Power Loss Reduction and Voltage Profile improvement by Photovoltaic Generation

Seyed Reza Seyednouri #1, Homayoun Ebrahimian *2, Aref Jalili #3

Department Of Electrical Engineering, Ardabil Branch, Islamic Azad University,
Ardabil, Iran 1, 2, 3

***Abstract*— Power Loss reduction and Voltage Profile improvement in radial distribution system by implementation of Photovoltaic Generation (PVDG) are the objectives of this study. The multiobjective function based on system performance indices of ILP and ILQ, related to real and reactive power losses, and IVD, related to voltage profile improvement, are utilized in the present work. The Particle Swarm Optimization (PSO) has been employed to minimize the multiobjective function. Two scenarios have been studded in this work. In the first scenario, the constraint for PVDG unit size has not been considered. In the second scenario, the constraint for PVDG unit size has been considered and in both scenario problem has been solved with one PVDG. The studies have been carried out on IEEE 33 bus test. The results show that PVDG penetration has decreased power loss and improved voltage profile. Comparison of the results obtained by the proposed method with those attained in other studies shows the effectiveness of the proposed method.**

Keywords **photovoltaic distributed generator (PVDG), radial distribution system, the Particle Swarm Optimization (PSO), power losses, voltage profile.**

I. INTRODUCTION

World net electricity generation increases by 93 percent, from 20.2 trillion kilowatthours in 2010 to 39.0 trillion kilowatthours in 2040. In many parts of the world, concerns about security of energy supplies and the environmental consequences of greenhouse gas emissions have spurred government policies that support a projected increase in renewable energy sources [1]. Among the renewable energy sources, photovoltaic (PV) application has received a great attention in research because it appears to be one of the most efficient and effective solutions to this environmental problem. In addition to the above expression another problem is with the existing electric power system. Most of the distribution networks were designed in order to operate in radial configuration with single source. With this kind of network, the power flows from the substation to the loads in every point of the grid [2].This unidirectional power flow results in power losses and voltage reduction along the distribution system.

Distributed generation units (also called decentralized generation, dispersed generation, and embedded generation) are small generating plants connected directly to the distribution network or on the customer site of the meter. In the last decade, the penetration of renewable and nonrenewable distributed generation (DG) resources is increasing worldwide encouraged by national and international policies aiming to increase the share of renewable energy sources and highly efficient micro-combined heat and power units in order to reduce greenhouse gas emissions and alleviate global warming [3]. Next to environmental advantages, DGs contribute to the technical benefits. Inappropriate DG placement may increase system losses and network capital and operating costs. On the contrary, optimal DG placement (ODGP) can improve network performance in terms of voltage profile, reduce flows and system losses, and improve power quality and reliability of supply. The DG placement problem has therefore attracted the interest of many research efforts in the last fifteen years [3].In order to maximize the benefits of using DGs in power systems, it is crucial to find the best location and size of DGs simultaneously [4]. The typical ODGP problem deals with the determination of the optimum locations and sizes of DG units to be installed into existing distribution networks, subject to electrical network operating constraints, DG operation constraints. The objective function of the ODGP can be single or multiobjective. The main single-objective functions are: 1) minimization of the total power loss of the system; 2) minimization of energy losses; 3) minimization of system average interruption duration index (SAIDI); 4) minimization of cost; 5) minimization of voltage deviations; 6) maximization of DG capacity; 7) maximization of profit; 8) maximization of a benefit/cost ratio; and 9) maximization of voltage limit [3].

The objectives of this work are to minimize power losses and improve voltage profile in the radial distribution system by the optimal placement and sizing of photovoltaic distributed generator (PVDG.

II. PVDG SYSTEM MODELING

The IEEE 1547 rules that the distributed recourses shall not actively regulate the voltage at the point of common coupling [5]. The most commonly used operational mode is simply unity PF. The inverter will output active power based on the insolation levels captured by the PV arrays. This mode complies with IEEE 1547 and is most common.

Inverter designs for both small- and large-scale applications typically size the inverter to match the dc rating of the PV cells, after applying derating factors. This is because the inverter does not need to be controlled to manage the reactive power export. For power flow analysis, this means that the inverters are to be modeled as current source inverters operating at unity PF, or simply negative active load. In this study the PVDG has been modeled as negative active load [6]. Another reason to operate the PVDG at unity PF is that it is normally considered that maximum benefit can be extracted when DG’s are operated on unity power factor because the cost of real power is higher [7].

III. PROBLEM FORMULATION

A. Objective Function Formulation

The objective of this study is to minimize the power losses and improve voltage profile by injecting PVDG in optimal location and size. The PVDG location and its corresponding size in the distribution feeders can be optimally determined using the following function.

$$\min f\left(P_{loss}, Q_{loss}, V_{level}\right) \tag{3}$$

In this work several indices will be computed in order to describe the effect of PVDG in the power losses and voltage improvement. These indices are defined as follows:

Real Power Loss Index (ILP): The real power loss indices are defined as:

$$ILP = \frac{P_{loss}^{withPVDG}}{P_{loss}^{withoutPVDG}} \tag{4}$$

Where $P_{loss}^{withPVDG}$ is the total real power loss of the distribution system after inclusion of PVDG. And $P_{loss}^{withoutPVDG}$ is the total real system loss without PVDG in the distribution system.

Reactive Power Loss Index (ILQ): The reactive power loss indices are defined as:

$$ILQ = \frac{Q_{loss}^{withPVDG}}{Q_{loss}^{withoutPVDG}} \tag{5}$$

Where $Q_{loss}^{withPVDG}$ is the total reactive power loss of the distribution system after inclusion of PVDG. And $Q_{loss}^{withoutPVDG}$ is the total reactive system loss without PVDG in the distribution system.

Voltage Profile Index (IVD): One of the advantages of proper location and size of the DG is the improvement in voltage profile. This index penalizes a size–location pair which gives higher voltage deviations from the nominal value (V_{nom}). In this way, the closer the index is to zero better is the network performance. The IVD can be defined as:

$$IVD = {}_{i=2}^{n}\max\left[\frac{\left|V_{nom}\right| - \left|V_i\right|}{\left|V_{nom}\right|}\right] \tag{6}$$

Where n is the number of buses.

The multiobjective performance index (IMO) was produced from the gather of these indices by the weighting factor assigned to that impact.

$$IMO = w_1 * ILP + w_2 * ILQ + w_3 * IVD \tag{7}$$

The sum of the absolute values of the weights assigned to all indices should add up to one as shown in the following equation:

$$w_1 + w_2 + w_3 = 1 \tag{8}$$

This weighting factor is chosen by the planner to reflect the relative importance of each parameter in the decision making of sitting and sizing the PVDG. Table I shows the values for the weights used in present work and they are selected guided by the weights in [7]. However, these values may vary according to engineer concerns.

TABLE I
Indices Weights

indices	weights
ILP	0.55
ILQ	0.25
IVD	0.2

B. Constrain formulation

Voltage limits: The voltage drop limits depend on the voltage regulation limits provided by the disco

$$V_{\min} \le V_i \le V_{\max} \tag{9}$$

Line Thermal limits: Power flow through any distribution feeder must comply with the thermal capacity of the line

$$S_i \le S_{i,\max} \tag{10}$$

PVDG capacity: This section defines the boundary of power generation by PVDG:

$$P_{\min}^{PVDG} \le P_i^{PVDG} \le P_{\max}^{PVDG} \tag{11}$$

IV. MYTHOLOGY

A. Backward Forward Sweep Load Flow Method

Traditional load flow methods, which incorporate the Gauss–Seidel method, the Newton–Raphson method, and fast decoupled techniques, were primarily developed for transmission system analysis. Additionally, a Backward Forward Sweep method for radial distribution systems using basic circuit theories and laws is another well-known method. Distribution systems usually fall into the category of ill-conditioned power systems having high R/X ratios, due to which the methods like Newton–Raphson and fast decoupled may provide inaccurate results and may not converge. Therefore, traditional load flow methods cannot be directly applied to distribution systems since the assumptions made for transmission systems are not valid for the unique characteristics of distribution systems [8]. On the other hand, Backward Forward Sweep methods are quite suitable for radial networks with high R/X ratio [10].

B. Partial swarm optimization (PSO)

Kennedy and Eberhart developed PSO through simulation of bird flocking in a two-dimensional space. The position of each agent is represented by its x, y axis position and also its velocity is expressed by v_x (the velocity of x axis) and v_y (the velocity of y axis). Modification of the agent position is realized by the position and velocity information. Bird flocking optimizes a certain objective function. Each agent knows its best value so far (pbest) and its x, y position. This information is an analogy of the personal experiences of each agent. Moreover, each agent knows the best value so far in the group (gbest) among pbests.

This modification can be represented by the concept of velocity (modified value for the current positions). Velocity of each agent can be modified by the following equation:

$$v_i^{k+1} = wv_i^k + c_1 rand_1 \times \left(pbest_i - s_i^k\right) + c_2 rand_2 \times \left(gbest - s_i^k\right) \tag{12}$$

where v_i^k is velocity of agent i at iteration k, w is weighting function, c_j is weighting coefficients, rand is random number between 0 and 1, s_i^k is current position of agent i at iteration k, pbesti is pbest of agent i, and gbest is gbest of the group. The following weighting function is usually utilized in (12):

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \tag{13}$$

Where wmaxis initial weight, wminis final weight, itermaxis maximum iteration number, and iter is current iteration number [11].

Shi and Eberhart tried to examine the parameter selection of the above parameters [9, 10]. According to their examination, the following parameters are appropriate and the values do not depend on problems: $c_1= 2$, $c_2=2$, $w_{\max}=0.9$, $w_{\min}=0.4$.

The current position (searching point in the solution space) can be modified by the following equation:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{14}$$

The power flow solution method given in section IV is used to calculate the IMO function which is the system losses and voltage profile. The PSO will be used to minimize IMO function while it is searching for the optimal site and sizing of the PVDG.

V. SIMULATION AND RESULTS

The studies have been carried out on an IEEE 33-bus test system. The load has been modelled as constantan power. We studied two load scenarios, scenario I and scenario II. For the first scenario, the constraint for PVDG unit size has not been considered. Scenario II, on the other hand, represents the situation where the constraint for PVDG unit size has been considered and problem has been solved with one PVDG. 25% of total active load of distribution system represent the constraint for PVDG unit size in the second scenario. The substation voltage in both scenarios was considered as 1.0 p.u. the PVDG can be can be connected to any buses except the first bus which is considered to be the slack bus.

The proposed PSO-based algorithm was applied to the IEEE 33-bus test system to determine the optimal size and site of DG units such that the multi-objective function given in (7) is minimized. For this test system, three DG units were optimally sized and placed.

The IEEE 33-bus test system operates at 12.66 kV is shown in Fig. 1. The network data can be found in [12]. This test network has loads connected to all buses except bus 1. The total demand of the network is 3.715 MW and 2.3 MVar.

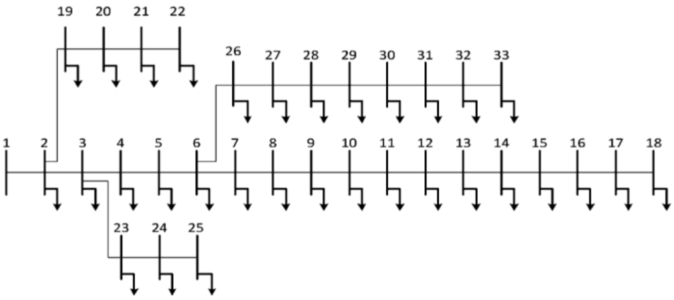

Fig. 1. Single line diagram of the IEEE 33-bus test system

The power losses for base case (without DG) of the IEEE 33-bus test system are 201.7897kW and 74.1422 Kvar.

A. scenario I:

As discussed above there isn't the constraint for PVDG unit size in this scenario. Table II shows the best results. Table III also shows Voltage and power losses for IEEE 33-bus test system for scenario I. Fig. 2 and 3 illustrate Voltage profiles and PSO convergence for PVDG placement, respectively.

TABLE II
RESULTS FOR IEEE 33-BUS TEST SYSTEM FOR SCENARIO I

	Impact index		**Site**	**Size kw**	**P_{loss} kw**	**Q_{loss}kvar**
One PVDG	ILP	0.50913	6	2594.8287	102.7901	74.1464
	ILQ	0.55064				
	IVD	0.047579				
	IMO	0.4272				

TABLE III
VOLTAGE AND POWER LOSS FOR IEEE 33-BUS TEST SYSTEM FOR SCENARIO I

Case	**Power Loss As % Of Total Active Load**	**power Loss reduction%**	**Minimum Voltage (pu)**
NO PVDG	5.43	-	0.9134
One PVDG	2.766	49.06	0.952421

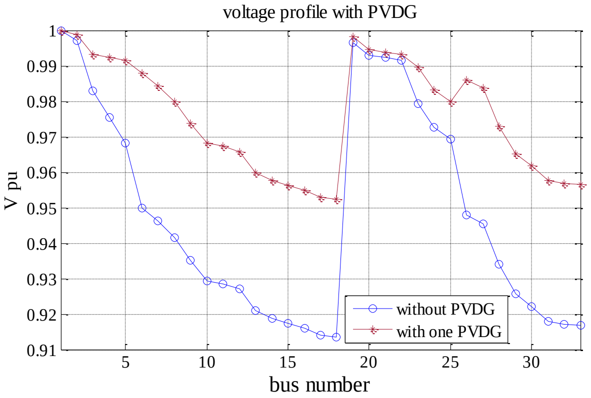

Fig. 2. Voltage profiles of the IEEE 33-bus test system for scenario I

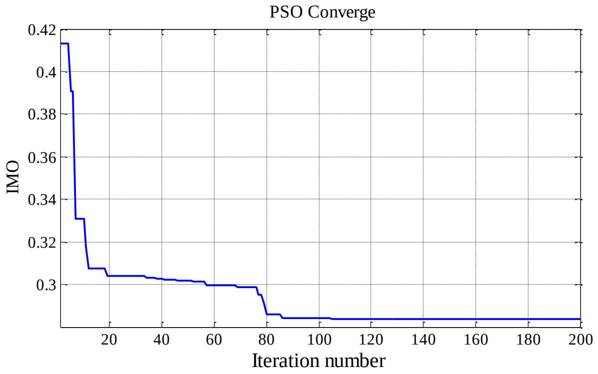

Fig. 3. The convergence of the PSO for PVDG placement on IEEE 33-bus test system

Table III and Fig. 2 show how PVDG cases power loss reduction and voltage improvement on IEEE 33-bus test system for the first scenario. In the case we penetrated PVDG the power loss reduction was 49.06% and minimum voltage improved from 0.9134 pu to 0.952421 pu.

B. scenario II:

Constraint for PVDG unit size has been defined for this scenario. Table IV shows the best results. Table V also shows Voltage and power losses for IEEE 33-bus test system for scenario II. Fig. 4 illustrates Voltage profile.

TABLE IV

RESULTS FOR IEEE 33-BUS TEST SYSTEM FOR SCENARIO II

Power generation of PVDG	**Impact index**		**Site**	**Size kw**	**P_{loss} kw**	**Q_{loss}kvar**
930 KW (25%)	ILP	0.62978	30	930	127.149	86.4207
	ILQ	0.64179				
	IVD	0.071684				
	IMO	0.52116				

TABLE V

VOLTAGE AND POWER LOSS FOR IEEE 33-BUS TEST SYSTEM FOR SCENARIO II

Case	**Power Loss As % Of Total Active Load**	**power Loss reduction%**	**Minimum Voltage (pu)**
NO PVDG	5.43	-	0.9134
930 KW (25%)	3.4225	36.97	0.928316

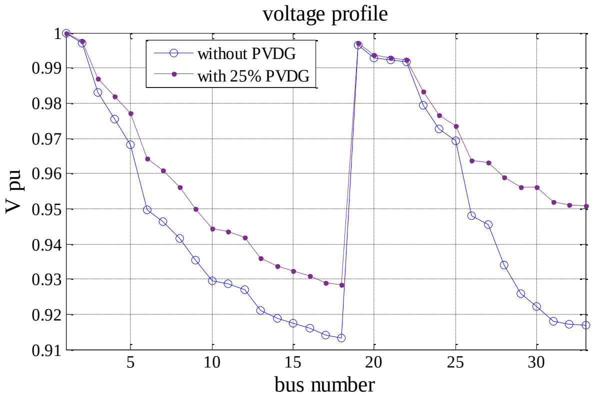

Fig. 4. Voltage profiles of the IEEE 33-bus test system scenario II

Results on IEEE 33-bus test system for the second scenario revealed that in the case the PVDG unit size was 25% of total active load, the power loss reduced by 36.98% and minimum voltage improved to 0.928316 pu.

VI. COMPARATIVE STUDY

The comparative study has been done for validity of the results. The results of the PSO algorithm for IEEE 33-bus test system in the first scenario were compared with the solutions obtained based on the analytical method [13], GA method [14] and ABC [15-16].

TABLE VI

COMPARATIVE STUDY FOR IEEE 33-BUS TEST SYSTEM FOR SCENARIO I

Case		**[13]**	**[14]**	**[15]**	**[16]**	**Proposed approach**
One DG	Site, size (kw)	6, 2490	6, 2380	6, 2400	6, 2590	6, 2594
	Loss reduction %	47.33	44.83	48.19	46.92	49.06

The comparison shows that the methodology is more effective in determining the sizes and PVDG locations for power loss reduction.

VII. CONCLUSION

In this paper, the PSO algorithm has been used to find the optimal solution of PVDGs sizing and sitting problems. The goal of this optimization was minimizing the power loss and improving voltage profile by penetrating PVDG. Inverter is formulated in form of negative active load. The simulation result demonstrates that PVDG in optimum sizing and sitting can reduce power loss and improve voltage profile.

For IEEE 33-bus test system in the first scenario power loss reduced by 49.06% and minimum voltage improved from 0.9134 pu to 0.952421 pu. And in the second scenario power loss reduced by 36.98% and minimum voltage improved by 0.928316 pu.

Results for IEEE 33-bus test system in the first scenario were compared by results of other studies and the comparisons show that the methodology is more effective in determining the sizes and PVDG size for power loss reduction.

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