P. Prakash, "Placement of distributed generation in radial distribution system by considering uncertainty of load demand," in *2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Oct. 2018, pp. 239–243, doi: 10.1109/ICPEICES.2018.8897462.
- [18] G. Sabarinath. and T. G. Manohar, "Optimal placement and sizing of distributed generation using flower pollination algorithm for power loss reduction maximization in distribution networks," in *2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Oct. 2018, pp. 253–256, doi: 10.1109/ICPEICES.2018.8897436.
- [19] M. Sarwar, A. S. Siddiqui, Z. Jaffery, and I. A. Quadri, "Optimal placement of distributed generation for congestion management: A comparative study," in *2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Oct. 2018, pp. 229–233, doi: 10.1109/ICPEICES.2018.8897282.
- [20] T. Tom and R. Scaria, "Active and reactive power compensation in distribution system based on biogeography based optimization technique," in *2013 International Conference on Control Communication and Computing (ICCC)*, Dec. 2013, pp. 216–220, doi: 10.1109/ICCC.2013.6731653.
- [21] L. M. Lukianenko, I. S. Goncharenko, and O. V. Blonska, "Determination of the optimal placement and capacity of distributed generation," in *2014 IEEE International Conference on Intelligent Energy and Power Systems (IEPS)*, Jun. 2014, pp. 159–162, doi: 10.1109/IEPS.2014.6874170.
- [22] N. Kaur, K. Singh, and S. Kansal, "Optimal placement of distributed generator in transmission system using an algorithmic approach," in *2014 IEEE 6th India International Conference on Power Electronics (IICPE)*, Dec. 2014, pp. 1–6, doi: 10.1109/IICPE.2014.7115745.
- [23] I. S. Goncharenko, "Distributed generation optimal placement. Climatic pattern consideration," in *2016 2nd International Conference on Intelligent Energy and Power Systems (IEPS)*, Jun. 2016, pp. 1–4, doi: 10.1109/IEPS.2016.7521875.
- [24] Narayanan K, S. A. Siddiqui, and M. Fozdar, "Identification and reduction of impact of islanding using hybrid method with distributed generation," in *2015 IEEE Power & Energy Society General Meeting*, Jul. 2015, pp. 1–5, doi: 10.1109/PESGM.2015.7286467.
- [25] X. Fu, H. Chen, and X. Jin, "Study on effectiveness evaluation of the siting of DG based on a TOPSIS method-based approach," in *2013 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Dec. 2013, pp. 1–6, doi: 10.1109/APPEEC.2013.6837122.
- [26] A. Selim, S. Kamel, A. S. Alghamdi, and F. Jurado, "Optimal placement of DGs in distribution system using an improved Harris hawks optimizer based on single- and multi-objective approaches," *IEEE Access*, vol. 8, pp. 52815–52829, 2020, doi: 10.1109/ACCESS.2020.2980245.
- [27] S. Remha, "Optimal DG location and sizing for minimum active power loss in radial distribution system using firefly algorithm,"






- International Journal of Energetica*, vol. 2, no. 1, pp. 6–10, Jun. 2017, doi: 10.47238/ijeca.v2i1.20.
- [28] K. C. Divya and P. S. N. Rao, “Models for wind turbine generating systems and their application in load flow studies,” *Electric Power Systems Research*, vol. 76, no. 9–10, pp. 844–856, Jun. 2006, doi: 10.1016/j.epr.2005.10.012.
- [29] K. Bhumkittipich and W. Phuangpornpitak, “Optimal placement and sizing of distributed generation for power loss reduction using particle swarm optimization,” *Energy Procedia*, vol. 34, pp. 307–317, 2013, doi: 10.1016/j.egypro.2013.06.759.
- [30] S. K. Sampangi and J. Thangavelu, “Optimal allocation of wind and solar based distributed generation in a radial distribution system,” *International Journal of Renewable Energy Research*, vol. 9, no. 1, pp. 73–85, 2019.

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