An Optimization Approach for Significant Positioning and Sizing of Solar-based Distributed Generation

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Abstract- Electric Power is one of the daily needs for everyone, whether it may be commercial, residential, or industrial. With the increased use of power-dependent equipment/devices, the power demand increases, and it is impossible to meet this demand with the non-renewable resources of power. Considering naturally available resources for distributed generation (DG) can be a significant choice to meet the growing power demand. However, integrating the power system with renewable resources is a big task for balancing power demand. Further positioning and sizing of the DG is the primary concern in the power system, and the solution for the same can be obtained through different techniques. Most existing methods fail to address power loss minimization, DG positioning, sizing, voltage stability enhancement, etc. Hence, this paper introduces a modified PSO algorithm for optimal DG positioning and sizing with reduced loss and improved voltage stability. An analysis of the solar DG system is carried out over the IEEE 33 bus system, and it shows that the power loss reduction in solar DG (157 kW) is much better than the conventional system without DG (206 kW). The DG system's voltage stability with the proposed approach is 0.99, while the conventional system is 0.92. The analysis confirmed that the 29th bus is an optimal bus for solar DG placement, and the DG size is 1.19 MW. The proposed system is compared with similar approaches with better improvements in DG Size and nominal reduction in real power loss.

Keywords Solar, Distributed Generation, Particle Swarm Optimization, Power Loss, Voltage Stability Index, Positioning, Sizing.

1. Introduction

A Distributed Generation (DG) system can be positioned on-site or in a critical area of the power system connected with numerous connected devices [1]. This form of power generation in a demand area for power balance and maintaining the most negligible loss can be referred to as decentralized, connected, or embedded generation. The DG is mainly working on renewable resources like solar, wind, etc. [2]. The DG system aims to provide an effective solution for the growing power demand and fulfill them. Most current researchers mention that DG with renewable resources can replace the conventional power system [3]. Several research works have been executed to make the power system more effective with naturally available resources. These renewable resources provide eco-friendly power generation. However, DG systems have more dependency on climatic or environmental conditions [4].

The DG systems exhibit a particular purpose of generation, storage, and delivering power to the respective area of the customer demand end [5]. The DG system can be used in many places where the power demand is very high. Thus, DG systems are more suitable for replacing the conventional system under static and dynamic power requirements [6]. However, integrating power systems with renewable resources is the biggest concern concerning the available power demand and balancing the power demand. The conventional transmission lines cannot withstand the dynamic power demand and cannot balance load balancing with limited power loss [1-4].

DG positioning is one of the exciting research areas because of economic and reliability aspects. DGs can minimize the loss rate of power and impact the total capital investment by expanding the transmission and distribution of power systems. Hence, positioning and sizing the DGs are prime aspects of reducing loss and capital investment [4]. Optimally setting DG is a kind of optimization problem. Hence, many researchers have evolved with different approaches by assuming that DG can supply both real and reactive power by consuming reactive power proportionately.

Positioning and sizing of the DG is the primary concern in the power system wherein various authors have conveyed their solution with different techniques. The authors have provided optimization techniques for sizing and positioning through analytical modeling (Gozel et al., [6]) with power loss minimization. [Devi et al. [7], in their work, have given an analytical model to achieve reduced loss and voltage profile improvement. Further, an Ant Colony approach is introduced in (Rao et al. [8]) for loss minimization. Moravej et al. [9] and Tan et al. [10] found the Cuckoo Search algorithm's implementation to gain loss minimization and voltage profile enhancement. The problem of output uncertainty due to environmental factors is addressed in Eseye et al. [11], and a predictor subset selection mechanism is introduced to get efficient PV-based DG. The author has mentioned that integrating power grids and PV plants can enhance the power grid efficiency and reliability. The proposed prediction mechanism can offer an accurate prediction of power enhancement. Alam et al. [12] have introduced an estimation mechanism for distributed PV generation by considering the Kalman kriging filter. The kringer step provides the spatial correction for estimating PV output power at the PV module's unobserved location, and the filter enables the effective performance measurement. Farh et al. [13] implemented a search algorithm and the PSO technique to avail significant sizing and optimal localization of the renewable DG systems. The outcomes suggest that the search algorithm can handle the power flow problems more effectively than the meta-heuristic approaches. The installation of solar DG on the apartment building areas is always challenging; hence Fleischhacker et al. [14] have presented a sharing DG with optimization and game theory mechanism. The idea of integrating the local and grid-connected power management is presented in Ospina et al. [15], where a predictive model is used for real-time solar power management while minimizing the cost.

The solar DG parking lots are presented in Ivanova et al. [16], where load scheduling and feasible PV systems are designed to minimize PV infrastructure's extra cost in the microgrid system. The DG systems face reliability and safety concerns in the power grid, and these concerns are addressed in Xiong et al. [17] by incorporating the bacterial forging and PSO algorithm. This risk-based multi-algorithm mechanism offers a cost-effective and reliable solution over the 69 node bus system. Muqeet et al. [18] addressed the university campus's power management, where PV DG is introduced that copes with the intermittency of irradiance and offers low-cost grid energy. The concept of microgrids plays a more significant scope in the highest utilization of distributed resources. Mahmud et al. [19] have performed the sensitivity analysis of PV modules over human health and the ecosystem. Achieving seamless power transmission in the grid-connected DG system is always a significant concern. Such a problem is addressed in Singh et al. [20] and proposed a PV array-based DG system consisting of a power converter, voltage source converter, and different sources of non-linear loads. The outcomes of the DG model yields better performance even under the faulty condition and the non-linear load condition of the grid system.

The issues associated with the battery storage in Microgrids have been studied in Jayawardhana et al. [21], where the grid system is composed of more solar PV cells. The author has introduced an optimization framework that can optimize the charging and discharging of the battery storage. The cost of Microgrids is reduced by incorporating the predictive control mechanism. Huang et al. [22] have focused on solar irradiance forecasting and presented a neural network-based wavelet transform technique to improve the PV integrated power system's accuracy and reliability. The optimization of reactive power loss is addressed in Hao et al. [23] using a composed power system consisting of gas turbines, wind, and solar power generation units and achieved optimized results. The work of Sundararajan et al. [24] has performed a case study on the solar eclipse's impact on the PV-DG systems. A unique idea of Ha and Phung [25] has expressed the IoT enabled solar energy harvesting and achieved significant results that can be applied for intelligent buildings.

From the recent studies, it is found that the solar DG is a significant replacement for the traditional power system. However, optimization techniques are still needed to minimize power loss, DG positioning, sizing, voltage stability enhancement, etc. Also, the existing solutions with PSO approaches fall in a loop in which particles face issues finding a local solution rather than a global one. Hence, the proposed study's novelty favors identifying the suitable place and size for DG to meet necessary power demand. The paper contributes:

- ➢ To formulate objective function for power loss minimization, voltage stability index (VSI) enhancement, DG sizing, and DG positioning.

- To build solar irradiance modeling by using Beta Probability Density Function (B-PDF).
- To improve the PSO approach by considering the inertial weight factors ($w^e{}_f$) and acceleration factors, i.e., A_1 and A_2, the constraints that affect identifying the optimal solution (P_{best}) impact the performance.
- The modified PSO algorithm system considers the IEEE-33 radial distribution bus data, and it is assumed that all buses can generate power.
- The solar DG system analysis over the IEEE 33 bus test system and comparing power loss and voltage stability are performed against the conventional power system.

The paper is categorized as Problem formulation and objective function (Section-2), System design and PSO implementation (Section-3), Results and discussion (Section-4), and conclusion of the proposed method (Section-5).

2. Problem Formulations and Objective Function

The proposed system minimizes the objective function viz., minimizes power loss, voltage stability index (VSI) enhancement, DG sizing, and DG positioning.

2.1 Power loss

Authors [26] [27] have mentioned that 13% of the power loss occurs in a distributed system. Hence, the distributed system's objective function can be obtained from the two-bus system given in Fig.1. The Load flow is analyzed using the backward /forward sweep technique.

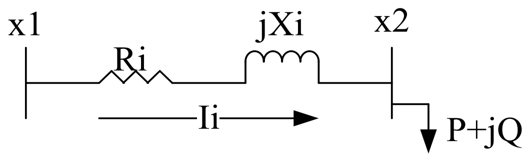

Fig. 1. Two bus system

The power loss in the distributed system at a particular branch 'i' can be obtained as [31-32]:

$$Pi = P_{x_2} + P_{iloss} \tag{1}$$

$$Qi = Q_{x_2} + Q_{iloss} \tag{2}$$

$$V_{x_2} = V_{x1} - I_i(R_i + jX_i) \tag{3}$$

The Real power (P_i) and reactive power (Q_i) at branch 'i' connect the buses x_1 and x_2. The Vx_1 and Vx_2 are voltage magnitudes at buses x_1 and x_2. The Resistance and reactance at branch 'i' are denoted as R_i and X_i. The current flowing between buses x_1 and x_2 is indicated as I_i. Eq. (1-3) uses forward /backward sweep technique to find the real, reactive loss and Voltages in the load flow analysis stage. The P_{x2} and Q_{x2} are the real and reactive power of the x_2 bus, which are acts as a load to the next bus connection, and it is continued till the 32nd bus in IEEE 33 bus system using the forward /backward sweep technique.

The power loss in each branch can be given as [31]:

$$P_{iloss} = R_i \times \frac{(P_{x_2}^2 + Q_{x_2}^2)}{\left|V_{x_2}^2\right|} \tag{4}$$

$$Q_{iloss} = X_i \times \frac{(P_{x_2}^2 + Q_{x_2}^2)}{\left|V_{x_2}^2\right|} \tag{5}$$

$$Total_{loss}(T_{loss}) = \sum_{i=0}^{i=Nbus-1} P_{iloss} + \sum_{i=0}^{i=Nbus-1} Q_{iloss} \tag{6}$$

Real and reactive power loss at branch 'i' is P_{iloss} and Q_{iloss}, respectively.

Therefore, the objective function can be represented as,

$$Ob_f = \min\left(\sum_{i=0}^{i=Nbus-1} P_{iloss}\right) \tag{7}$$

2.2 Voltage stability index (VSI)

The voltage stability of the proposed system can be analyzed as [33]:

$$VSI = \left|V_{x2}\right|^4 - 4\{P_{x1} \times X_i - Q_{x2} \times R_i\}^2 - 4\{P_{x2} \times R_i + Q_{x2} \times X_i\}\left|V_{x1}\right|^2 \tag{8}$$

The objective function can be given as,

$$Ob_{f2} = \max\left(\sum_{xi=2}^{Nbus} (VSI)_{x_i}\right) \tag{9}$$

Where x_i are branches and N_{bus} are the number of buses.

Maintaining security and stability (VSI) should be greater than '0'; otherwise, it will be of critical concern.

2.3 DG positioning

The bus-1 is considered a starting/slack bus; hence, the DG position must not be considered bus-1.

$$2 \le DG_{position} \le N_{buses} \tag{10}$$

2.4 DG sizing

The DG size must be maintained not more than the total power demand and should not be zero.

$$0 \le DG_{size} \le \sum_{i=1}^{N_{buses}} \tag{11}$$

3. System Design

The consideration of naturally available resources for DG can be a significant choice to meet growing power demand. The characteristic feature of solar irradiance plays a pivotal role in the output power of solar DG. The solar irradiance modeling can be performed using Beta Probability Density Function (B-PDF) and is highly recommended in many research works. The B-PDF at time 't' for the particular irradiance can be given as [28]:

$$b^t(s) = \begin{cases} \frac{\Gamma(m^t + n^t)}{\Gamma(m^t) \times \Gamma(n^t)} \times (s^t)^{m^t - 1} \times (1 - s^t)^{n^t - 1} \end{cases}$$

$$\text{at } 0 \le s \le 1; m, n \ge 0 \quad (12)$$

Where $b^t(s)$ is B-PDF at time t^{th} hours (s) is solar irradiance (KW/m2)

The statistical parameters are considered as m, n of $b^t(s)$ is represented in Eq. (13) as follows [28]:

$$m^t = \frac{\mu^t \times n^t}{(1-\mu^t)} \text{ and } n^t = (1-\mu^t) \times \left(\frac{\mu^t \times (1+\mu^t)}{(s^t)^2} - 1 \right) \quad (13)$$

Where μ is represented as a mean.

The probability of (s) at any time for different states (w) can be given as:[28]:

$$P(s_w^t) = \begin{cases} \int_0^{\frac{(s_w^t + s_{w+1}^t)}{2}} b^t(s)\,ds \;\; for\; w = 1 \\ \int_0^{\frac{(s_{w-1}^t + s_w^t)}{2}} b^t(s)\,ds \;\; for\; w = 2, \ldots (Nbs, s-1) \\ \int_0^{\frac{(s_w^t + s_{w+1}^t)}{2}} b^t(s)\,ds \;\; for\; w = Nbus, s \end{cases} \quad (14)$$

3.1 Solar DG generation

The output power of solar DG depends on solar irradiance at the site and the manufacturer's PV module characteristics. Therefore, power output (P^t_{solor}) at time 't' hours at state (w) can be given by [28]:

$$P^t_{solar} = \sum_{w=1}^{Nbs,s} P_{DG(solar),w} \times P(s^t_w) \quad (15)$$

Where, $P_{DG(solor),w}$ is the power output defined by the manufacturer at different steps (w). Using the below equations $P_{DG(solor),w}$ can be calculated as follows [28]:

$$T_{pv} = T_A + S_\mu \left(\frac{T_0 - 20}{0.8} \right) \quad (16)$$

$$I_w = S_\mu \left[I_{sc} + K_i (T_c - 25) \right] \quad (17)$$

$$V_w = V_{oc} - K_v T_{pv} \quad (18)$$

$$F_f = \left(\frac{V_{mpp} \times I_{mpp}}{V_{oc} \times I_{sc}} \right) \quad (19)$$

Where, T_{pv} is PV Cell temperature (^{0}C), T_A is Ambient temperature (^{0}C), S_μ is mean irradiance at state (w), T_0 is Operating temperature (^{0}C), I_w is total current at state (w), V_w is the total voltage at state (w), I_{sc} is short circuit current (A), V_{oc} is open-circuit voltage, K_i is current co-efficient (Amp/^{0}C), K_v is voltage co-efficient (volts/^{0}C), I_{mpp} is the maximum point of the current, V_{mpp} is the maximum point of Voltage, F_f is fill factor. So, the $P_{DG(solar),w}$ can be computed as follows [28]:

$$P_{DG(solar),w} = Pv_{total} \times F_f \times I_w \times V_w \quad (20)$$

3.2 Load Modelling

The proposed solar DG system is validated on the IEEE 33-bus load system. The mathematical modelling presented in prior sections are basically used in an integrated for in load modelling. In this case the input bus and line data are considered as an elementary data followed by configuring the voltage factor at all the nodes. This mechanism is further followed by evaluating the branch current as well as voltage and phase using backward and forward sweep propagation as exhibited in Fig.2. In case of convergence (using voltage for all nodes), the system computes the power losses followed by saving current and voltage. Further PSO is applied by initializing the population of particle. A specific iteration is set followed by checking of the multi-objective functions are satisfied. In positive case of satisfying the multi-objective function, the loss function is evaluated for each particle followed by initialization of P_{best} and G_{best} value. Further the velocity and particles are updated along with P_{best} and G_{best} value. The system checks for maximum iteration to filter the optimal outcome.

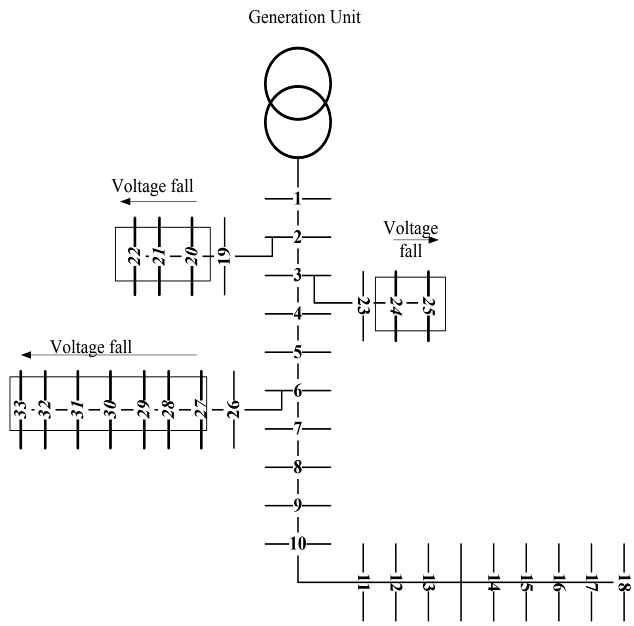

Fig. 2. DG integration and VSI flow to get optimal positioning

The time-varying load values of every hour are obtained from the load and line database. The problem associated with positioning and sizing of the DG is categorized into two parts, one for optimal positioning by identifying the nodes randomly in a DG system and another with sizing of DG by obtaining VSI from all the bus voltages to determine the weakest bus for DG integration. Also, VSI enhances the voltage stability of the DG system. The VSI performs the computation of the node's proximity to a voltage collapse in the DG system. Hence, the less values of VSI values than initial values of VSI are considered for the DG positioning. The flow for optimal DG positioning and sizing is given in Fig.2, where the IEEE-33 bus system is used. The nodes away from the primary distribution will have voltage fall than the initial values and are considered for the DG positioning while other nodes are neglected for DG positioning. In Fig.2, the nodes for positioning of DG are 20, 21, 22, 27, 28, 29, 30, 31, 32 and 33.

The algorithm for DG positioning and DG sizing is given below:

Algorithm for DG positioning and DG sizing

Input: IEEE-33 bus system data
Output: DG positioning and sizing
Start:
1. Consider→ Line and Load Data for DG
2. Extract → voltage (all bus)→ compute VSI
3. Combine→ nodes (less VSI) & integrate
4. Consider → nodes (less VSI) for DG positioning
5. Apply→ PSO for Optimization

End

As discussed above, the algorithm is incorporated to get optimal DG positioning and sizing. Finally, the PSO algorithm is modified with inertial weight factors ($w^e{}_f$) and acceleration, i.e., A_1 and A_2. The implementation of the PSO algorithm is given below.

3.3 Particle Swarm Optimization (PSO) for solar DG positioning and sizing

This technique works on the swarm intelligence concept, i.e., social interaction and solving the optimization issues. A combined study of Kennedy and Eberhart [29] has introduced the PSO technique that uses particles (swarm movement) in space to identify the reliable solution, i.e., Personal best (P_{best}). Every particle in PSO is considered a point where it interacts with other particles to get better results, i.e., global best (G_b). The optimization concept of PSO lies towards Pbest and G_{best} solutions at each time step. Every particle updates its current position to the best position (P_{best} and G_{best}). The particle position can be corrected by using the below equation [29].

$$v_i^{e+1} = w_f{}^e \times v_i^e + A_1 \times rand_1 \times (P_{best\,i} - s_i^e) + A_2 \times rand_2 \times (G_{best} - s_i^e) \quad (21)$$

Where v_i^e represents particle (i) velocity at eth iteration while updated velocity is v_i^{e+1}. The random numbers generated (rand1 and rand2) are distributed over 0 and 1. The existing position of the particle at eth iteration is represented as s_i^e. The particle best and global best of the group are given as P_{besti} and G_{best}, respectively. The inertial weight factors ($w^e{}_f$) control the impact of velocity (v_i^e) over current. The parameters A_1 and A_2 indicate the acceleration factor that specifies the effect of P_{besti} obtaining an effective solution. The updated position of a particle can be given as [29]:

$$S_i^{e+1} = S_i^e + v_i^{e+1} \quad (22)$$

Where i = 1,2,...., N_s. N_s means several swarms.

The flow of the PSO algorithm for solar DG positioning and sizing is given in Fig.3. The existing solutions with PSO approaches fall in a loop where the particles face issues finding a local solution than the global one. The constants like inertial weight factors ($w^e{}_f$) and acceleration factors, i.e., A_1 and A_2 constraints, affect identifying the optimal solution (Pbest) and impact performance.

These constraints are appropriately adjusted in the proposed system by considering the generated random numbers (0 and 1) while specifying the Pbest solution. Choosing $w^e{}_f$, A_1, and A_2 based on the arbitrary number generation concept can offer an optimal solution in identifying the global best solution. The algorithm considers the IEEE-33 bus system, and it is assumed that all buses can generate power. The inequality constraints are subjected to each node (1%-5% of the total load) supplied with real power, and the load flow analysis is conducted through the negative PQ method. The algorithm generates the random values for the DG sizing, and it runs for a defined number of iterations and particle populations. The PSO gives the optimal sizing for every node and also achieves global fitness values. Finally, the best positioning and sizing of DG are obtained from the globally optimal values. The following section gives an analysis of the obtained results.

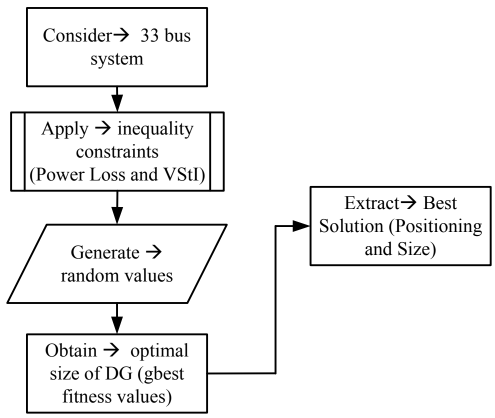

Fig. 3. The flow diagram of PSO for DG positioning and sizing

4. Results and Discussions

The proposed renewable (solar) DG systems are analyzed using MATLAB over the IEEE 33 bus system, as shown in Fig. 4.

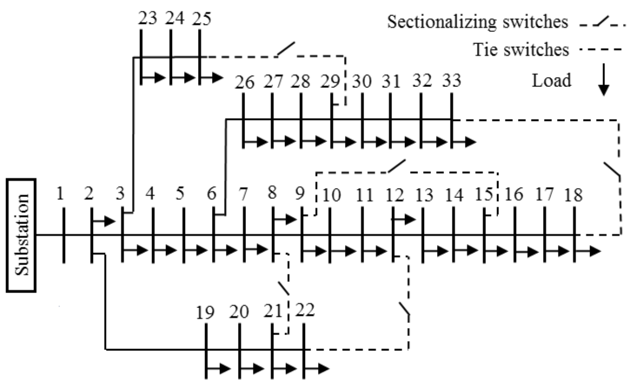

Fig. 4. IEEE 33 Bus System

The bus system consists of 32 lines (branches), 33 loads, and end nodes: 18, 22, 25, and 33. These buses are treated with voltage levels of 12.66 kV and rated MVA of 100 with a steady-state power factor of 0.8. The characteristic of PSO considered in this system is 10 (iterations), (1.0) inertial weight, (2.0) acceleration factor, and (50) Swarms.

The Line data and load data of the IEEE-33 bus are considered from the power system case test archive [34] directly for the conventional and Solar DG systems. The conventional system is designed without using the DG system. The voltage level of 12.66 kV is considered for all buses. The ±5% voltage limits (maximum and minimum) are considered for all the buses. The complete IEEE 33 bus system is fed by the substation (synchronous generator), which is loaded from 3.715 MW (Real Load) and 2.3 MVar (Reactive Load) connected to 32- buses of different power factors.

The impact of the DG positioning is computed by analyzing the real power loss, reactive power loss, and voltage stability index (VSI). Fig. 5 indicates the respective real power loss (RPL) in the conventional and solar DG system. In contrast, the conventional method has more RPL than that of the solar DG system.

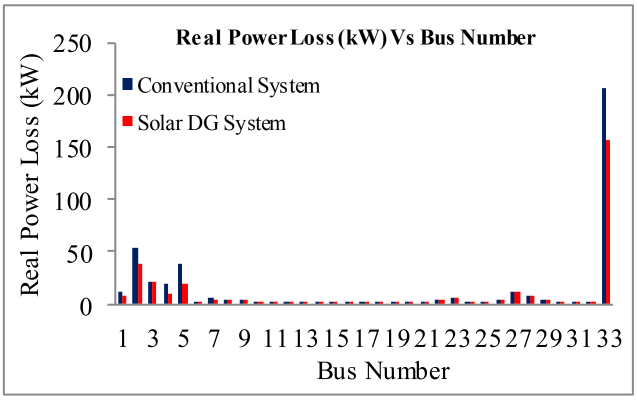

Fig. 5. Real power loss (RPL) analysis

Similarly, Fig.6 indicates the respective reactive power loss in the conventional and solar DG systems. Under the heavily loaded condition of the power system, the reactive power loss is predominantly high. In Fig.5, it is observed that the reactive power loss in a conventional system is higher due to the non-existence of the DG system, and the optimal location of solar DG in the distribution system has resulted in a reduction of losses to the greater extent.

The following Table 1 gives the performance analysis of the proposed solar DG system with a conventional system. The voltage stability analysis for both the conventional and solar DG systems is provided in Fig. 7. The value of the data considered for this analysis is considered to be mapped with probability theory which makes it quite simpler to obtain an inference with respect to performance parameters. For an effective analysis, the proposed system is exposed to a practical world environment where there is an absence or infrequent distributed generation (DG) system. In such case, it is found that VSI value associated with the conventional system is relatively low due to high losses. This challenge is further investigated by applying proposed PSO technique in order to find that the positioning of DG in optimal location offers an enhanced VSI. Owing to inclusion of probability, the VSI ranges between 0 to 1, and it is found to be 0.85 to 0.91 for the conventional system, and in the solar DG system is 0.92 to 0.99. However, it should be noted that this is carried out in order to intentionally increase the value of voltage stability index so that proposed PSO approach contributes further to control the index value within defined permissible limit. This assessment shows that proposed system is capable of extracting a sample parameter, increase its value, and further, it can be controlled, which is completely a predictive approach before even the actual voltage collapse occurs.

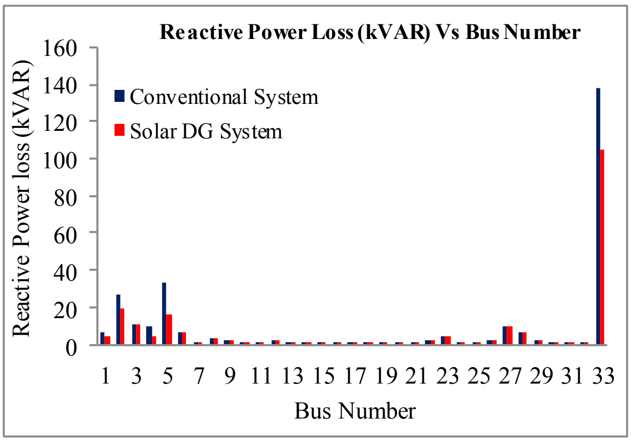

Fig. 6. Reactive power loss analysis

Table 1. Performance analysis

Parameters	Conventional (without DG)	Solar DG
Elapsed time (s)	0.1	6.98
Real power loss (kW)	206	157
Reactive power loss (kVAR)	137	105

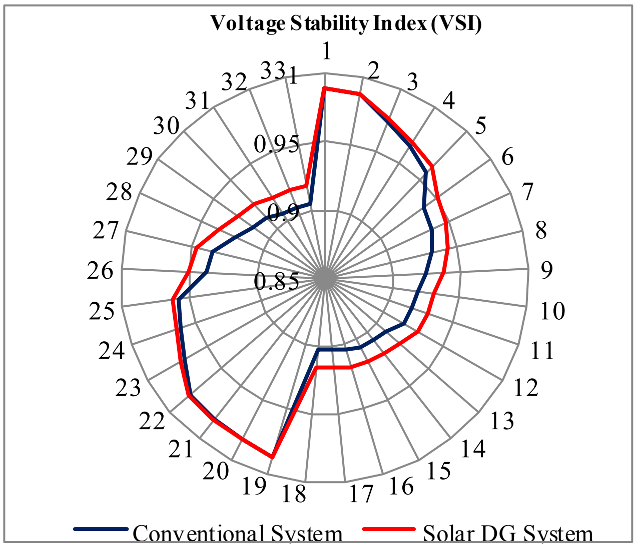

Fig. 7. Voltage Stability Index (VSI) analysis

The comparative results with existing approaches are tabulated in Table 2. The design work [35] uses an annealing algorithm (AA) for the optimal placement of DG in the IEEE 33 bus radial system. The result achieves a DG size of 1.68 MW at the 31st DG position with a power loss of 164.78 kW by placing three DG's. The design work [36] uses Decision – making Algorithm (DMA) for optimum size and placement of DG units in a distributed network system. The result achieves a DG size of 1.65 MW at the 33rd DG position with a power loss of 250.5 kW. The design work [37] uses a Genetic Algorithm (GA) for optimum location and sizing of Solar PV-based DG units in a radial distribution system. The result achieves a DG size of 1.46 MW at the 28th DG position with a power loss of 75.6 kW. The design work [13] uses a crow search algorithm with PSO for optimum size and allocation of DG units in a distributed system. The result achieves a DG size of 18.15 MW at the 30th DG position with a power loss of 248.99 kW.

Table 2. Comparative results with existing works

Parameters	Ref [35]	Ref [36]	Ref [37]	Ref [13]	This work
Algorithms	AA	DMA	GA	PSO	PSO
DG position	31	33	28	30	29
DG size (MW)	1.68	1.65	1.46	18.15	1.19
Real power Loss (kW)	164.78	250.5	75.6	248.99	157.4

The Proposed work uses the PSO algorithm for optimal positioning and sizing of solar-based DG system. The proposed work achieves a DG size of 1.19 MW at the 29th DG position with a power loss of 157.4 kW. The proposed work reaches better DG size (MW) and less real power loss (kW) than the existing DG-based systems [13, 35-37] and [13, 35-36], respectively.

5. Conclusion

The positioning and sizing of DG in a power system are some of the major concerns. The modified PSO algorithm is introduced for efficient positioning and sizing of the DG system. The impact of the DG positioning is computed by analyzing the real power loss, reactive power loss, and voltage stability index (VSI). The following are the conclusions drawn from the work carried out in this paper:

- The loss reduction in solar DG (157 kW) is much better than the conventional system (206 kW).
- As the positioning of the DG is varied due to the generation of random numbers in the PSO algorithm, the capacity of the DG is reduced from a higher number to 1.19 MW.
- The Solar DG system's voltage stability is 0.99, while the conventional system's (without DG) voltage stability is 0.92.

From observation of the results, the modified PSO with different design characteristics has obtained better positioning and sizing of DG, and the voltage stability of the DG is improved. Further, the research can be extended to analyze the fault in the DG system and minimize the voltage sag and swells to enhance system performance.

References

[1] S.N. Saxena, "Smart Distribution Grid and How to Reach the Goal", International Journal of Smart Grid-ijSmartGrid, Vol. 3, No. 4, pp.188-200, 2019.

[2] V.J. Foba, A.T. Boum, and C.F. Mbey, "Optimal Reliability of a Smart Grid", International Journal of Smart Grid-ijSmartGrid, Vol. 5, No. 2, pp.74-82, 2021.

[3] D. Motyka, M. Kajanova, and P. Bracinik, "The Impact of Embedded Generation on Distribution Grid Operation", In 7th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 360-364, IEEE, October, 2018,.

[4] Y. Iwasaki, K. Yukita, T. Hosoe, and K. Ikeda, "Basic study for the construction of a microgrid using small wind turbines as the main power source", In 2021 9th International Conference on Smart Grid (icSmartGrid) (pp. 1-1). IEEE, June, 2021.

[5] M. Colak, I. Cetinbas, and M. Demirtas, "Fuzzy Logic and Artificial Neural Network Based Grid-Interactive Systems for Renewable Energy Sources: A Review", in 2021 9th International Conference on Smart Grid (icSmartGrid), pp. 186-191, IEEE, June, 2021.

[6] T. Gözel, and M.H. Hocaoglu, "An analytical method for the sizing and siting of distributed generators in radial systems", Electric power systems research, Vol. 79, No. 6, pp.912-918, 2009.

[7] A.L. Devi, and A. Chaithanya, "A new analytical method for the sizing and siting of DG in radial system to minimize real power losses", International Journal of Computational Engineering Research, Vol.2, No. 7, pp.31-37, 2012.

[8] R.S. Rao, S.V.L. Narasimham, and M. Ramalingaraju, "Optimization of distribution network configuration for loss reduction using artificial bee colony algorithm", International Journal of Electrical Power and Energy Systems Engineering, Vol.1, No. 2, pp.116-122, 2008.

[9] Z. Moravej, and A. Akhlaghi, "A novel approach based on cuckoo search for DG allocation in distribution network", International Journal of Electrical Power & Energy Systems, Vol.44, No.1, pp.672-679, 2013.

[10] W.S. Tan, M.Y. Hassan, M.S. Majid, and H.A. Rahman, "Allocation and sizing of DG using cuckoo search algorithm", In IEEE international conference on power and energy (PECon). pp. 133-138, IEEE, December 2012.

[11] A.T. Eseye, M. Lehtonen, T. Tukia, S. Uimonen, and R.J. Millar, "Adaptive predictor subset selection strategy for enhanced forecasting of distributed PV power generation", IEEE Access, Vol.7, pp.90652-90665, 2019.

[12] S.S. Alam, A.R. Florita, and B.M. Hodge, “Distributed PV generation estimation using multi-rate and event-driven Kalman kriging filter”, IET Smart Grid, Vol. 3, No.4, pp.538-546, 2020.

[13] H.M. Farh, A.M. Al-Shaalan, A.M. Eltamaly, and A.A. Al-Shamma, “A novel crow search algorithm auto-drive PSO for optimal allocation and sizing of renewable distributed generation”, IEEE Access, Vol. 8, pp.27807-27820, 2020.

[14] A. Fleischhacker, H. Auer, G. Lettner, and A. Botterud, “Sharing solar PV and energy storage in apartment buildings: resource allocation and pricing”, IEEE Transactions on Smart Grid, Vol. 10, No.4, pp.3963-3973, 2018.

[15] J. Ospina, N. Gupta, A. Newaz, M. Harper, M.O. Faruque, E.G. Collins, R. Meeker, and G. Lofman, “Sampling-based model predictive control of PV-integrated energy storage system considering power generation forecast and real-time price”, IEEE Power and Energy Technology Systems Journal, Vol.6, No.4, pp.195-207, 2019.

[16] A. Ivanova, D. Chassin, J. Aguado, C. Crawford, and N. Djilali, “Techno-economic feasibility of a photovoltaic-equipped plug-in electric vehicle public parking lot with coordinated charging”, IET Energy Systems Integration, Vol. 2, No.3, pp.261-272,2020.

[17] X. Xiong, W. Wu, N. Li, , L. Yang, J. Zhang, and Z. Wei, “Risk-based multi-objective optimization of distributed generation based on GPSO-BFA algorithm”, IEEE Access, Vol.7, pp.30563-30572, 2019.

[18] H.A.U. Muqeet, and A. Ahmad, “Optimal scheduling for campus prosumer microgrid considering price based demand response”, IEEE Access, Vol.8, pp.71378-71394, 2020.

[19] M.P. Mahmud, N. Huda, S.H. Farjana, and C. Lang, “Techno-economic operation and environmental life-cycle assessment of a solar PV-driven islanded microgrid”, IEEE Access, Vol.7, pp.111828-111839, 2019.

[20] S. Singh, S. Kewat, B. Singh, B.K. Panigrahi, and M.K. Kushwaha, “Seamless control of solar PV grid interfaced system with islanding operation”, IEEE Power and Energy Technology Systems Journal, Vol. 6, No.3, pp.162-171, 2019.

[21] A.Jayawardana, A.P. Agalgaonkar, D.A. Robinson, and M. Fiorentini, “Optimisation framework for the operation of battery storage within solar-rich microgrids”, IET Smart Grid, Vol.2, No.4, pp.504-513,2019

[22] X. Huang, J. Shi, B. Gao, Y. Tai, Z. Chen, and J. Zhang, “Forecasting hourly solar irradiance using hybrid wavelet transformation and Elman model in smart grid”, IEEE Access, Vol.7, pp.139909-139923, 2019.

[23] W. Hao, B. Liu, S. Yao, W. Guo, and W. Huang, “Reactive power optimisation of distribution network with distributed generation based on genetic and immune algorithm”, The Journal of Engineering, Vol. 2019, No.16, pp.1280-1284, 2019.

[24] A. Sundararajan, T.O. Olowu, L. Wei, S. Rahmanand A.I. Sarwat, “Case study on the effects of partial solar eclipse on distributed PV systems and management areas”, IET Smart Grid, Vol.2, No.3, pp.477-490, 2019.

[25] Q. Ha, and M.D. Phung, “IoT-enabled dependable control for solar energy harvesting in smart buildings”, IET Smart Cities, Vol.1, No.2, pp.61-70, 2019.

[26] V. Rashtchi M. Darabian, S. Molaei, “A robust technique for optimal placement of distribution generation”, In Proceedings of the International Conference on Advances in Computer and Electrical Engineering, Manila, Philippines, November 2012.

[27] K. Nekooei, M.M. Farsangi, H. Nezamabadi-Pour, and K.Y. Lee, “An improved multi-objective harmony search for optimal placement of DGs in distribution systems”, IEEE Transactions on smart grid, Vol.4, No.1, pp.557-567, 2013.

[28] Y.M. Atwa, E.F. El-Saadany, M.M.A. Salama, and R. Seethapathy, “Optimal renewable resources mix for distribution system energy loss minimization”, IEEE Transactions on Power Systems, Vol.25, No.1, pp.360-370, 2009.

[29] R. Eberhart, and J. Kennedy, “A new optimizer using particle swarm theory”, In MHS'95. Proceedings of the Sixth International Symposium on Micro Machine and Human Science, pp. 39-43, IEEE, October 1996.

[30] S. Kansal, B.B.R. Sai, B. Tyagi, and V. Kumar, “Optimal placement of distributed generation in distribution networks”, International journal of engineering, science and technology, Vol.3, No. 3, pp. 47-55, 2011.

[31] M. E. Baran and F. F. Wu, “Network Reconfiguration in Distribution Systems for Loss Reduction and Load Balancing”, IEEE Trans. on Power Delivery, Vo1.4, No.2, pp.1401-1407, April 1989.

[32] K.M. Muttaqi, V. Ganapathy, G.B. Jasmon, and M. Buhari, “A novel method for loss minimization in distribution networks”, In international Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), pp.251-256, IEEE, 2000.

[33] M. Chakravorty and D. Das, "Voltage stability analysis of radial distribution networks", International Journal of Electrical Power and Energy Systems, Vol. 23, pp. 129-135, 2001.

[34] University of Washington, Power Systems Test Case Archive. Available online: https://www.ee.washington.edu/research/pstca/ (accessed on 10 August 2019).

[35] K. Dharageshwari, and C. Nayanatara, “Multiobjective optimal placement of multiple distributed generations in IEEE 33 bus radial system using simulated annealing”, In International Conference on Circuits, Power and

Computing Technologies [ICCPCT-2015], pp. 1-7, IEEE, March, 2015.

[36] V. Vita, "Development of a decision-making algorithm for the optimum size and placement of distributed generation units in distribution networks", Energies, Vol.10, No.9, p.1433, 2017.

[37] M.Q. Duong, T.D. Pham, T.T. Nguyen, A.T. Doan, and H.V. Tran, "Determination of optimal location and sizing of solar photovoltaic distribution generation units in radial distribution systems", Energies, Vol. 12, No. 1, p.174, 2019.