# Flower Pollination Algorithm Based Optimal Placement of Solar Based Distributed Generators in Distribution System

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**Abstract-** Rapid exhaustion of fossil fuels, concern about environmental issues, enforces renewable distributed generations (RDGs) in the existing power system network. Appropriate allocation of these sources in the distribution network needs proper planning. In this paper an efficacious method for optimal placement of solar DGs is presented. Proper probabilistic models are used for modelling the solar irradiance, and determine the exact output power from the photo voltaic (PV) array. Different seasons are considered for the analysis. The main objectives are power loss reduction, voltage profile enhancement. First the best locations for placement of PV arrays are identified using voltage stability factor (VSF) method. Flower pollination algorithm, a new meta heuristic technique is used for determining the optimal number of PV arrays placed at these identified locations. The proposed methodology is tested on IEEE 33 and 69 bus systems and compared with other methods for validation.

**Keywords** Renewable Distributed Generators (RDGs), Probability Distribution Function(PDF), Flower pollination algorithm (FPA), Power loss minimization

## 1. Introduction

With mounting electricity demand, concern about environmental issues, fuel cost uncertainties, deregulation trends and fast development of technology leads to use distributed generators (DGs) in the distribution system. DG is a small generating source connected nearly to the distribution network [1]. Conventional and renewable resources like diesel generator, gas turbines, reciprocating engines, solar photovoltaic, wind and biomass are the main DG energizers. From these technologies, most commonly used are photo voltaic and wind based generation, because of its environmentally friendly nature. But the integration of these sources to the distribution network needs proper planning.

Generally, distribution system suffers with high power losses and large voltage drops, because of its radial nature and high R/X ratio. So the performance of the distribution system is improved in terms of technical as well as economical aspects by placing DG units optimally. Installing DG units at inappropriate places reduces the benefits and sometimes imperil the total system operation [2]. So, allocation of DG units optimally in the radial distribution system(RDS) is a significant issue for achieving the desired benefits.

In recent years, several analytical [3-6], numerical [7-10] and search based optimization techniques [11-17] are effectively applied for solving DG placement sizing problems in the distribution system. In [3] analytical approach is used for placement of DGs in both radial and meshed systems with an objective of improving power loss reduction. An analytical method is proposed for determining best locations and sizes of DGs in RDS is presented in [4]. Different types of DGs are considered for placement and studied the performance of the distribution network is presented in [5,6]. A linear programming (LP) based method for DG allocation in RDS is presented in [7]. In [8] MILP method is used for determining the optimal location and sizes of DGs in RDS with an objective of minimizing operational and investment costs. Optimal allocation of renewable based DGs in the RDS for energy loss minimization is presented in [9,10].

For determining the location and size of DGs in RDS different heuristic techniques are applied till date. A combined GA/PSO [11] method is used for solving DG allocation problem in RDS with an objective of reducing power loss and enhancing voltage stability of the system. An integrated approach of the loss sensitivity factor method along with simulated annealing (SA) technique [12] is presented for determining best locations and sizes of DGs in RDS. Application of a backtracking search optimization algorithm (BSOA) for solving multiple DG allocation is presented in [13]. A Shuffled Bat algorithm is used for solving multiple DG allocation in the RDS is presented in [14]. Poornazaryan, Bahram, et al. [15] proposed a new index for solving the DG allocation effectively in the distribution network. MOPSO technique is utilised for placement of RDGs in the distribution system has been presented in [16]. Optimal placement of RDGs in the distribution system with minimizing energy losses is presented in [17].

From the literature, it is observed that different authors used analytical, numerical and artificial intelligence techniques for solving DG allocation problem effectively. Implementation of analytical methods is easy and the results are indicative, but these methods depend upon consideration of certain assumptions taken in the initial stages. Next numerical methods like LP, MILP and MINLP are effectively solved the DG placement and sizing problem, but these techniques not suitable for solving large scale test systems. So the above mentioned problems are addressed carefully and then solve the DG allocation problem efficiently in the distribution system using different heuristic methods.

### *1.1. Proposed work*

In this proposed work application of FPA along with the voltage stability factor concept is used for determining the best location of solar based DGs in the RDS is presented. The objectives are to improve power loss reduction, voltage stability and voltage profile of the system. Before placement of these renewable based DGs in the system the exact output power is determined. Because the output power of PV arrays mainly depends upon of solar irradiance level of the particular location. The random nature of solar irradiance effectively modeled by using beta probability distribution function. After determining the output power of PV arrays the best locations are found out by using voltage stability factor (VSF) concept. Next number PV arrays placed at the identified locations have been found out by using recently developed swarm intelligence technique FPA.

Even though heuristic techniques have effectively solved the complex optimization problems, but the actual challenge lies how effectively tunes its control parameters. Also, many search based optimization techniques suffer with convergence and optimality issues. In this paper, FPA is used for solving the optimization problem. Because in case of FPA only one control parameter tuned, that is a probability switch for achieving desired results. Developed methodology is implemented on the two diffrent test systems considering two different seasons.

The organization of the paper is given as follows. Probem formulation with constraints is explained in section 2. Modelling of solar farm and power output calculations of the PV array is explained in section3. In section 4 optimal placement of solar based DGs using voltage stability factor concept is explained. In section 5, Application of FPA for determining no of PV arrays at the installed locations is explained. Results and discussion analysis is explained in section 6. İn section 7 conclusion of the article is explained.

## 2. Problem Formulation

More attention is required to proper allocation of distributed generators in the distribution system. In this paper formulation of the objective function is adapted to minimize power losses, improve the voltage profile and VSI of the system with the optimal allocation of solar distributed generators in the RDS. The objective function should satisfy different constraints of the distribution network.

### *2.1. Objective functions*

#### *2.1.1 Power loss minimization*

The main objective of optimal placement of PV arrays in RDS is minimization of power loss, which can be calculated using

$$f_1(X)=\sum_{k=1}^{nb}|I_k|^2 R_k \tag{1}$$

Where $R_k$ , $I_k$ are resistance, current magnitude of the $k^{th}$ branch and nb is the total number of branches.

#### *2.1.2. Voltage stability index maximization*

Under heavy loaded conditions, there is a chance of severe voltage collapse problem in the distribution networks. So it is necessary to improve VSI of the system. For this DG sources are connected optimally to the distribution network. The VSI of RDS can be given as follows [18,19].

$$f_2(x)=VSI_j=|V_k|^4-4[P_j r_{jk}+Q_j x_{jk}]|V_k|^2-4[P_j x_{jk}-Q_j r_{jk}]^2 \quad j=2,3,4\ldots nb \tag{2}$$

Where $VSI_j$ is the voltage stability index of the $j^{th}$ bus.

### *2.2. Constraints*

The objective functions should satisfy various constraints of the distribution network.

#### *2.2.1 Power balance*

$$P_{slack}+\sum_{k=1}^{N_{SDG}}P_{SDG,k}=\sum_{k=1}^{N_L}P_{D,k}+\sum_{k=1}^{nb}P_{loss}(k) \tag{3}$$

#### *2.2.2 Voltage limits*

$$|V_{\min}|\le|V_k|\le|V_{\max}| \tag{4}$$

*2.2.3 DG sizing limits*

$$P_{SDG,\min} \le P_{SDG,k} \le P_{SDG,\max} \quad (5)$$

Thermal limits

$$I_{jk} \le I_{jk}^{\max} \quad (6)$$

### 3. Output Power Calculation of PV Array

The random nature of solar irradiance is represented by using suitable probability distribution functions and determine exact output power from the PV array. From the different probability distribution functions, beta probability distribution function (PDF) is apt for modelling the solar irradiance [9,20]. The beta PDF at corresponding solar irradiance level(s) is given by [20].

$$f_b(s) = \frac{\Gamma(\alpha_p + \beta_p)}{\Gamma(\alpha_p)\Gamma(\beta_p)} s^{\alpha_p - 1}(1-s)^{(\beta_p - 1)} \; with \; \alpha_p, \beta_p > 0 \quad (7)$$

Where $\Gamma(^\circ)$ is the gamma function, $\alpha_p = \dfrac{\mu\beta_p}{1-\mu}$, $\beta_p = (1-\mu)\left(\dfrac{\mu(1+\mu)}{\sigma^2} - 1\right)$ are shape parameters and these are calculated by mean($\mu$), standard deviation($\sigma$) and s is a random variable (kW/m$^2$).

Finally the output power of the PV array depends on the specifications of PV module, solar irradiance level of particular location that is calculated using [20]. The specifications and data related to the PV module are taken from [21].

$$PG_{PV\,array} = N_{PV\,\mathrm{mod}} * FF * V_x * I_x \quad (8)$$

$$V_x = V_{oc} - K_v T_{cx} \quad \mathbf{(9)}$$

$$I_x = s[I_{sc} + K_i(T_{cx} - 25) \quad \mathbf{(10)}$$

$$T_{cx} = T_A + s\left(\frac{N_{OT} - 20}{0.8}\right) \quad (11)$$

Where $N_{OT}$, $I_{sc}$, $V_{oc}$ are the nominal operating temperature, short circuit current and open circuit voltage of PV module. $K_v$, $K_i$, $T_{cx}$ and $T_A$ are the voltage temeperature coefficient, current temperature coefficient, PV module temperature and ambient temperature respectively.

$V_x$ and $I_x$ are voltage and current corresponding to the PV module. $N_{PVmod}$ is number of PV modules used, FF is the fill factor. The total output power of PV array is given by [20].

$$P(s) = PG_{PV\,array} * f_b(s) \quad (12)$$

Finally the total expected power output of the PV array at a specific time segment is calculated as follows.

$$ETP = \int_0^1 PG_{PV\,array} * f_b(s)\, ds \quad (13)$$

The expected total output power of PV module during 12$^0$ clock considering one random day in the summer season is shown in Fig.1.

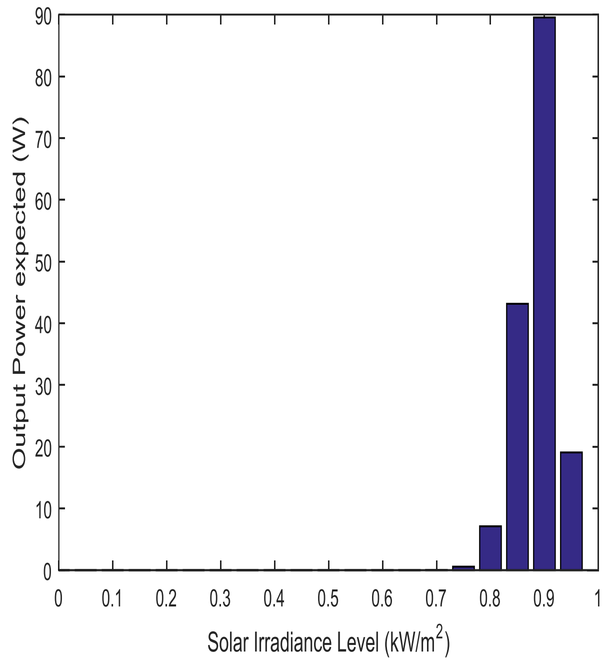


**Fig.1.** Expected output power of PV module during summer season at 12$^o$ clock

### 4. Voltage Stability Factor Concept for Solar Dg Installation

Voltage stability factor (VSF) [16] is concept is used to identify the weak buses for placement of solar based DGs in the distribution system. The initial identification of these candidate buses reduces the problem search space. VSF for bus k+1 is designated as

$$VSF_{k+1} = 2V_{k+1} - V_k \quad (14)$$

Using the above equation determines the voltage stability factors of all buses and place the solar based DGs in which buses have less value of VSF. The advantage of this technique is calculation procedure is simple compared to other stability indices. The data required for calculation of VSF are only voltage values of all buses. Finally voltage stability factor technique gives good information about system voltage stability.

### 5. Flower Pollination Algorithm (FPA)

FPA is developed by Deb and Yang in 2012 [22]. The basic concept to develop this algorithm is the pollination process of flowering plants. Also, the implementation of FPA mainly based upon four rules [23,24] which can be converted into proper mathematical equations.

The flower constancy can be represented by

$$x_i^{t+1} = x_i^t + L(x_i^t - g_*) \quad (15)$$

Where $x_i^t$ is the solution vector and $g_*$ is the current best solution. The parameter L is a step size drawn from a Levy distribution and ϵ is a random number.

$$L \sim \frac{\lambda\Gamma(\lambda)\sin(\pi\lambda/2)}{\pi}\,\frac{1}{s^{\lambda+1}}, \quad (s \gg s_0 > 0) \tag{16}$$

Here $\Gamma(\lambda)$ is the standard gamma function, which is valid for long steps s>0.

Next the flower constancy based on rule 2 is represented as

$$x_i^{t+1} = x_i^t + \in\left(x_j^t - x_k^t\right) \tag{17}$$

Where $x_j^t$ and $x_k^t$ is pollens from the various flowers of that plant species.

In most of the studies probability switch p is taken as 0.8 for achieving better results [22].

The important steps and mathematical equations are represented in pseudo code and it is shown in Fig.2.

FPA technique is used to solve most of the power system problems [23]. In this work FPA is used to determine the number of PV arrays placed on identified locations. Due to less control parameters FPA is simple and easy to balance between exploration and exploitation abilities during the optimization process.

Min objective or max f (x), x=($x_1$,$x_2$,………$x_d$)
Initialize a population of and flowers/ pollen gametes with random solutions
Find the best solution $g_*$ in the initial population
Define a switch probability pϵ [0,1]
**while (**t< max generation)
  **for** i=1:n (all n flowers in the population)
    **if** rand<p
      Draw a (d-dimensional) step vector L which obeys a Levy distribution
      Global pollination via

$$x_i^{t+1} = x_i^t + L(x_i^t - g_*)$$

    **else**
      Draw ϵ from a uniform distribution in [0,1]
      Do local pollination via

$$x_i^{t+1} = x_i^t + \varepsilon\left(x_j^t - x_k^t\right)$$

    **end if**
    Evaluate new solutions
    If new solutions are better, update them in the population
  **end for**
      find the current best solution
**end while**
output best solution found

**Fig.2.** Pseudo code of the flower pollination algorithm

*5.1. Steps to solve optimal allocation of PV arrays using FPA technique*

1) Read the data related to the test systems, initialize the parameters of FPA i.e. dimension of serach space (No of PV arrays), population size (n=20), Maximum no of iterations (50) and probability switch (p=0.8).

3) Identify the best locations for placement of PV arrays in RDS using voltage stability factor concept [16].

4) The identified best locations are given as input to the FPA.

5) If rand>p then no of PV arrays placed at the installed locations are found out by using global pollination concept via Levy flight i.e. by using Eq.(15).

6) Else the number PV arrays placed at the identifying locations determined by using a local pollination concept i.e. by using Eq. (17).

7) Update the current global best

8) Display the results of the solution, if those values are best stopped the procedure otherwise repeat the procedure from step 5.

## 6. Simulated Results and Discussion

The data related to the test systems, i.e. IEEE 33 and 69 bus systems are taken from [26]. It is assumed that test systems are placed near Vellore ( state: Tamilnadu, country: India ) and data related to these location, i.e. solar irradiance and ambient temperature are taken from [27]. The latitude and longitude of the specified location are $12.9165^0$ N and 79.1325° E respectively. Two different seasons considered for the analysis, i.e. summer (May to July) and winter ( November to January) according to environmental conditions of india. The mean and standard deviations of the two seasons,i.e. summer (mean=0.886, standard deviation=0.151) and winter (mean=0.739, standard deviation=0.225) are obtained from historical data [27]. After calculating mean and standard deviations, determine the beta PDF and calculate corresponding power output of a PV module. Two different seasons are considered and output power of 1 PV module corresponding to these mean and standard deviation in winter and summer seasons is 135.58W and 159.42W. The specifications of PV module are taken from [21]. Due to the space and land requirements 1000 PV modules are utilized for forming a PV array. So output power of one PV array in winter and summer season is 135.58kW and 159.42kW. The developed method is implemented in MATLAB environment.

*6.1. Case 1: 33 bus system*

The base case power loss before allocation of PV arrays is 210.99kW and minimum voltage magnitude is 0.9038 p.u.. The best locations for placement of PV arrays are identified by using voltage stability factor concept. Next number PV arrays placed at the identified locations are found out by using heuristic technique flower pollination algorithm. The results with the optimal allocation of PV arrays from minimum penetration level to maximum penetration level considering winter and summer seasons are presented in Tables 1 and 2. From the Tables, it is clear that exact number of PV arrays placed at exact locations minimize the power losses effectively. Also the minimum voltage magnitude and stability index of all buses are improved effectively after allocation of PV arrays considering winter season is shown in Figs.3. and 4

**Table 1.** Optimal locations and different penetration level of PV arrays for IEEE 33 bus RDS in winter season

| Test system | No of connected buses | Bus location (No of connected PV arrays) | Power loss (kW) | % Reduction of power loss | $V_{min}$ in p.u. | $VSI_{min}$ in p.u. |
|---|---|---|---|---|---|---|
| 33- bus system | 1 | 13(6) | 136.21 | 35.44 | 0.9292 | 0.7371 |
| | 2 | 13(6), 31(6) | 91.40 | 56.68 | 0.9620 | 0.8483 |
| | 3 | 13(6), 25(6), 31(6) | 75.76 | 64.09 | 0.9644 | 0.8594 |
| | 4 | 13(6), 25(6),31(4), 32(4) | 75.39 | 64.26 | 0.9682 | 0.8726 |

**Table 2.** Optimal locations and different penetration level of PV arrays for IEEE 33 bus RDS in summer season

| Test system | No of connected buses | Bus location (No of connected PV arrays) | Power loss (kW) | % Reduction of Power loss | $V_{min}$ in p.u. | $VSI_{min}$ in p.u. |
|---|---|---|---|---|---|---|
| 33- bus system | 1 | 13(6) | 131.79 | 37.53 | 0.9312 | 0.7437 |
| | 2 | 13(6), 31(6) | 89.28 | 57.68 | 0.9678 | 0.8780 |
| | 3 | 13(6), 25(6), 31(6) | 75.51 | 64.21 | 0.9714 | 0.8911 |
| | 4 | 13(6), 25(5),31(3), 32(3) | 75.38 | 64.27 | 0.9708 | 0.8924 |

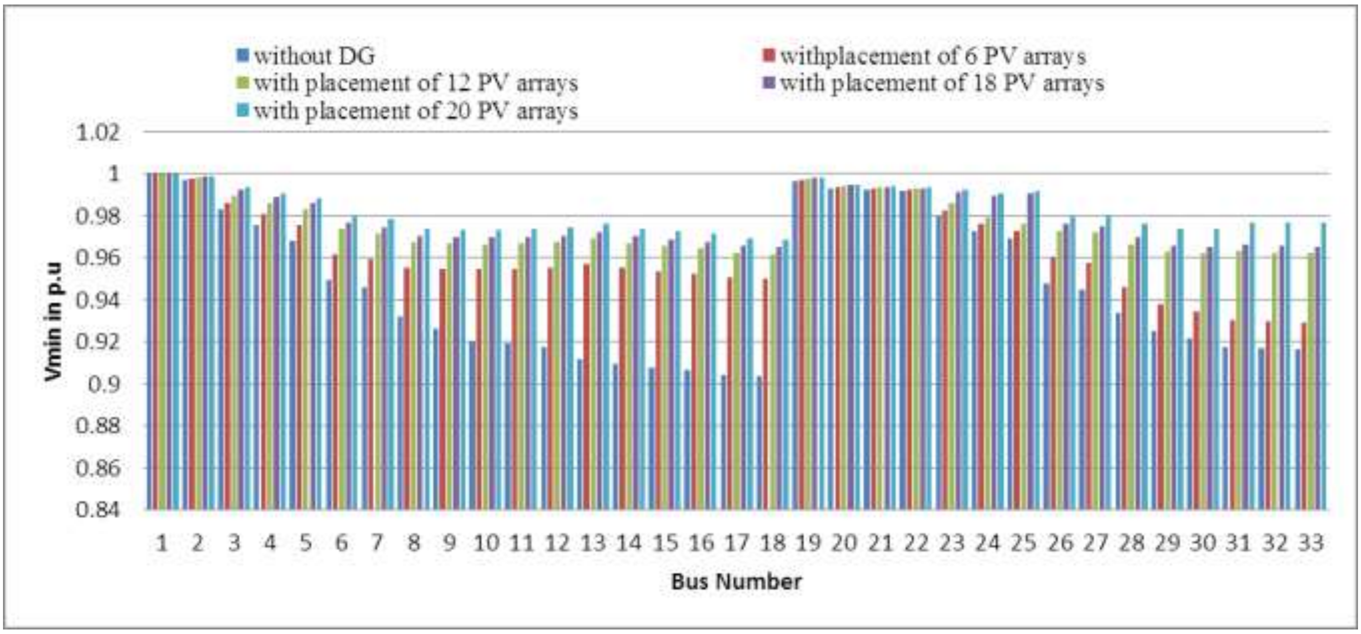


**Fig.3.** Minimum voltage magnitude of 33 bus system with and without placement of PV arrays considering winter season

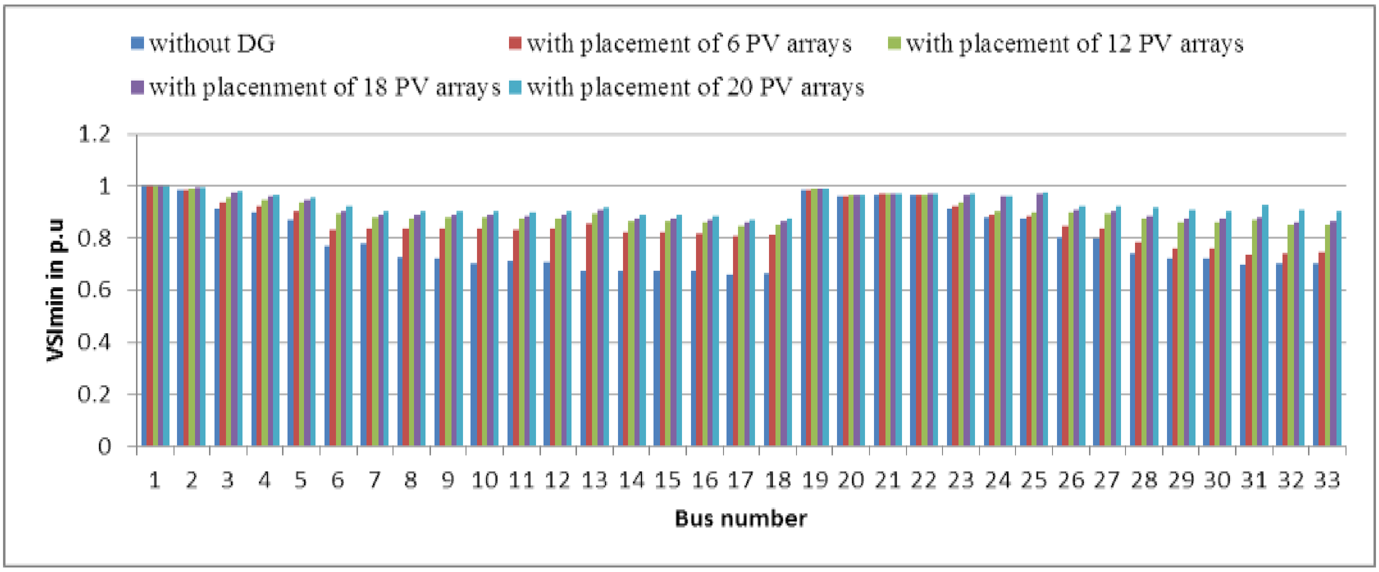


**Fig.4.** Minimum VSI of 33 bus system with and without placement of PV arrays considering winter season

For validation, the results obtained by the FPA method without considering seasonality are compared with other methods and it is given in Table 3. It is observed that power losses of the FPA method are less compared to all other methods with good enhancement in voltage profile.

Next performance of the proposed method without and with considering seasonality and obtained results are tabulated in Table 4. From the results, it is observed that power losses with considering summer and winter season are less compared to without seasonality.

**Table 3.** Comparative analysis of the FPA method with other methods for 33 bus system

| Method | FPA | SA [12] | GA [11] | PSO [11] | GA/PSO [11] |
|---|---|---|---|---|---|
| Location of DG | 13<br>25<br>31 | 30<br>18<br>6 | 30<br>29<br>11 | 32<br>13<br>8 | 32<br>16<br>11 |
| Size of DG in kW | 857.62<br>1114.2<br>804.10 | 867.90<br>487.40<br>1112.4 | 1071.4<br>422.80<br>1500.0 | 829.70<br>981.60<br>1176.8 | 1200.0<br>863.00<br>925.00 |
| Power loss (kW) | 76.28 | 82.03 | 106.30 | 105.35 | 103.40 |
| %Red of power loss | 63.84 | 61.12 | 49.61 | 50.06 | 50.99 |
| $V_{min}$ in p.u | 0.9704 | 0.9676 | 0.9809 | 0.9806 | 0.9808 |

**Table 4.** Performance of FPA method without and with considering seasonality for 33 bus system

| Parameters | FPA without seasonality | FPA (winter) | FPA(summer) |
|---|---|---|---|
| Location of DG | 13<br>25<br>31 | 13<br>25<br>31 | 13<br>25<br>31 |
| Size of DG in kW | 857.62<br>1114.2<br>804.10 | 813.48<br>813.48<br>813.48 | 956.52<br>956.52<br>956.52 |
| Power loss (kW) | 76.28 | 75.76 | 75.51 |
| %Red of power loss | 63.84 | 64.09 | 64.21 |
| $V_{min}$ in p.u | 0.9704 | 0.9644 | 0.9714 |

Heuristic methods are more efficient in solving complex optimization problems. But the performance is evaluated by its convergence ability. The convergence characteristics of an FPA method for solving corresponding objective function are shown in Fig.5. It is clear that the proposed method reached the best solution only in 15 iterations and 0.51 secs.

*6.2. Case 2: 69 bus test system*

The base case power loss before placement of solar based DGs is 224.99 kW and also the minimum voltage magnitude is 0.9092 p.u.. Optimal locations for placement of PV arrays are found out by using voltage stability factor concept, i.e. 61,64,59,27 and 21.

Next number PV arrays placed at these identified locations are evaluated by using FPA method. The optimal allocation of PV arrays from minimum penetration level to maximum penetration level considering two different seasons, i.e. winter and summer and the obtained results is tabulated in Tables 5 and 6. From the simulated results, it is clear that placement of the exact number of PV arrays in appropriate locations minimizes the power losses effectively. Also, the voltage stability index and voltage profile is improved to the maximum values with allocation of maximum PV arrays. The minimum voltage magnitude and voltage stability index without and with placement of PV arrays, considering summer reason is shown in Figs.6 and 7.

Next comparison of the proposed method with other methods in view of validation purpose and the results are presented in Table 7. From the simulated results, it is observed that power loss reduction of FPA method is best compared to all other methods with good enhancement in voltage profile.

Next performance of the FPA method without and with considering seasonality and the obtained results are tabulated in Table 8. From the simulated results, it is verified that power loss reduction with considering seasonality is high compared to without seasonality. Also, the total DG size, injected into the system is high in case of without considering seasonality. So considering seasonality, exact location with optimal number of PV arrays placed at these locations plays an significant role for achieving desired results.

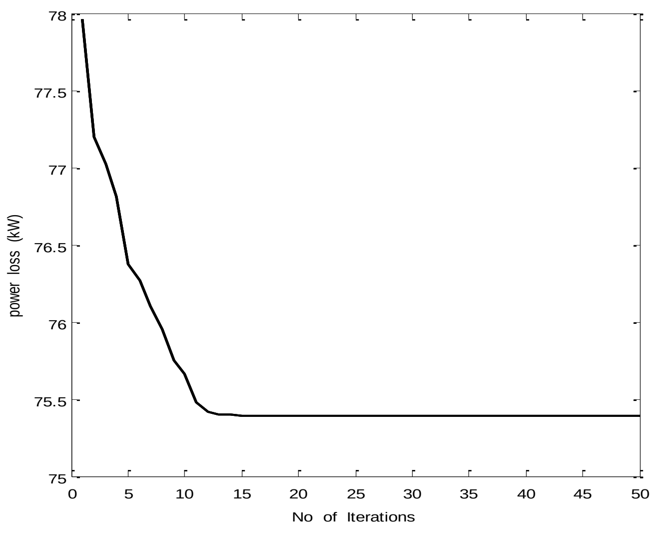


**Fig.5.** Convergence characteristics of the FPA method in solving corresponding objective function for 33 bus system

**Table 5.** Optimal locations and different penetration level of PV arrays for IEEE 69 bus RDS in winter season

| Test system | No of connected buses | Bus location (No of connected PV arrays) | Power loss (kW) | % Reduction of Power loss | $V_{min}$ in p.u. | $VSI_{min}$ in p.u. |
|---|---|---|---|---|---|---|
| 69- bus system | 1 | 61(6) | 125.60 | 44.17 | 0.9404 | 0.7816 |
| | 2 | 61(6), 64(6) | 86.63 | 61.76 | 0.9667 | 0.8734 |
| | 3 | 61(6), 64(6), 21(6) | 78.42 | 65.14 | 0.9771 | 0.9136 |
| | 4 | 61(6), 64(6), 21(2), 27(2) | 74.94 | 66.69 | 0.9756 | 0.9079 |
| | 5 | 61(6), 64(5), 59(2), 21(2),27(2) | 73.12 | 67.50 | 0.9787 | 0.9191 |

**Table 6.** Optimal locations and different penetration level of PV arrays for IEEE 69 bus RDS in summer season

| Test system | No of connected buses | Bus location (No of connected PV arrays) | Power loss (kW) | % Reduction of Power loss | $V_{min}$ in p.u. | $VSI_{min}$ in p.u. |
|---|---|---|---|---|---|---|
| 69- bus system | 1 | 61(6) | 114.58 | 49.07 | 0.9457 | 0.7992 |
| | 2 | 61(6), 64(6) | 85.57 | 61.96 | 0.9684 | 0.8795 |
| | 3 | 61(6), 64(6), 21(5) | 79.61 | 64.61 | 0.9866 | 0.9503 |
| | 4 | 61(6), 64(5),21(2), 27(1) | 73.45 | 67.35 | 0.9796 | 0.9226 |
| | 5 | 61(6), 64(6), 59(1),21(1),27(1) | 77.28 | 65.65 | 0.9840 | 0.9376 |

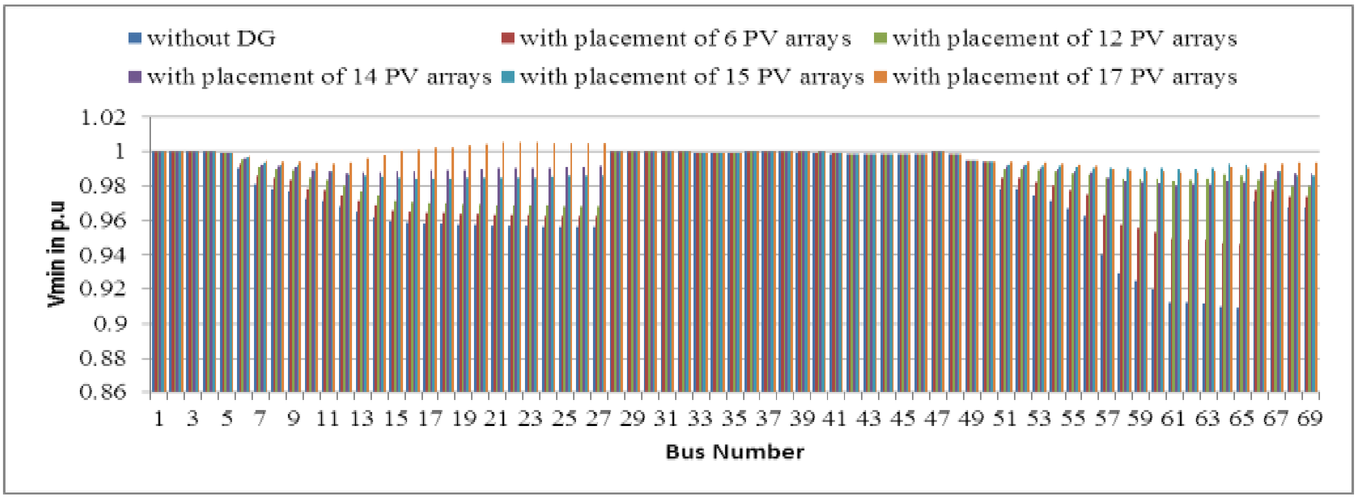


**Fig.6.** Minimum voltage magnitude of 69 bus system with and without PV arrays considering summer season

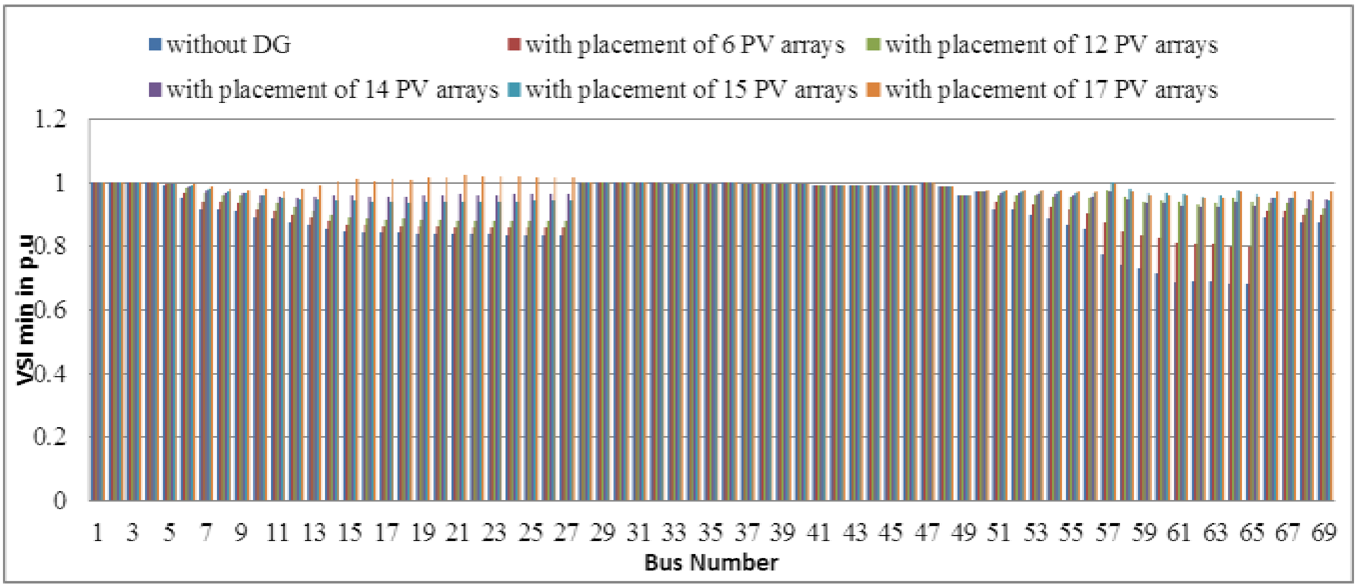


**Fig.7.** Minimum VSI of 69 bus system with and without placement of PV arrays considering summer season

**Table 7.** Comparative analysis of the FPA method with other methods for 69 bus systems

| Method | FPA | SA [12] | GA [11] | PSO [11] | GA/PSO [11] |
|---|---|---|---|---|---|
| Location of DG | 21<br>61<br>64 | 65<br>60<br>18 | 64<br>62<br>21 | 63<br>61<br>17 | 63<br>61<br>21 |
| Size of DG in kW | 359.70<br>1391.5<br>643.70 | 429.80<br>1331.1<br>420.40 | 992.50<br>1075.2<br>929.70 | 795.60<br>1199.8<br>992.50 | 884.90<br>1192.6<br>910.50 |
| Power loss (kW) | 74.86 | 77.10 | 89.00 | 83.20 | 81.10 |
| %Red of power loss | 66.72 | 65.73 | 60.44 | 63.02 | 63.95 |
| $V_{min}$ in p.u | 0.9855 | 0.9811 | 0.9936 | 0.9901 | 0.9925 |

**Table 8.** Performance analysis of FPA method without and with considering seasonality for 69 bus system

| Parameters | FPA without seasonality | FPA (winter) | FPA (summer) |
|---|---|---|---|
| Location of DG | 21<br>61<br>64 | 61<br>64<br>59<br>21<br>27 | 61<br>64<br>21<br>27 |
| Size of DG in kW | 359.70<br>1391.5<br>643.70 | 813.48<br>677.90<br>271.16<br>271.16<br>271.16 | 956.52<br>797.10<br>318.84<br>159.42 |
| Power loss (kW) | 74.86 | 73.12 | 73.45 |
| %Red of power loss | 66.72 | 67.50 | 67.35 |
| $V_{min}$ in p.u | 0.9855 | 0.9787 | 0.9796 |

The convergence characteristics of the FPA method with solving corresponding objective functions are shown in Fig.8. From the figure it is clear that FPA method achieves the best solution only in 18 iterations. Also the convergence time to achieve best solution is 1.11 secs.

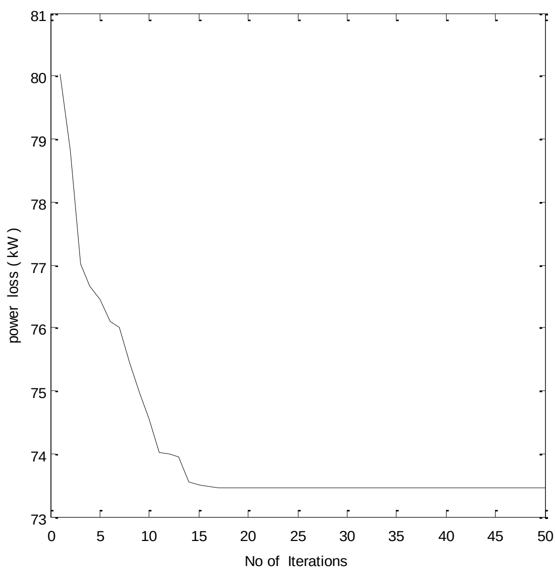


**Fig.8.** Convergence characteristics of the FPA method in solving corresponding objective function for 69 bus system

## 7. Conclusion

In this paper, optimal allocation of PV arrays in the distribution system using an integrated approach of voltage stability factor (VSF) concept and FPA was presented. The developed method is tested on IEEE 33 and 69 bus test systems. A Beta probability distribution function is used to model the stochastic nature of solar irradiance. Different seasons are considered for the analysis and the results are presented with the optimal allocation of PV arrays from minimum penetration level to maximum penetration level. From the results, it is observed that placement of PV arrays in optimal locations with optimal number reduces the power losses effectively. Also, the minimum voltage magnitude and the system stability index without and with placement of PV arrays at different penetration level are represented. At highest penetration level, there is a good improvement in voltage profile and VSI. The results obtained by the FPA method are compared with other methods. The results clearly show the effectiveness of the FPA method in solving the objective function. Next the performance of the FPA method with seasonality effect is considered and the simulated results are presented. From the obtained results, it can be concluded that considering seasonality with optimal number PV arrays placed in optimal locations plays a vital role in minimizing power losses in the distribution network.

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