Optimal Placement and Sizing of Distributed Generations in Unbalanced Distribution Networks Considering Load Models and Uncertainties

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Abstract: Development of distributed generations' technology, trends in the use of these sources to improve some of the problems such as high losses, low reliability, low power quality and high costs in distributed networks. Choose the correct location to install and proper capacity of these sources, such as important things that must be considered in their use. Since distribution networks are actually unbalanced and asymmetric consumption loads are different, so in this paper with optimal placement and sizing of distributed generation sources that dependent on the load model and type of load connection and the uncertainties which caused by the generated power of wind turbines and solar panels, the positive effects of these sources have been examined on unbalanced distribution network. Hence with linear three-phase unbalanced load flow method and IPSO algorithm, allocation of distributed generation sources in IEEE standard of 37 bus unbalanced network have been done. Obtained results show improvement of voltage profile in each phase and reduction of network power losses and buses' voltage unbalance factor.

Keywords: Distributed Generations' Uncertainty, Linear Three Phase Unbalanced Load Flow, Load Model, Unbalanced Distribution Network.

1.Introduction

The development of power industry around the world, has affected the use of new technologies in related industries. Hence with development of power systems and increased demand for electrical energy, power network has been divided in to three parts; generation, transmission and distribution to supply electrical energy with high quality and reliability. Distribution part, is connecting distribution substations to electrical equipment in the place of consumers. Therefore proper operation and optimization of distributed systems are great importance. Supply electricity to customers must be accompanied by an increase reliability of electrification to consumers, power delivery to customers without any increase or decrease voltage and overload, the ability to deal with peak load demand of customers, reduce losses and etc. by electricity distribution companies. In addition to the listed issues, actually distributed systems are unbalanced systems and there is mutual induction between different phases of lines. The Main reasons of distribution systems' imbalance can be mentioned to different loading of single phase loads on a three phase loads, existence of two phase and single phase lines in addition to three phase lines, randomness connection of each loads and disconnection of single phase loads from the network [1]. Imbalance of distribution networks will have significant negative effects such as increased losses, voltage drop, occupying network capacity and increased costs [2]. Also, undesirable effects of currents' zero and negative sequence are quite evident for power system engineers on protective relays, transformators and induction motors [3], [4]. So far, different methods are provided in order to reduce imbalance of distribution systems, such as counting of customers, using the contractual power of customers, using the average power of customers, using active filters [5], SVC installation [6], using capacitors and inductors and equalization with the help of reactive power control [7]. In recent decades many countries that their industry was dependent on fossil fuels, have chosen distributed generation sources the right alternative for these fuels. Distributed generation sources are renewable and do not create environmental pollution. These sources are installed near the site of consumption. As a result it is not required high-voltage transmission lines for transmission of generated electricity and transmission

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costs. Also the power losses are reduced [8]. The use of these sources in convenient size and location, will have other benefits for distribution systems like improving voltage profile, active and reactive line loss reduction, increasing network reliability, improving electrical efficiency, improving voltage stability and etc. [9]. The important thing about solar and wind generation sources is that, power generation of these sources dependent on external factors such as wind speed and intensity of sunlight. So the generated power of these units are constantly changing, and modeling them with constant speed and constant output power is incorrect and it will create a lot of errors in simulations. Hence, the methods of uncertainty analysis should use to achieve a model for generated power's uncertainty of these sources [10]. Several studies have been conducted on the above topics. In [11] has been reminded that the usual methods such as Newton-Raphson load flow is not suitable for unbalanced distribution networks, and used ZBus method to investigate load flow in unbalanced network. In [12] with backward-forward load flow and genetic algorithm, reconfiguration and change arrangement of feeders has been done, ultimately this method lead to reducing losses and improving voltage profile in two unbalanced distribution networks. In [13] using the new method, 4-wire unbalanced load flow networks have been investigated.

So far, DGs allocation have been discussed in balanced networks. In this paper, DGs allocation have been done on IEEE standard of 37 bus unbalanced network, which has unequal loads on the phases and mutual inductance between phases of lines. Therefore appropriate size of sources has been obtained according to the uncertainty of generated power and convenient location of sources has been chosen by IPSO algorithm. Also, linear three phase unbalanced load flow method with considering load model and type of loads connection has been used in calculations. According to the obtained results voltage profile of each phase has been improved and both network power losses and voltage unbalance factor have been reduced.

This paper is structured as follows.

Loads are modeled in section 2. Type of loads connection are expressed in section 3. Voltage unbalance is expressed in section 4. Multi objective function that include the reduction of network active power losses, voltage profile improvement and reduction of the voltage unbalance factor is described in section 5. Network constraints are given in section 6. The power of distributed generations (wind turbine and solar panels) are obtained considering their uncertainty in section 7. Linear three phase unbalanced load flow is described in section 8. IPSO algorithm and its implementation are described respectively in section 9 and section 10. Case study and simulation results are elaborated in section 11 and conclusions are expressed in section 12.

2. Load Modeling

In most studies, power of network loads has been assumed constant. In the event that, actually loads are dependent on the voltage and powers will not be constant. Generally static load model is as shown below.

$$P = P_0\left(\frac{V}{V_0}\right)^{\alpha} \quad , \quad Q = Q_0\left(\frac{V}{V_0}\right)^{\beta} \tag{1}$$

That P_0 and Q_0 are rated power at rated voltage and loads are divided into three cαategories based on the amounts of α and β, as below [14].

- constant power load α= β= 0
- constant current load α= β= 1
- constant impedance load α= β= 2

3. Type of Load Connection

Loads can be connected to the respective bus as star or delta. Voltage of star connected load is considered to be phase to neutral and voltage of delta connected load is considered to be line to line. Connection of unbalanced loads as star and delta are shown respectively in Fig. 1 and Fig. 2.

4. Define and Measure Voltage Unbalance

In a three-phase system, the difference in size or angle of the phase or line voltage will cause the creation of voltage imbalance. An unbalanced three-phase system is using symmetrical component method in the form of Eq. (2) to turns in to three components of balanced positive, negative and zero sequence [15].

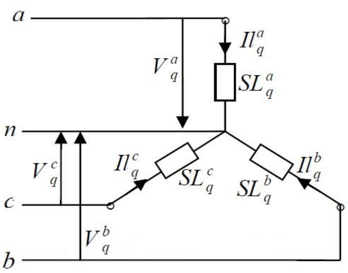

Fig. 1. Star connection load.

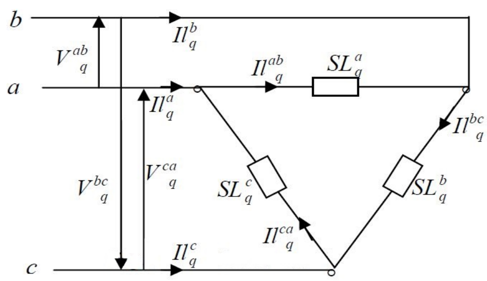

Fig. 2. Delta connection load.

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2}$$

That V_a, V_b and V_c are respectively phase voltages of phase a, b and c and V_0, V_1 and V_2 are respectively voltage components of zero, positive and negative and $a=e^{j120}$.

So far, due to the importance of voltage unbalance, different definitions of voltage imbalance is provided. According to IEEE standard, VUF[2] is as follows [16].

$$\%VUF_i = \frac{V_{2,i}}{V_{1,i}} \times 100 \tag{3}$$

5. Multi Objective Function

The multi objective function in this paper include the reduction of network active power losses, voltage profile improvement and reduction of the voltage unbalance factor.

5.1. Reducing of Network Active Power Losses

One of the important parameters of network is reduce losses and it is possible with the help of the DGs. Power losses of unbalanced distribution network is obtained as follows [17]:

$$\begin{aligned} F_1 = P_{Loss} &= \sum_{P=A,B,C} P_{Loss}^{(P)} \\ &= \sum_{P=A,B,C} \left[\sum_{i=1}^{n} \sum_{j=1}^{n} V_i^{(P)} Y_{ij}^{(P)} V_j^{(P)} \cos(\theta_i^{(P)} - \theta_j^{(P)} - \delta_{ij}^{(P)}) \right] \end{aligned} \tag{4}$$

That P is representing phases A, B and C, n is the number of network buses, $V_i^{(P)}$ and $\theta_i^{(P)}$ are respectively voltage size and angle of phase P at bus i, $V_j^{(P)}$ and $\theta_j^{(P)}$ are respectively voltage size and angle of phase P at bus j, $Y_{ij}^{(P)}$ and $\delta_{ij}^{(P)}$ are respectively admittance size and angle of phase P between i and j buses.

5. 2. Improving of Voltage Profile

Optimal DG placement can improve voltage profile of phases. In fact, the purpose of improving voltage profile is that the voltage of each phase is close to 1 perunit [18].

$$\begin{aligned} VD_A &= \left| V_{i,ref} - V_{i,A} \right| \\ VD_B &= \left| V_{i,ref} - V_{i,B} \right| \\ VD_C &= \left| V_{i,ref} - V_{i,C} \right| \end{aligned} \tag{5}$$

That $V_{i,A}$, $V_{i,B}$ and $V_{i,C}$ are voltage size of bus i in phases A, B and C respectively, and $V_{i,ref}$ is the desired voltage value, which is usually considered 1 perunit. The aim of this section is that Eq. (6) is minimized.

$$F_2 = \max(VD_A, VD_B, VD_C) \tag{6}$$

5. 3. Reducing of Voltage Unbalance Factor

The aim of this section is that Eq. (7) is minimized. That was defined in Eq. (3).

$$F_3 = \max(VUF_i) \tag{7}$$

To improve efficiency and achieve better results, the objective function is defined as a combination of the three above objectives and weighted sum of these objectives is considered as Eq. (8).

$$\begin{aligned} &F = k_1 \times F_1 + k_2 \times F_2 + k_3 \times F_3 \\ &k_1 + k_2 + k_3 = 1 \ , \ k_1, k_2, k_3 \in [0,1] \end{aligned} \tag{8}$$

Values of the coefficients are selected based on the importance of objectives in such a way that the best results are achieved. The amount of phase voltages and power can obtain as perunit. Also, perunit expressed as a percentage. So all the terms are in perunit.

6. Network Constraints

Network constraints are as follows:

- Voltage of each phase, should be between the minimum and maximum voltage. So standard limit of voltage profile is considered to be 0.9-1.1 (perunit) or close to it [9].
- Losses with presence of DG must be less than the losses without DG.
- Allowable voltage unbalance factor is considered 2 percent [19].

7. Determining Distributed Generation's Power Considering Uncertainty

Generated power of wind turbines and solar panels are respectively dependent on wind speed and sun intensity. So generated power of these sources are uncertain. In this section, generated power uncertainty modeling of these sources have been studied by probabilistic methods.

7.1. Wind Turbine Power Probabilistic Modeling

Wind speed profile follows the Weibull distribution function [20]. Wind speed probability density distribution function divided into several sections and the probability of each section is attributed to midpoint of each section.

So the probability of wind speed can be obtained as follows [20].

$$P_v\{G_w\} = \int_{v_{w2}}^{v_{w1}} f_r(v)dv \tag{9}$$

That $f_r(V)$ is probability density function of wind speed, V_{w1} and V_{w2} are respectively beginning and end speed of the desired section. Linear relation between active output power and wind speed is shown as follows [20].

$$P_{out}(v)=\begin{cases}0 & 0\le v_{aw}\le v_{ci}\\ P_{rated}*\dfrac{v_{aw}-v_{ci}}{v_r-v_{ci}} & v_{ci}\le v_{aw}\le v_r\\ P_{rated} & v_r\le v_{aw}\le v_{co}\\ 0 & v_{co}\le v_{aw}\end{cases} \quad (10)$$

That V_{ci}, V_r and V_{co} are respectively wind turbine start speed, nominal speed and cutting speed, V_{aw} is middle of each section's speed and P_{rated} is wind turbine rated power. Finally, wind turbine average power can be obtained from Eq. (11).

$$P_{av}=\sum_{v_{ci}}^{v_{co}}P_{out}(v)\times P_v\{G_w\} \quad (11)$$

7. 2. Solar Panel Power Probabilistic Modeling

Beta probability distribution function follows the profile of solar irradiance [21]. In this function, solar irradiance is divided into 0.1 (kw/m²) intervals and for the middle of each interval as representative, the solar irradiance probability function for each interval is calculated from Eq. (12) [21].

$$P_s\{G_y\}=\int_{s_{y1}}^{s_{y2}}f_b(s)ds \quad (12)$$

That $f_b(s)$ is solar irradiance probability density distribution function, s_{y1} and s_{y2} are respectively beginning and end solar irradiance of the desired section. Solar panel linear characteristic "Power- irradiance" will be obtained from Eq. (17) [21].

$$T_{cy}=T_A+s_{ay}\left[\frac{N_{oT}-20}{0.8}\right] \quad (13)$$

$$I_y=s_{ay}[I_{sc}+k_i(T_{cy}-25)] \quad (14)$$

$$V_y=V_{oc}-k_v\times T_{cy} \quad (15)$$

$$FF=\frac{V_{MPP}\times I_{MPP}}{V_{oc}\times I_{sc}} \quad (16)$$

$$P_{sy}(s_{ay})=N\times FF\times V_y\times I_y \quad (17)$$

That T_{cy} is the cell temperature during y interval (°C), T_A is the environment temperature(°C), K_v is the voltage temperature coefficient (V/°C), N_{OT} is the cell nominal temperature (°C), K_i is the current temperature coefficient (A/°C), FF is the filling factor, I_{SC} is the short circuit current(A), V_{OC} is the open circuit voltage(V), V_{MPP} is the voltage at the maximum power point(V), I_{MPP} is the current at the maximum power point(A), s_{ay} is the average solar irradiance in the range of y(kw/m²), N is the number of modules and P_{Sy} is the output power of the module. On this basis, average power of solar panel obtained as follows.

$$P_{av}=\sum_{s_{y1}}^{s_{y2}}P_{sy}(s_{ay})\times P_s\{G_y\} \quad (18)$$

8. Linear Three Phase Unbalanced Load Flow

In the unbalanced distribution systems, because of high ratio and unbalanced structure, using common load flow methods like Newton-Raphson and Gauss-Seidel are not suitable. So in this paper the new method of load flow, named linear three-phase unbalanced load flow is used. In this method distribution network unbalanced structure and model and type of connection loads are considered. Therefore, compared with other methods of distribution network load flow like backward-forward load flow is more accurate and faster [22].

In this method there is a relation between buses voltage and current as follows.

$$\begin{pmatrix}I_S\\ I_N\end{pmatrix}=\begin{pmatrix}Y_{SS} & Y_{SN}\\ Y_{NS} & Y_{NN}\end{pmatrix}\cdot\begin{pmatrix}V_S\\ V_N\end{pmatrix} \quad (19)$$

In which the S index represents the slack bus and the N index represents other buses, Y_{SS} and Y_{NN} are respectively insider admittance of nodes with S and N index, Y_{SN} and Y_{NS} are mutual admittance between nodes with S and N index, I_S and V_S are respectively current and voltage of bus with S index, I_N and V_N are respectively current and voltage of bus with N index. The N index represents three nodes that is related to each phase. So admittance matrix size will be as $(N_{bus}*N_{bus})*(N_{bus}*N_{bus})$ that N_{bus} shows the number of network buses. There is a relation between current and voltage of each bus as combined load model as follows.

$$I_k=\frac{S^*_{Pk}}{V^*_k}+h\cdot S^*_{Ik}+h^2\cdot S^*_{Zk}\cdot V_k \quad (20)$$

That $h=1/V_{nom}$ and V_{nom} is network nominal voltage. Phrases S^*_{Pk}/V^*_K, $h.S^*_{Ik}$ and $h^2.S^*_{Zk}.V_k$ are respectively current of constant power load model, constant current load model and constant impedance load model that S_{Pk},S_{Ik},S_{Zk} are respectively network powers in constant power load model, constant current load model and constant impedance load model and V_k is voltage of bus k. This relation is nonlinear toward in current of constant power load model section that is approximated to obtain linear load flow. Therefore, with the help of the Taylor series $[\frac{1}{1-\Delta V}=\sum_{n=0}^{+\infty}(\Delta V)^n]$ and with remove the great exponents of this series and define $[V=1-\Delta V]$, linear form can be obtained as follows.

$$\frac{1}{V}=\frac{1}{1-\Delta V}\approx 1+\Delta V=2-V \tag{21}$$

In unbalanced network for loads with delta connection, line voltage can be obtained from phase voltage as follows.

$$V_{N(Line)}=M\cdot V_{N(Phase)} \tag{22}$$

M matrix is defined as follows:

$$M=\begin{bmatrix}1 & -1 & 0\\ 0 & 1 & -1\\ -1 & 0 & 1\end{bmatrix} \tag{23}$$

That $V_{N(Line)}$ is line voltage and $V_{N(Phase)}$ is phase voltage. After applying the linear approximation in Eq. (20) and using Eq. (22), linear form is arranged as the following phrase.

$$A+B.V_N^*+C.V_N=0 \tag{24}$$

In this relation A, B and C are as follows.

$$A=Y_{NS}\cdot V_S-2h\cdot M^T\cdot S_{PN}^*\cdot T-h\cdot M^T\cdot S_{IN}^*\cdot T \tag{25}$$

$$B=h^2\cdot M^T\cdot diag\left(S_{PN}^*\cdot T^2\right)\cdot M \tag{26}$$

$$C=Y_{NN}-h^2\cdot M^T\cdot diag\left(S_{ZN}^*\right)\cdot M \tag{27}$$

That $T=e^{j\varphi}$ and $\varphi=\{0, -2\pi/3, 2\pi/3\}$. In Eq. (24) the real and imaginary values of voltage (respectively with r and i index) can be obtained from the following equation.

$$\begin{pmatrix}-A_r\\ -A_i\end{pmatrix}=\begin{pmatrix}B_r+C_r & B_i-C_i\\ B_i+C_i & -B_r+C_r\end{pmatrix}\cdot\begin{pmatrix}V_r\\ V_i\end{pmatrix} \tag{28}$$

After obtaining the voltage of all buses, load flow calculations has ended and network power losses is calculated.

9. IPSO Algorithm

IPSO algorithm is improved PSO algorithm. PSO, first time was presented by Eberhart and Kennedy that it has been inspired from the mass movement of birds that they are looking for food [23]. This algorithm works with a group of particles and search with update generations to find the optimal solution in the problem space. Each particle has two values, position(X_i) and speed (V_i) that update at each stage of the population with the better of two values. The first value is P_{best} that is the best answer in terms of fitness which has been obtained for each particle and the second value is G_{best} that is the best value which has been achieved by all particles among the total population so far. In each iteration after finding values of two best, speed and new place of each particle update from Eq. (29) and Eq. (30).

$$V_i^{k+1}=wV_i^k+c_1r_1+(P_{besti}^k-X_i^k)+c_2r_2+(G_{besti}^k-X_i^k) \tag{29}$$

$$X_i^{k+1}=X_i^k+V_i^{k+1} \tag{30}$$

That V_i^k is speed of the particle i in k iteration, c_1 and c_2 are acceleration coefficient in 1-2 interval, r_1 and r_2 are random numbers between 0-1, X_i^k is position of the particle in the k iteration, $P^k_{best\ i}$ is the best position of the particle in the k iteration, $G^k_{best\ i}$ is the best position of the group in the k iteration and w is stiffness factor parameter that generally defined as follows.

$$w=w_{\max}-\frac{w_{\max}-w_{\min}}{Iter_{\max}}\times Iter \tag{31}$$

That w_{min} and w_{max} are respectively lowest and highest weight, $Iter_{max}$ is the highest number of iteration and Iter is iteration number.

In IPSO algorithm a repeater is used that is a dynamic system and shows irregular behavior. The following equation shows how the behavior of these repeaters [24].

$$D_k=\mu\cdot D_{k-1}\cdot(1-D_{k-1}) \tag{32}$$

where D_k is an irregular parameter that is sensitive to μ changes, which is a control parameter and its amount is changed between 0-4. The amount of μ determines that the amount of D_k remain constant or swing between limited quantities or behaves randomly. When μ=4 and D_0={0. 0,25, 0.5, 0.75, 1} the relation shows irregular behavior and the behavior of the system is very sensitive to the initial state of D_k.

One of the major weaknesses of PSO is premature convergence and particles do not discover responses better local. So in IPSO, weight parameter is determined as Eq. (33) which enhances the search for PSO in the problem space.

$$w_{new} = w \cdot D \tag{33}$$

That w_{new} and w are respectively IPSO and PSO weight parameter. w_{new} is reduced as oscillatory and with the total number of iterations. Whereas w is reduced constantly from w_{max} to w_{min} .

10. IPSO Algorithm Implementation

In this section by using the IPSO algorithm, optimal placement of DGs would be reviewed. So the algorithm is implemented as follows.

1. The amount of DGs generated power that is obtained due to the methods of uncertainty, is considered as input parameters of the algorithm.
2. The first generation of particles is produced in random order (first place candidates) and P_{best} and G_{best} are recorded.
3. Linear three-phase unbalanced load flow run and network constraints are examined.
4. The next generation is produced, if the number of iterations reach to the specified value and network constraints are not violated, G_{best} is selected and location of DG is introduced and the multi objective function is calculated. Otherwise, the algorithm is repeated so as to reach the maximum number of iterations.

11. Case study

Performance of unbalanced load flow method and proposed algorithm has been applied to IEEE standard of 37 bus unbalanced network. The studied network is shown in Fig. 3. The network is unbalanced due to phases unequal loads and mutual impedances between line phases. Network nominal voltage is 4.8 (kV) and bus with index 701 is slack bus. A variety of load models are shown as constant power (PQ), constant current (I) and constant impedance (Z) and type of loads connection are shown as star (Y) and delta (D). [25].

Simulations have been performed regardless of network transformator and regulator in MATLAB R2010a computing environment with Core i5, 2.20 GHz computer with 8.00 GB RAM. So buses with 799 and 775 index are neglected and the number of buses reduced to 35.

Coefficients of multi-objective function are selected as $K_1=K_2=0.3$ and $K_3=0.4$ that gives the best results. The maximum number of iterations is considered 100.

Necessary parameters for modeling generated power uncertainty of wind turbines and solar panels are respectively shown in Table 1 and Table 2.

In wind turbine k=3 and c=8 and in solar panel α,β=3.5 and N=500 have been considered on the basis of regional conditions.

According to the above information, the appropriate amount of DGs power obtained as shown in Table 3.

Table 1. Characteristics of the wind turbine [21].

Wind turbine characteristics	Features
Rated power	2 MW
Cut-in speed (m/s)	4
Rated speed (m/s)	15
Cut-out speed (m/s)	25

Table 2. Characteristics of the PV module [21].

PV module characteristics	Features
Open circuit voltage (V)	21.10
Short circuit current (A)	3.80
Voltage at maximum power (V)	17.10
Current at maximum power (A)	3.50
Voltage temperature coefficient $(\mathrm{mV}/{}^\circ\mathrm{C})$	75
Current temperature coefficient $(\mathrm{mA}/{}^\circ\mathrm{C})$	3.10
Nominal cell operating temperature $({}^\circ\mathrm{C})$	43

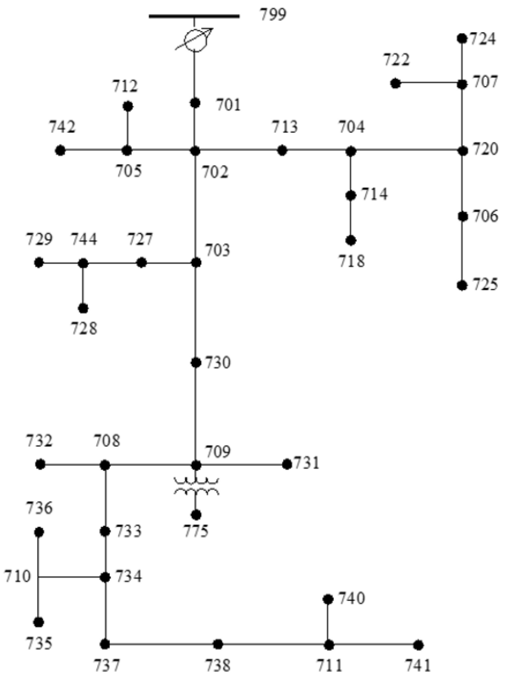

Fig. 3. IEEE 37 bus unbalanced network [25].

Table 3. DGs obtained power.

P_{ave} (kw)	
Wind turbine	PV module
553.5	344.35

Because the system is unbalanced, single phase DG sources must be installed on one phase of elected bus to achieve optimum results.

So by the proposed algorithm and according to the size of DGs obtained in Table 3, elected phases and buses to install DGs are shown in Table 4.

The obtained results for network power losses and maximum voltage unbalance factor, with and without DG installation are shown in Table 5.

Table 4. Elected phases and buses for DG installation.

Number of DGs	Bus Number	Bus Phase	Type of DG
2	725	B	PV
	727	C	wind

Table 5. Comparison results with and without DGs

P_{Loss} (KW)		VUF_{max} (%)	
Without DG	With DGs	Without DG	With DGs
33.1192	23.3648	1.3816	1.0490

Obtained results from the placement of DGs, according to the obtained powers from probabilistic methods and consider the model and type of loads connection, in Table 5 show that network losses and maximum percentage of voltage unbalance factor are reduced after installing DGs.

Because the system is unbalanced, the size and angle of the phases' voltage are different. Therefore, to better illustrate the voltage changes, phases' voltage profile before and after DG installation are shown in Fig. 4. The percentage of voltage unbalance factor of each bus before and after DG placement has been compared in Fig. 5.

As shown in Fig. 4 voltage profile of each phase after placement of DGs improved. It is observed that the index decreased after placement in all buses by comparing buses' voltage unbalance factor before and after placement of DGs as shown in Fig. 5.

To demonstrate the effectiveness of the methods used in this paper, a comparison has been done according to Table 6 between the losses that obtained from genetic algorithm in [26] and this article after DG placement. In [26] DGs power is considered 2500 KW for each bus.

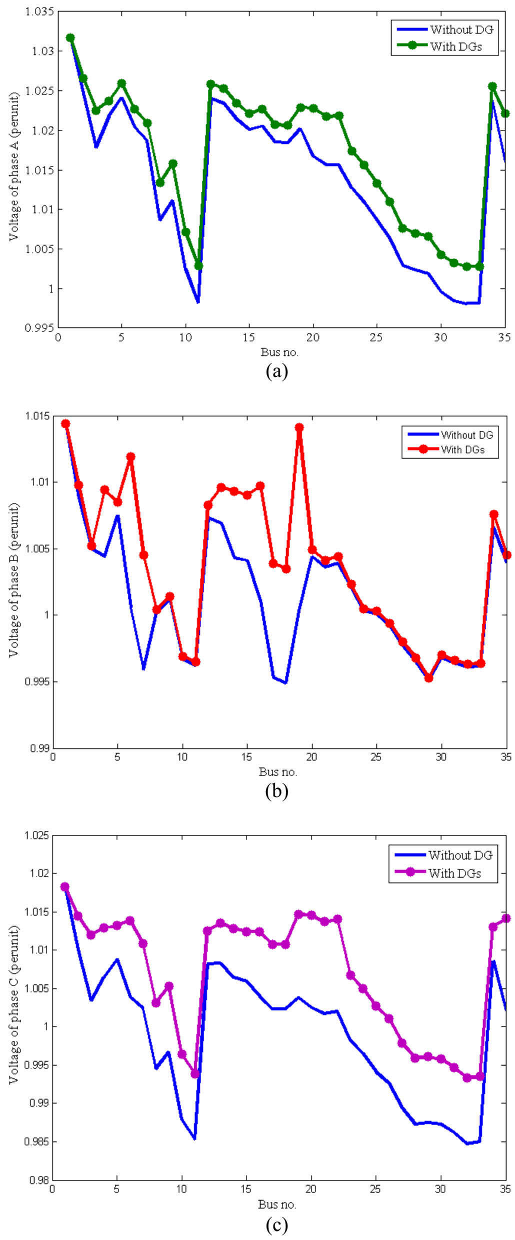

Fig. 4. Voltage profile with and without DGs (a) in phase A, (b) in phase B, (c) in phase C.

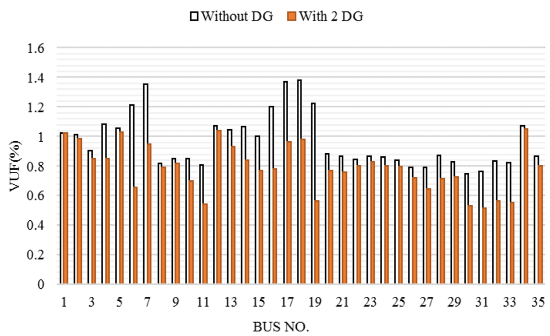

Fig. 5. Comparison VUF with and without DGs.

Table 6. Comparison of simulation results

Ref. [26]		Calculated	
Bus number	Losses (kw)	Bus number	Losses (kw)
709 712 742	27.7365	725 727	23.3648

According to Table 6, the losses derived from calculations in this article is lower than that derived from [26]. In [26] allocation has been done regardless of DGs power uncertainty, load model and the type of loads connection. So placement done in this paper is more accurate than [26].

In Table 7, voltage angle results for this paper are observed before and after DG placement.

12. Conclusion

Because of the imbalance loads and mutual inductance between different phases, distributed systems are actually unbalanced systems. An imbalance has various negative effects on distribution networks such as reducing of voltage instability, increasing of network losses and etc. So we should consider all details of the network to reduced imbalance of network by appropriate methods. In this paper first, load models and type of loads connection are described using the corresponding relations. Then since the generated power of wind turbines and solar panels sources depend on external factors such as, wind speed and sun intensity, modeling generated power uncertainty of these sources is done. Then linear three-phase unbalanced load flow method is presented and reviewed that it is a new load flow method with low computation time, for unbalanced distribution networks. And for optimal DG placement, IPSO algorithm has been suggested. To eval-

Table 7. Comparison angle (degree) of voltage different phases with and without DGs

Bus no.	Bus Number	Without DG			With DGs		
		θ_A	θ_B	θ_C	θ_A	θ_B	θ_C
1	701	-0.0795	-120.3894	120.6089	-0.0795	-120.3894	120.6089
2	702	-0.1414	-120.5827	120.4231	-0.1188	-120.3689	120.577
3	703	-0.1801	-120.704	120.1924	-0.1978	-120.3271	120.5882
4	704	-0.1796	-120.6157	120.4562	-0.039	-120.2771	120.5442
5	705	-0.1352	-120.5961	120.4543	-0.1129	-120.3821	120.6081
6	706	-0.2239	-120.6649	120.5324	0.1055	-120.1288	120.5149
7	707	-0.3034	-120.6343	120.6629	-0.0548	-120.1804	120.6896
8	708	-0.0857	-120.7371	120.0126	-0.1055	-120.3589	120.4114
9	709	-0.1144	-120.7356	120.0706	-0.1336	-120.3579	120.4685
10	710	0.0039	-120.7684	119.9043	-0.0181	-120.389	120.3052
11	711	0.049	-120.742	119.7509	0.0266	-120.3622	120.1544
12	712	-0.1193	-120.6107	120.4579	-0.0971	-120.3966	120.6116
13	713	-0.1499	-120.6046	120.4345	-0.0792	-120.3397	120.5615
14	714	-0.1787	-120.6089	120.4517	-0.0381	-120.2702	120.5397
15	718	-0.168	-120.5735	120.4198	-0.0274	-120.2349	120.5079
16	720	-0.2143	-120.664	120.5216	0.0341	-120.2118	120.5493
17	722	-0.3119	-120.6318	120.6773	-0.0632	-120.1777	120.7038
18	724	-0.323	-120.6252	120.6892	-0.0746	-120.1713	120.7159
19	725	-0.2311	-120.6615	120.5421	0.1663	-120.0827	120.4749
20	727	-0.1618	-120.6916	120.184	-0.2453	-120.2119	120.6487
21	728	-0.1586	-120.6807	120.1744	-0.2425	-120.2009	120.6395
22	729	-0.1595	-120.6743	120.163	-0.2433	-120.1945	120.6282
23	730	-0.1258	-120.7337	120.0997	-0.1446	-120.3562	120.4971
24	731	-0.1339	-120.7385	120.0918	-0.1531	-120.3607	120.4895
25	732	-0.0746	-120.7469	120.0156	-0.0947	-120.3686	120.4144
26	733	-0.0624	-120.7322	119.9556	-0.0829	-120.3537	120.3554
27	734	-0.0185	-120.7421	119.8782	-0.0398	-120.3629	120.2793
28	735	0.0178	-120.7809	119.9074	-0.0044	-120.4014	120.3083
29	736	-0.0295	-120.7531	119.949	-0.0515	-120.3736	120.3495
30	737	0.0085	-120.7133	119.7872	-0.0134	-120.3338	120.1898
31	738	0.0277	-120.7176	119.757	0.0056	-120.338	120.1603
32	740	0.0629	-120.7545	119.7541	0.0403	-120.3746	120.1575
33	741	0.056	-120.7501	119.7491	0.0336	-120.3702	120.1527
34	742	-0.1513	-120.5874	120.4745	-0.1291	-120.3734	120.6282
35	744	-0.1626	-120.6837	120.1714	-0.2463	-120.2039	120.6365

uate the effectiveness of three-phase unbalanced load flow method and IPSO algorithm, IEEE standard of 37 bus unbalanced network is studied. Simulations are done in Matlab software with considering buses load models and type of loads connection according to IEEE standard and generated power uncertainty of solar and wind sources. The results of the simulations, represent improving of each phase voltage profile, and reduction both network losses and percentage of buses voltage unbalance factor.

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