*J. Basic. Appl. Sci. Res.*, 2(1)703-709, 2012

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ISSN 2090-4304
**Journal of Basic and Applied Scientific Research**
*www.textroad.com*

# PSO-Based Optimal Placement of DGs in Distribution Systems Considering Voltage Stability and Short Circuit Level Improvement

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## ABSTRACT

This paper presents PSO based distributed generator placement technique in a distribution system to achieve the best voltage stability and improve the short circuit level of system. Utilities are continuously planning the expansion of their existing electrical networks in order to face the load growth and to properly supply their consumers. Distribution system provides a final link between the high voltage transmission system and the consumer. With the deregulation of electricity markets, the system operation strategies have changed in recent years. The systems are operated with smaller margins. This paper investigate the voltage stability assessment with the consideration of uneven regional load growth pattern and economic dispatch of the online generation units, aiming at assessing the voltage stability margin of a power system for a given operating condition and network topology in more realistic manner. Both the optimal size and location are obtained as outputs from the genetic algorithm toolbox. The results are verified using two popular power flow analytical tools for distribution system load flow.

**KEY WORDS:** Distributed generation; distribution system; PSO; voltage stability; short circuit level.

## I. INTRODUCTION

In this paper, a new objective function to calculate optimal location and optimum size value for DG is proposed. The DG is considered to be located in the primary distribution system and the objective of the DG placement is to improve the voltage profile and short circuit level at each bus of system. The cost and other associated benefits have not been considered while solving the location and sizing problem. Electricity networks are in the area of major transition from stable passive distribution networks with unidirectional electricity transportation to active distribution networks with bidirectional electricity transportation. Distribution networks without any DG units are passive since the electrical power is supplied by the national grid system to the customers embedded in the distribution networks. Utilities are continuously planning the expansion of their existing electrical networks in order to face the load growth and to properly supply their consumers. Distribution system provides a final link between the high voltage transmission system and the consumerIt becomes active when DG units are added to the distribution system leading to bidirectional power flows in the networks (H. Zareipour, and et.al, 2004). Hence, utilities and distribution companies need tools for proper planning and operation of Active Distribution Networks. The most important benefits are reduction of line losses and voltage stability improvement. They are crucially important to determine the size and location of DG unit to be placed. Studies indicate that poor selection of location and size would lead to higher losses than the losses without DG (T. E. Kim, 2001). In (W.EI-hattam, M.M.A. Salma,2004 ), an analytical approach has been presented to identify appropriate location to place single DG in radial as well as loop systems to minimize losses. But, in this approach, optimal sizing is not considered. Loss Sensitivity Factor method (LSF) (Graham W. Ault, James R. McDonald, 2000) is based on the principle of linearization of the original nonlinear equation (loss equation) around the initial operating point, which helps to reduce the amount of solution space. In an active distribution network the amount of energy lost in transmitting electricity is less as compared to the passive distribution network, because the electricity is generated very near the load centre, perhaps even in the same building. Active Distribution Network has several advantages like reduced line losses, voltage profile improvement, reduced emission of pollutants, increased overall efficiency, improved power quality and relieved T&D congestion. The LSF method has widely used to solve the capacitor allocation problem. Optimal placement of DG units is determined exclusively for the various distributed load profiles to minimize the total losses. They have iteratively increased the size of DG unit at all buses and then calculated the losses; based on loss calculation they ranked the nodes. Top ranked nodes are selected for DG unit placement. The Genetic Algorithm (G.A) based method to determine size and location of DG unit is used in (Eduardo G. Carranoand et,al, 2006). They have addressed the problem in terms of cost, considering cost function may lead to deviation of exact size of the DG unit at suitable location. It always gives near optimal solution, but they are computationally demanding and slow in convergence.

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## II. Modeling

### *II.1 Short Circuit Level Index (ISC):*

This index is related to the protection and sensitivity issues since it evaluates the short circuit current at each bus with and with-out DG (Eduardo G. Carranoand et,al, 2006).

$I_{SC}^{without\,DC}$ is the short circuit current before installing the DG and $I_{SC}^{with\,DC}$ is the short circuit current after installing the DG.

$$I_{SC} = \frac{I_{SC}^{without\,DC} - I_{SC}^{with\,DG}}{I_{SC}^{without\,DC}} \qquad (1)$$

### *II.2 Voltage Stability Index (VSI):*

Accurate voltage stability contingency analysis could be accomplished by performing a PV (active load power-voltage magnitude) curve study. Some other methods introducing different stability indices have also been introduced and compared in (H. Zareipour, and et.al, 2004). A line stability index LQP is proposed in (M.E. Baran and F.F. Wu, 2005). The voltage stability index is derived from a 2 bus system as shown in Figure 2.

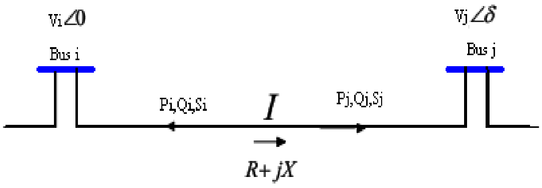

Fig.1.2-bus model representation

| | |
|---|---|
| $V_i, V_j$ | Voltages at the sending and receiving buses |
| *Pi,Qi* | Active and reactive power at the sending bus. |
| *Pj,Qj* | Active and reactive power at the receiving bus. |
| *Si,Sj* | Complex power on the sending and receiving buses |
| $\delta$ | Angle of the voltage at the receiving end |

The current flow from sending bus to receiving bus can be computed As:

$$I = \frac{V_i\angle 0 - V_j\angle\delta}{R + jX} \qquad (2)$$

Where, *R* is the line resistance and *X* is the line reactance.
The received complex power at receiving bus:

$$S_j = V_j \times I_j = P_j + jQ_j \qquad (3)$$

In above equation we have:

$$\begin{cases} P = \left[\dfrac{R}{R^2+X^2}(V_i\cos\delta - V_j) - \dfrac{X}{R^2+X^2}(V_1\sin\delta)\right]V_j \\ Q = \left[\dfrac{X}{R^2+X^2}(V_i\cos\delta - V_j) - \dfrac{R}{R^2+X^2}(V_1\sin\delta)\right]V_j \end{cases} \qquad (4)$$

If the line resistance is very small compared to the reactance we have:

$$\begin{cases} \sin\delta = \dfrac{XP_j}{V_iV_j} \\ \cos\delta = \dfrac{XQ_j + V_j^2}{V_iV_j} \end{cases} \qquad (5)$$

Then:

$$(\frac{XP_j}{V_iV_j})^2 + (\frac{XQ_j + V_j^2}{V_iV_j})^2 = \\ = \sin^2\delta + \cos^2\delta = 1 \qquad (6)$$

So

$$V_j^4 + (2XQ_j - V_i)V_j^2 + (X^2Q_j^2 + X^2P_j^2) = 0 \qquad (7)$$

Consider this equation, to be equaled equation of $V_j^2$ ,for $V_j^2$ in order to have a real solution the follow expression must be satisfied:

$$(2XQ_j - V_i)^2 - 4(X^2Q_j^2 + X^2P_j^2) \geq 0 \tag{8}$$

So

$$Q_j \leq \frac{V_i^2}{4X} - \frac{P_j^2 X}{V_j^2} \tag{9}$$

Since the line is lossless, then $P_i = -P_j$ ,so we have:

$$4\left(\frac{X}{V_i^2}\right)\left(-\frac{X}{V_i^2}P_j^2 + Q_j\right) \leq 1 \tag{10}$$

The line stability index is therefore defined for line between bus I and bus j as:

$$VSI_{ij} = 4\left(\frac{X}{V_i^2}\right)\left(-\frac{X}{V_i^2}P_j^2 + Q_j\right) \tag{11}$$

When there is no load at bus j,the $VSI_{ij}$ is 0,as the load in the system increases, the $VSI_{ij}$ value increases from 0 to 1.the $VSI_{ij}$ value must be smaller than 1 for the system to be stable. The higher $VSI_{ij}$ value is, the closer the system is working near its stability margin. The system stability factor SSF in a contingency is defined as the biggest $VSI_{ij}$ for all transmission lines. In case the system becomes unstable or collapse Newton-Raphson's method for power flow analysis will not converge, therefore the system stability factor cannot be calculated correctly by performing power flow analysis. In this case, the SSF is assigned to be 1.

### *II.3 Multiobjective Based Problem Formulation*

The multiobjective index for the performance calculation of distribution systems for DG size and location planning with load models considers all previous mentioned indices by giving a weight to each index. The PSO-based multiobjective function (MOF) is given by

$$MOF = w_1 * SSF + w_2 * ISC \tag{12}$$

Where

$$w_1 + w_2 = 1 \tag{13}$$

These weights are indicated to give the corresponding importance to each impact indices for the penetration of DG with load models and depend on the required analysis (e.g., planning, operation, etc.). The weighted normalized indices used as the components of the objective function are due to the fact that the indices get their weights by translating their impacts in terms of cost. It is desirable if the total cost is decreased. In this work, due to more important the stability factor respect to short circuit level, these weights are assigned as $w_1 = 0.65\, and\, w_2 = 0.35$ .However, these values may vary according to engineer's concerns, Subjected to various operational constraints to satisfy the electrical requirements for distribution network. These constraints are the following.

## III. Particle Swarm Optimization (PSO)

In order to better clarify, the solution of optimization problem in regional level with PSO can be presented by an algorithm in five steps as follows:

***Step1: Initialization*** $\gamma$

In this step d, n, T, itermax, w, c1, c2 and velocities are assigned.

In this step, the lower and higher bound of regional constraints is specified too. Based above d initial particles are generated in random in the range of regional constraint. Set iteration=1.

***Step2: Objective function calculation***

In this step the objective function and fitness value of each particle qi,d is calculated.

Compare fitness value of each particle with its qbest.The best fitness value among qbest is denoted as sbest.

***Step3: Velocity modification***

In this step the velocity of each particle is modified based on bellow equation, and then generate the new particles based follow equation:

$$v_{dn}^{t\ r+1} = w.v_{dk}^{r} + c_1 * rand() * (qbest_{dk} - q_{dn}^{t\ (r)}) + c_2 * Rand() * (sbest_d - x_{dk}^{r}) \qquad 14$$

$$q_{dn}^{t\ (r+1)} = q_{dn}^{t\ (r)} + v_{dn}^{t\ (r+1)} \qquad 15$$

In these equations $q_{dn}^{t\ (r)}$ is a part of abobe equation in the rth iteration. It should be noted that $q_{dn}^{t\ (r)}$ is defined earlier, if $v_{dn}^{t}$ reaches to its boundary values, it will be adjust to the extreme values. In other words, If $v_{dn}^{t} > V^{\max}$ then $v_{dn}^{t} = V^{\max}$.Similarly, If $v_{dn}^{t} < V^{\min}$ then $v_{dn}^{t} = V^{\min}$.Finally the all of regional constraints are checked and the offender particles are penalized with the penalty factor expressed by above equation:

***Step4: Upgrading of qbest,sbest***

If the fitness value of each particle is better than the previous qbest,then qbest is updated with the current value.If the best qbest is better than sbest, then sbest will be substituted with the best qbest. This is the end of iteration. Set iteration=iteration+1.

If iteration>itermax then the algorithm is stopped unless it is continued by going to step2. Otherwise step 5.

***Step5: Results of PSO***

The particle that generates the latest sbest is the optimal solution of PSO.1 to P for location and Cmin and Cmax for capacity, that R is the number of possible buses where DGs may be placed and Cmin to Cmax, that Cmin and Cmax are minimum and maximum possible capacity of DGs. So, a single solution can be defined as a specific allocation of individual DGs and protective devices on the feeder, i.e., the kth solution in the population is an (2N)-dimensional row vector of discrete numbers:

$$X_k = \begin{Bmatrix} [x\ y\ z] \mid x_i \in \{1,\dots,P\}, i = 1,\dots,N, y_i \in \{C_{\min},\dots,C_{\max}\} \\ z_j \in \{1,\dots,R\}, j = 1,\dots,M \end{Bmatrix}$$

Where:

| | |
|---|---|
| $X$ | Location list of each chromosomes, |
| $P$ | Number of buses |
| $N$ | Number of DGs |
| $M$ | Number of lines |
| $C_{min}$ | Minimum Capacity of DGs |
| $C_{max}$ | Maximum Capacity of DGs |

With constraint

$$m \le M_{\max}$$

$$n \le N_{\max}$$

$$P_{\min} \le P_{DG}(i) \le P_{\max}$$

$$Q_{\min} \le Q_{DG}(i) \le Q_{\max}$$

$$\sum_{i=1}^{m} P_{DG}(i) \le P_{DG,total}$$

where:

| | |
|---|---|
| $m$ | Number of DGs, |
| $M_{\max}$ | Maximum number of DGs, |
| $n$ | Number of MGs, |
| $N_{\max}$ | Maximum number of MGs, |
| $P_{DG}$ | Active power of DGs, |
| $Q_{DG}$ | Reactive power of DGs, |
| $P_{\min}, P_{\max}$ | Constraint of active power of DGs, |
| $Q_{\min}, Q_{\max}$ | Constraint of reactive power of DGs |
| $P_{DG,total}$ | Maximum capacity of DGs for Network, |

The first part of constraint is related to DGs that is formed of number, possible location, active and reactive power for each source. The second part is related to permissible voltage of each load point in islanding mode, and the last part is the number and possible location of MGs, so:

$$P_{DG-i,\min} \le P_{DG-i} \le P_{DG-i,\max}$$

$$Q_{DG-i,\min} \le Q_{DG-i} \le Q_{DG-i,\max}$$

$$V_{i-\min} \le V_i \le V_{i-\max}$$

Which:

| | |
|---|---|
| $P_{DG-i}$ | Active power of *ith* DG |
| $Q_{DG-i}$ | Reactive power of *ith* DG |
| $V_i$ | Voltage at *ith* load point |
| $P_{DG-i,\min}, P_{DG-i,\max}$ | Constraint of active power of *ith* DG |
| $Q_{DG-i,\min}, Q_{DG-i,\max}$ | Constraint of reactive power of *ith* DG |
| $V_{\min}, V_{\max}$ | Constraint of load point voltage in islanding mode |

The Newton-Raphson method is applied in each island, and if one of the constraints about DGs or load point voltage has been broken the island will be shut down. For each combination of switches and DGs, reliability areas are determined. Then, considering the islanding capability of the network, reliability index is calculated after the fault simulation on each line. In order to calculate the loss and voltage profile, a complete power flow is applied. Finally, for each chromosome, the amount of objective function is calculated.

## IV. SIMULATION AND RESULTS

To investigate the presented methodology on optimized results, it is tested on test systems. The test system is a 12 bus system with the total load of 761.04 KW and 776.50 KVAR and base voltage 11KV. A single line diagram of the test system is shown in Figure 3.

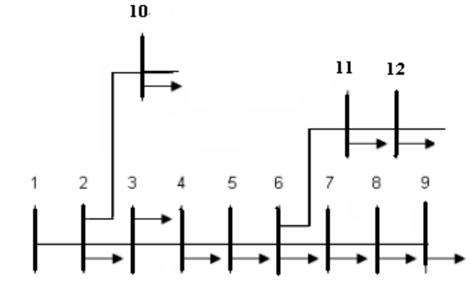

Fig.3.Test distribution system

To calculate the optimum location and sizes of DG at various buses using PSO and reparative load flow method to identify the best location and size of DG a computer program has been written in MATLAB 7.6 . Load flow program A complex Newton based is implemented to solve the load flow problem. The multiobjective function optimally minimized is shown in Figure 4.

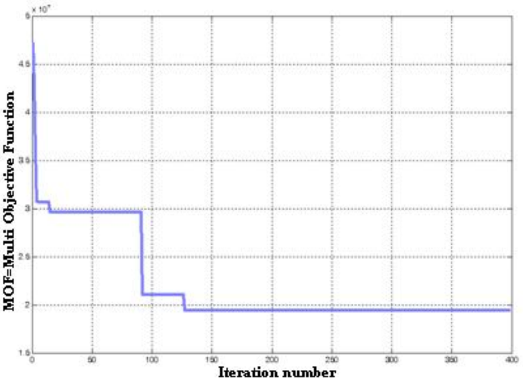

Fig.4.Multiobjective function optimally minimized value versus iteration number

The best location in 12 bus system is in the order 3, 6, 7 and 11 and corresponding optimal sizes are 447.41 KW, 460.85 KW, 487.11 KW and 523.27 KW for reducing voltage deviation obtained using the present method described here, .The corresponding optimal size of DGs is presented in TABLE 1.

TABLE I

OPTIMAL DG UNIT SIZES FOR 12-BUS RADIAL DISTRIBUTION SYSTEM

| Test System | Optimal Locations | Optimum DG Size in KW |
|---|---|---|
| 12 bus | 3 | 447.41 |
| | 6 | 460.85 |
| | 7 | 487.11 |
| | 11 | 523.27 |

Top ranked buses and their corresponding SSF and ISC with optimal DG size for 12 bus are shown in Figure 5 .

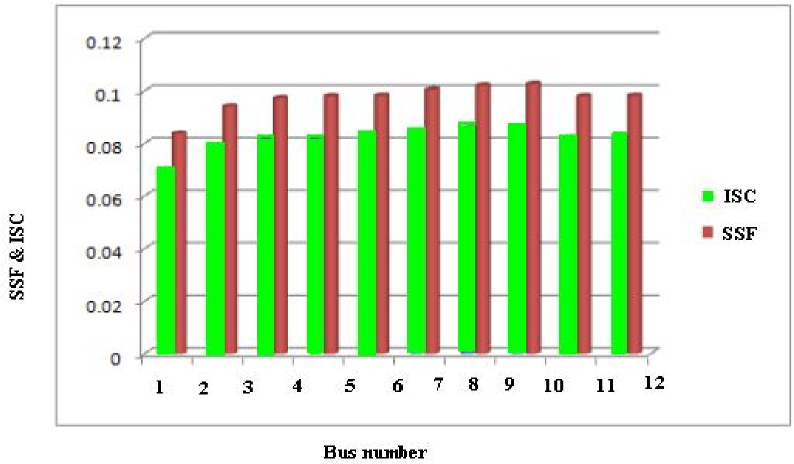

Fig.5. SSF and ISC of each bus of system after installing DGs

The improvement in voltage profile under different load models is shown in Fig.5. This figure indicate the voltage at all buses before inserting DG units to the system is higher than 0.90 pu except at buses 10, 11 and 12 in the case of constant load model. Due to the insertion of DG units, the voltage profile significantly improved for all studied load models. Improvement in voltage stability was observed from Fig.6.in this figure the voltage stability index at each buses of system is shown.

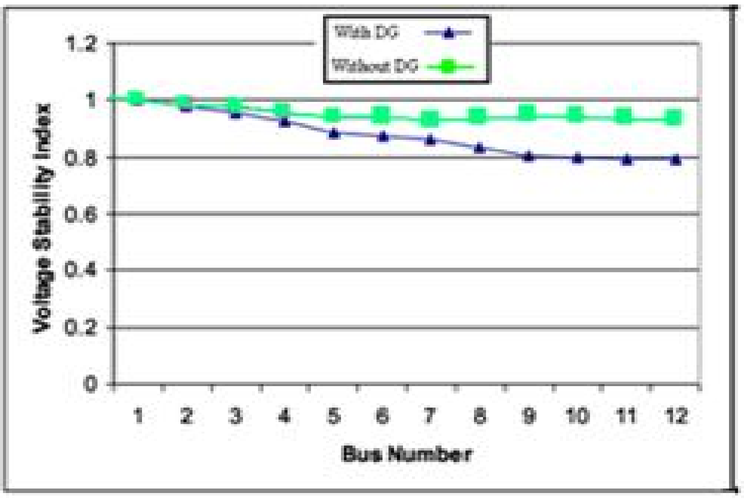

**Fig.6**. Voltage Stability Index before and after DG installation at each bus of system

As a result of the placement of DG units in the system, the short circuit level at most of the system buses was increased. Figure 7 shows the difference between the short circuit level at each bus of the system with and without DG as a percent of the value of short circuit level before placement of DG units in the system. As shown in figure, the maximum increase is very low where a maxi-mum difference of 3.89% occurred at bus 4.

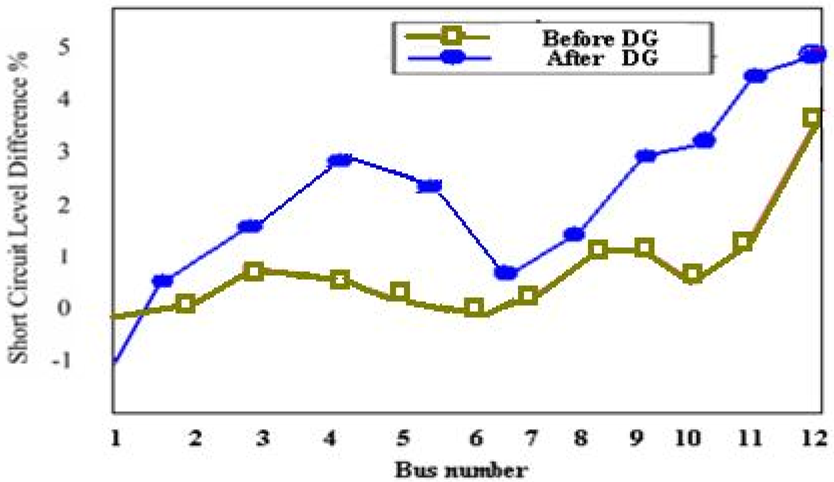

Fig.7.The short circuit level difference of the system at each bus

## V. Conclusion

The optimization location of distribution generation in distribution must meet some objective functions in order to enhance the quality of network. The proposed objectives of the paper are met to Iran condition. These objective functions must be reflex not only the benefit of utility but also the private owner. Beside, the expanding of objective and constraints are available in this work, so the paper's program is very convenient for users.

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