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Optimal Placement and Sizing of Solar Constructed DG Using SSO Technique

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ABSTRACT

Proper placement of Distributed Generation (DG) in distribution system is still very challenging issue for obtaining their maximum potential benefits. This paper proposes a constrained multi objective Social spider optimization (SSO) based performance model of photovoltaic (PV) array placement approach for power loss reduction and voltage stability improvement of radial distribution system. The paper reflects the effectiveness of PV array performance models in DG placement problem formulation. Voltage Stability Factor (VSF) has been used in this paper which can quantify voltage stability levels of buses in the system. Optimal placement and sizing of Solar based DG tested on15-bus system. The results clear that the proposed SSO outperforms than the other methods.

Keywords:- Voltage stability factor, Performance model of PV array, Social Spider Optimization.

I. INTRODUCTION

With growing load demand in the distribution network, it provides potential scope for research in terms of analyzing the distribution network to meet the demand with the present infrastructure. Shortage of distribution current carrying capabilities and increased interest in application of green technology has led to use of Distributed Generation (DG) [1]. DG units are mainly energized by wind, solar and fuel cell. There are a number of DG technologies available in the market today and a few are still at the research and development stage. Among available technologies, wind and solar-based DG technologies are going to dominate the electricity market because of their environmental friendly characteristics and abundant availability of resources.

Normally the structure of distribution system is radial in nature because of their simplicity. Most of the radial distribution system suffers with high power losses because of high resistance to reactance ratios. The overall efficiency of the system can be improved using DG units. It is important to determine the optimal location for sitting of DGs. DG devices is strategically placed in power systems for grid reinforcement, reducing power losses and on-peak operating costs, improving voltage profiles and load factors, deferring or eliminating for system upgrades, and improving system integrity, reliability, and efficiency [2]. Installing DG units at non-optimal places may result in an increase in system losses, implying an increase in costs, and therefore, having an opposite effect to what is desired. Moreover, if multiple DG units are installed, optimal approach for placement of DGs in order to maintain the stability and reliability of the system become more crucial.

Previously the economic placement of coal fired generating station of the main grid is solved using the optimization technique such as Bacterial Foraging Optimization (BFO) [3], Ant Colony Optimization (ACO) [4], Bio-geography Based Optimization (BBO) [5] and so on.

A VSF has been used in this paper comparing with other voltage stability index and power stability index, VSF has emerged as simpler and efficient tool. In case of installation of multiple DGs, the problem of optimal placement of DGs is already solved by optimization techniques such as Genetic Algorithm (GA) [6], Particle Swarm Optimization (PSO) technique [7] and Artificial Bee Colony (ABC) optimization [8], Bio-geography Based Optimization (BBO) [9], Bat Inspired algorithm (BIA) [10]. Also the capacitor placement problem in microgrid is solved using the ABC [11], shuffled frog leaping algorithm (SFLA) [12] etc.

This paper proposes optimal placement of DGs using a recent new optimization technique called

Social Spider Optimization (SSO), which has the less iteration to find the optimal solution and has fast ability to find global optima during evaluation compared with other techniques, so the SSO technique is opted for the considered problem.

II. PROBLEM FORMULATION

2.1 FORMULATION OF VOLTAGE STABILITY MEASUREMENT

Voltage stability has become a major concern in modern power system scenario. Voltage Stability Factor (VSF) is helpful to measure voltage stability of the system or to find out critical buses in the network. Among different techniques, VSF based method has emerged as very fast and effective tool for off-line voltage stability analysis.

2.1.1. Voltage Stability Factor

A novel technique for determination of voltage stability [13] is discussed in detail here.

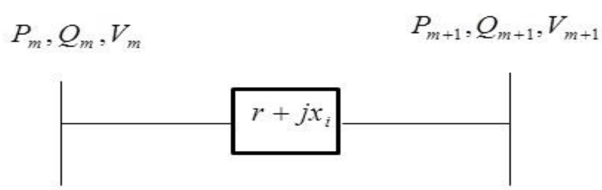

Fig 2.1 Two-bus section of radial distribution system

Considering two bus section of distribution system of Fig. 2.1, branch current of any branch 'i' can be obtained as follows.

$$I_i^2 = \left(\frac{P_{m+1}^2 + Q_{m+1}^2}{V_{m+1}^2} \right) \quad (1)$$

Where P_{m+1}, Q_{m+1} and V_{m+1} are the active load, reactive load and bus voltage magnitude at bus '$m+1$'.

So, active and reactive power losses in the branch are given by

$$P_{lossi} = r_i \left(\frac{P_{m+1}^2 + Q_{m+1}^2}{V_{m+1}^2} \right) \quad (2)$$

$$Q_{lossi} = x_i \left(\frac{P_{m+1}^2 + Q_{m+1}^2}{V_{m+1}^2} \right) \quad (3)$$

Here P_{lossi} and Q_{lossi} are active and reactive power losses of branch 'i'

$$I_i^2 = \frac{P_{lossi}^2 + Q_{lossi}^2}{(V_m - V_{m+1})^2} \quad (4)$$

From (5) and (8), equating I_i^2 becomes

$$\frac{P_{m+1}^2 + Q_{m+1}^2}{V_{m+1}^2} = \frac{P_{lossi}^2 + Q_{lossi}^2}{(V_m - V_{m+1})^2} \quad (5)$$

Putting the values of P_{lossi} and Q_{lossi} in (5)

$$(P_{m+1}^2 + Q_{m+1}^2)(r_i^2 + x_i^2) = (V_{m+1}^2 - V_{m+1}.V_m)^2 \quad (6)$$

Taking positive root of (6)

$$S_{m+1} = \left(\frac{V_{m+1}^2 - V_{m+1}.V_m}{Z_i} \right) \quad (7)$$

S_{m+1} is the magnitude of complex power at receiving end .For critical power flowing at receiving end.

$$\frac{dS_{m+1}}{dV_{m+1}} = \left(\frac{V_{m+1}^2 - V_{m+1}.V_m}{Z_i} \right) = 0 \quad (8)$$

For stable operation of the system

$$\frac{dS_{m+1}}{dV_{m+1}} > 0 \quad ie \ (2V_{m+1} - V_m) > 0 \quad (9)$$

Voltage stability factor for any bus 'm+1' is designated as

$$VSF_{m+1} = (2V_{m+1} - V_m) \quad (10)$$

At voltage collapse point VSF will become zero and that will be occurred when magnitude receiving end bus voltage become half of magnitude of sending end bus voltage. The more the value of the VSF nearer to zero, the system is more vulnerable.

Voltage stability condition of the whole distribution system can be justified summing the values of VSF of all the load buses.

So,

$$VSF_{total} = \sum_{m=1}^{k-1} \left(2V_{m+1} - V_m\right) \tag{11}$$

Where k is the total number of buses in the system and V_1 is the magnitude of substation voltage. The higher value of VSF_{total} indicates more voltage stable operation.

2.2 PERFORMANCE MODELING OF SOLAR GENERATION SYSTEM

Power generation of PV array depends on their model and resource such as solar radiation and ambient temperature. In this section modeling PV array is discussed to understand solar based DG placement technique in better way.

2.2.1. Performance model of PV array

For a PV array consist of $N_S \times N_P$ PV modules, maximum output power can be calculated as

$$P_{pv} = N_s N_p P_{md} \tag{12}$$

P_{md} is the maximum electrical power generated by PV module, which is formulated as

$$P_{md} = FF * V_{oc} * I_{sc} \tag{13}$$

V_{oc}, I_{sc} and FF are the open circuit voltage, short circuit current and fill factor of PV module. V_{oc}, I_{sc} and FF are the function of solar irradiance and PV module temperature; and these are obtained as follows

$$V_{oc} = \frac{V_{Noc}}{1 + c_2 * \ln \frac{G_N}{G_a}} \left(\frac{T_N}{T_a}\right)^{c_1} \tag{14}$$

$$I_{sc} = I_{Nsc} \left(\frac{G_a}{G_N}\right)^{c_3} \tag{15}$$

$$FF = \left(1 - \frac{R_s}{V_{oc} / I_{sc}}\right) \frac{\frac{V_{oc}}{nKT/q} - \ln\left(\frac{V_{oc}}{nKT/q} + 0.72\right)}{1 + \frac{V_{oc}}{nKT/q}} \tag{16}$$

G_N and G_a are the nominal and actual solar irradiance on module; T_N and T_a are nominal and actual module temperature, respectively; V_{Noc} and I_{Nsc} are nominal the open circuit voltage and short circuit current of PV module; R_s is the series resistance of module; c_1, c_2, c_3 are the three different constant which are introduced to show non-linear relationship between solar irradiance, photo-current and cell temperature n is density factor (n = 1.5); T is the PV module temperature (in Kelvin); K is Boltzman constant ($1.38*10^{-23}$ J/K); and q is the charge of electron ($1.6*10^{-19}$ C).

III. SOCIAL SPIDER OPTIMIZATION TECHNIQUE

It is the one of the nature inspired optimization technique and it is developed from behavior of social spiders [14]. The algorithm considers two different search agents (spiders): males and females, in web female spider highly biased and male spiders reach about 30%. The social spiders form colonies that remain together over a communal web with close spatial relationship to other group members. The communal web is used as a "medium of communication" which conveys important information that is available to each colony member. This information encoded as small vibrations is a critical aspect for the collective coordination among members. Vibrations are employed by the colony members to decode several messages such as the size of the trapped preys, characteristics of the neighboring members, etc. The intensity of such vibrations depends on the weight and distance of the spiders that have produced them.

3.1 STEPS INVOLVED IN SOLVING SSO ALGORITHM

The SSO assumes that entire search space is a communal web, where all the social-spiders interact to each other. In the proposed approach, each solution within the search space represents a spider position in the communal web. The algorithm steps are described below.

Step 1: Considering T as the total number of n-dimensional colony members, define the number of male P_m and females P_f spiders in the entire population S, Where S is the combined total spiders $S = \{s_1 = f_1, s_2 = f_2, \ldots, s_{N_f}, s_{P_{f+1}} = m_1, \ldots s_N = m_{P_m}\}$

$$P_f = floor[(0.9 - rand.0.25).T]$$
$$and$$
$$P_m = T - P_f \tag{17}$$

Where rand is random number between [0, 1] whereas floor (.) maps real number into integer number

Step 2: Initialize randomly the female and male members in the search space. Each spider position, f_i or m_i, is an n-dimensional vector containing the parameter values to be optimized. Such values are randomly and uniformly distributed between the pre-specified lower initial parameter bound P_j^{low} and the upper initial parameter bound P_j^{high}, just as it described by the following expressions:

$$f_{i,j}^0 = P_j^{low} + rand(0,1).(P_j^{high} - P_j^{low})$$
$$i = 1,2,\ldots,P_f;\ j = 1,2,\ldots,n \tag{18}$$

$$m_{i,j}^0 = P_j^{low} + rand(0,1).(P_j^{high} - P_j^{low})$$
$$i = 1,2,\ldots,P_m;\ j = 1,2,\ldots,n \tag{19}$$

Where i, j and k are the parameter and individual indexes respectively whereas zero signals the initial population. The function rand (0,1) generates a random number between 0 and 1. Hence, (i, j) is the j[th] parameter of the i[th] spider position.

Step 3: Calculate the weight of every spider of S

$$w_i = AF(s_i) - worst_s / (best_s - worst_s)$$
$$best_s = \max_{k \in \{1,2,..N\}} AF(s_k)$$
$$and$$
$$worst_s = \min_{k \in \{1,2,..N\}} AF(s_k) \tag{20}$$

Where $AF(s_i)$ is argument fitness value obtained by the evaluation of spider position s_i with regard to the objective function *AF (.)*

Step 4: Move female spiders according to female cooperative operator

The vibrations perceived by the individual i as results of the information transmitted by the member j are modeled according to the following equation

$$Vib_{i,j} = w_j.e^{-d_{i,j}^2} \tag{21}$$

Where $d_{i,j}$ is the Euclidian distance between the spiders i and j, such that

$$d_{i,j} = || s_i - s_j || \tag{22}$$

Although it is virtually possible to compute perceived vibrations by considering any pair of individuals, three special relationships are considered within the SSO approach:

Case 1: Vibrations $Vibc_i$ are perceived by the individual $i(s_i)$ because of the information transmitted by the member $c(s_c)$ who is an individual that has two important characteristics: it is the nearest member to i and possesses a higher weight in comparison to $i(w_c < w_i)$.

$$Vibc_i = w_c.e^{-d_{i,c}^2} \tag{23}$$

Case 2: The vibrations $Vibb_i$ perceived by the individual i as a result of the information transmitted by the member $b(s_b)$, with b being the individual holding the best weight (best fitness value) of the entire population S, such that $w_b = \max_{k \in \{1,2,\ldots N\}} (w_k)$.

$$vibb_i = w_b.e^{-d_{i,b}^2} \tag{24}$$

Case 3: The vibrations $vibf_i$ perceived by the individual $i(s_i)$ because of the information transmitted by the member $f(s_f)$, with f being the nearest female individual to i.

$$vibf_i = w_f .e^{-d_{i,f}^2} \tag{25}$$

Female cooperative operator

Female spiders present an attraction or dislike over others irrespective of gender. For this operation, a uniform random number r_m is generated within the range [0,1]. If r_m is smaller than a threshold Probability Function (PF) value, an attraction movement is generated; otherwise, a repulsion movement is produced. Therefore, such operator can be modeled as follows:

$$PF = \frac{w_i}{\sum_{j=1}^{T} w_j} \tag{26}$$

$$f_i^{k+1} = \begin{cases} f_i^k + \mu Vibc_i.(s_c - f_i^k) + \gamma.Vibb_i.(s_b - f_i^k) + \xi.(rand - 1/2) & for \quad r_m < PF \\ f_i^k - \mu.Vibc_i.(s_c - f_i^k) - \gamma.Vibb_i.(s_b - f_i^k) + \xi.(rand - 1/2) & if \quad else \end{cases} \tag{27}$$

Where μ, γ, ξ and rand are random numbers between [0,1] whereas k represents the iteration number.

Step 5: Move the male spiders according to the male cooperative operator

For emulating such cooperative behavior, the male members are divided into two different groups (dominant members D and non-dominant members ND) according to their position with regard to the median member. Male members, with a weight value above the median value within the male population, are considered the dominant individuals D. On the other hand, those under the median value are labeled as non-dominant ND males According to this, change of positions for the male spider can be modeled as follows:

$$m_i^{k+1} = \begin{cases} m_i^k + \alpha.vibf_i.(s_f - m_i^k) + \delta.(rand - 1/2) & if \quad w_{P_f+i} > w_{P_f+m} \\ m_i^k + \alpha.\left(\dfrac{\sum_{h=1}^{N_m} m_h^k . w_{N_f+h}}{\sum_{h=1}^{N_m} w_{N_f+h}} - m_i^k \right) & if \quad w_{P_f+i} \le w_{P_f+m} \end{cases} \tag{28}$$

Step 6: Perform Mating operation

Mating in a social-spider colony is performed by dominant males and the female members. Under such circumstances, when a dominant male m_g spider $(g \in D)$ locates a set E^g of female members within a specific range r (range of mating), it mates, forming a new brood S_{new}. It is important to emphasize that if the set E^g is empty, the mating operation is canceled. The range r is defined as a radius which depends on the size of the search space, which is given by

$$r = \sum_{j=1}^{n} (P_j^{high} - P_j^{low}) / 2.n \tag{29}$$

After mating process compare with old spider and new spiders weights if new spider weight is high means replace otherwise do with same weight.

Step 7: If the stop criteria is met, the process is finished; otherwise, go back to Step 3.

IV. OPTIMAL PLACEMENT AND SIZING OF SOLAR CONSTRUCTED DG USING SSO TECHNIQUE

Step 1: Initialize the parameters such as bus number, number of DG units and its minimum and maximum capacity of generation, maximum number of iteration, total loss of the system (eqn. 32), total VSF of the system (eqn. 33)

$$Sloss_{total} = \sum_{i=1}^{n} \sqrt{Ploss_i^2 - Qloss_i^2} \tag{30}$$

$$VSF_{total} = \sum_{m=1}^{k-1} \left(2V_{m+1} - V_m\right) \qquad (31)$$

Step 2: Randomly place the DG unit in distribution system and calculate generation of real (eqn. 34) and reactive power (eqn. 35) of DG units using the below equations.

$$P_{DG,i} = I_i * DG_i * \cos\theta \qquad (32)$$

$$Q_{DG,i} = I_i * DG_i * \sqrt{1-\cos^2\theta} \qquad (33)$$

Using newton raphson power flow solution calculates voltage magnitude of buses.

Step 3: Check the power flow constraints, the power flow constraints equations are given by,

$$P_{G,i} + P_{DG,i} - P_{D,i} = 0 \qquad (34)$$

$$Q_{G,i} + Q_{DG,i} - Q_{D,i} = 0 \qquad (35)$$

If above equations are satisfied go to next step, otherwise increase the DG unit and go to step 2

Step 4: Check the each bus voltage magnitude by below equation

$$|V_{i,bus}| \le 1.05\, p.u \qquad (36)$$

If above equation satisfied means compute and store the values of total loss (eqn) and total VSF (eqn). If above equation not satisfied, increase the iteration and increase the DG units until reach the maximum number of DG units and repeat the step 2

.

Step 5: Continue the process until reach maximum number of DG unit. Update the total loss and total VSF of the Distribution system.

Step 6: Check for maximum number of iteration. If satisfied store the location of DG at the bus and number of DG unit at connected bus. If not satisfied, go to step 2.

Step 7: calculate the optimal size of DG for the results obtained from step 5 using below equation.

For solar PV array,

$$DG_{pv,i} = \sum_{n_i=1}^{n_{i,\max}} n_i * P_{pv} \qquad (37)$$

Stop the process.

V. RESULTS AND DISCUSSIONS

5.1 RESULTS FOR DG PLACEMENT

DG placement tested on IEEE15-bus radial distribution system. The program was carried out in MATLAB environment for getting validates VSF. Newton–Raphson algorithm based power flow program is used to solve the power flow problem. The 15-bus radial distribution system have total load of 1.226 + j1.251. Complex voltages of all the load buses are calculated using power flow solution technique.

5.1.1 Photo Voltaic Array placement

Before the placement, size of one PV array consider to be tabulated below,

Table 5.1 Parameters and their corresponding values of PV module.

PV module parameter	Values
Maximum output (W)	100
Nominal solar intensity on module (W/m^2)	1000
Nominal open circuit voltage (V)	21

Nominal short circuit current (I)	6.5
Series resistance (ohm)	0.012
Nominal cell operating temperature $(°C)$	25

For 15-bus system 24 PV array require for satisfy the reliable operation. Using SSO algorithm found weak buses are the 5, 6, 8, 9, 12 and 15 based on the VSF values. So these buses are opted for the placement of PV arrays.

Table 5.2. Optimal location and number PV arrays at unity power factor for 15-bus system along with voltage stability improvement and power loss reduction

	No. of connection bus	Location at bus (No. of PV array)	Value of total VSF	Improvement of voltage stability (%)	Total power loss (KVA)	Power loss minimization (%)
15-bus system	1	Bus -15 (5)	13.261	0.9	80.1	21.5
	2	Bus-4 (5), bus-15 (5)	13.354	1.53	67.4	33.17
	3	Bus-4 (4) , bus-7 (5), bus-12 (3),	13.408	1.86	60.5	40.23
	4	Bus-6 (4), bus-11 (5), bus-13 (3), bus-15 (4)	13.491	2.55	54.5	45.67
	5	Bus-2 (5), bus-5 (5), bus-6 (3), bus-7 (4), bus-11 (5),	13.541	2.93	51.54	48.6
	6	Bus-5 (4), bus-6 (4), bus-8 (5), Bus-9 (3), bus-12 (4), bus-15 (4)	13.615	3.51	50.6	49.12

After placement of PV array in found weak buses of 15-bus system, the obtained total VSF, total power loss, percentage of voltage stability improvement and percentage of loss minimization that shown in table 5.2.

Table 5.3 Respective voltage magnitude of each bus for without and with placement of PV array

Bus number	Without PV array	With 5 PV array	With 10 PV array	With 12 PV array	With 16 PV array	With 22 PV array	With 24 PV array
1	1	1	1	1	1	1	1
2	0.965	0.969	0.974	0.979	0.984	0.986	0.989
3	0.95	0.955	0.960	0.964	0.968	0.972	0.98
4	0.945	0.95	0.955	0.959	0.964	0.968	0.975
5	0.94	0.945	0.950	0.954	0.959	0.963	0.968
6	0.95	0.955	0.960	0.964	0.968	0.972	0.976
7	0.945	0.95	0.955	0.959	0.963	0.967	0.973

8	0.949	0.954	0.959	0.964	0.968	0.972	0.981
9	0.961	0.966	0.971	0.975	0.979	0.984	0.986
10	0.959	0.964	0.969	0.973	0.977	0.981	0.985
11	0.94	0.944	0.949	0.953	0.957	0.960	0.964
12	0.935	0.94	0.945	0.949	0.953	0.957	0.965
13	0.932	0.937	0.942	0.946	0.950	0.954	0.968
14	0.94	0.945	0.950	0.954	0.958	0.962	0.969
15	0.939	0.944	0.949	0.955	0.961	0.966	0.971

The voltage magnitude of buses is improved after placement of WTGU in found weak bus of 15-bus system. The voltage magnitude values varied from without PV array placement, with 5, 10, 12, 16, 22 and 24 PV arrays. That improvement of voltage magnitude of different buses gives reliable operation of system. Table 8 shows the voltage magnitude variation of each bus for without WTGU, with 5 PV array, 10 PV array, 12 PV array, 16 PV array, 22 PV array and 24 PV array. The voltage magnitude improvement from without PV array to different number of PV array connection different buses in 15-bus radial distribution system shows in figure 5.1. The table 5.3 respective values are plotted in graph and it is shown below.

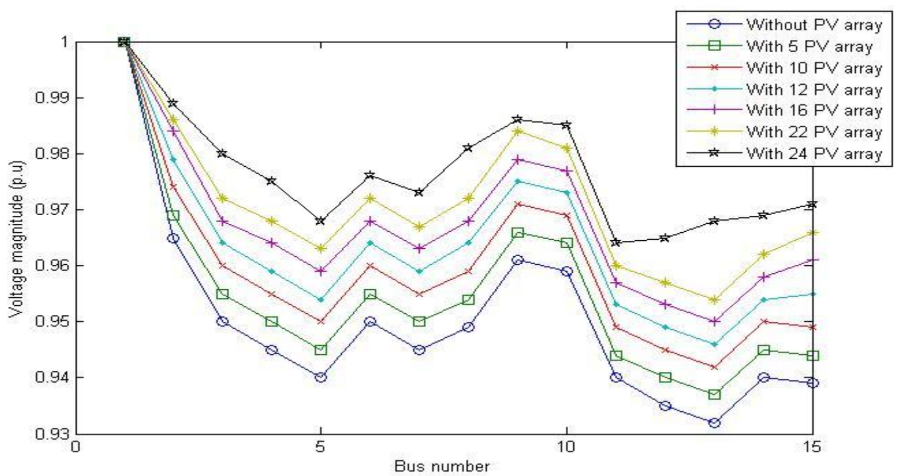

Figure 5.1 Illustration of voltage magnitude of 15- bus test system for different number of connection in bus of PV array placement.

Table 5.4 Comparative results of PV array placement with power loss minimization based method; voltage stability based method and proposed technique at maximum penetration level DG with unity power factor.

	Techniques	**Location at bus (No. of WTGU)**	**Total VSF**	**Total power loss (KVA)**
15- bus system	Power loss minimization based DG placement [15,16,17]	bus-4 (5), bus-6 (3), bus-8 (4), bus-9 (4), bus-12 (6), bus-14 (2)	13.617	50.9
	Voltage stability based DG placement [18]	bus-6 (6), bus-7 (6), bus-8 (6), bus-11 (6)	13.5856	67.0
	SSO Method	**bus-5 (4), bus-6**	**13.615**	**50.6**

	[Props.]	**(4), bus-8 (5), bus-9 (3), bus-12 (4), bus-15 (4)**		

The proposed methodology is compared with other DG placement technique in Table 5.4. VSI based DG placement method is not suitable for multiple DG placement. The result obtained on the basis of power loss minimization technique is quite competent and results match with proposed methodology in some cases. But, data of Table 8 reflect that proposed method can allocate PV array in better way to improve voltage stability of the network and reduce system power losses

VI. CONCLUSION

This paper has presented a novel multi-objective Social Spider Optimization (SSO) based method for optimal placement of solar-based Distributed Generation (DG) units into distribution system. The method targets to improve the voltage stability margin and reduce network power losses utilizing supply from DG units. The Voltage Stability Factor (VSF) to measure the voltage stability level of different buses in the network, it is used to quantify voltage stability condition of the whole distribution network also. Comparing with other voltage stability indexes, it can be concluded that VSF is very efficient and simple in form. Utilizing performance modeling, optimal location and size selection of photovoltaic (PV) array in distribution system are discussed.

Optimal placement of inverter interfaced PV arrays has been investigated on 15-bus radial distribution system. Optimal locations and sizes of PV arrays in distribution systems at maximum penetration level have been determined. It is seen that proposed method performs more efficiently than other DG placement techniques in the both power loss minimization and voltage stability improvement of the system.

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