IMPLEMENTATION OF EMBEDDED GENERATOR FOR VOLTAGE REGULATION AND LOSS MINIMIZATION IN DISTRIBUTION SYSTEM

T.K.A. Rahman, S.R.A. Rahim and I. Musirin
Faculty of Electrical Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia
E-mail: takitik@tm.net.my

ABSTRACT

Recent years, embedded generators have been increasingly installed in distribution system in many parts of the world. Depending on their operating characteristics and locations, embedded generators could significantly affect the voltage profile, network losses and fault level in a distribution system. This paper presents a new technique for determining optimal allocation and sizing of embedded generator in a distribution system. Sensitivity indices based on voltage stability improvement with respect to change in injected active and reactive power at a load bus were derived and used to identify the suitable location for the embedded generators. In order to determine the optimal output of the embedded generators, an evolutionary programming optimization technique was developed with an objective to minimize the distribution losses while satisfying the voltage constraint in the system. The proposed technique was tested on the 69 bus distribution system and the results shown a significant reduction in the line losses and voltage profile improvement has been obtained with the installation of embedded generator. A comparative study has also shown that embedded generator is capable to provide better voltage improvement and loss minimization than those obtained from the installation compensating capacitor.

Key words: *Voltage Regulation, Distribution System, Embedded Generator, Evolutionary Programming*

INTRODUCTION

Rapid industrialization and population growth have resulted in an escalation in the electrical power demand. Due to limited area and slow progress in network expansion some regions have become high density load areas, for example in the urban areas. These phenomena may lead to power quality and voltage stability issues [1]. At the same time, rural electrification networks are also experiencing poor network performance in terms of large voltage drop and high distribution losses along the lines. For these reasons, distribution utilities are trying very hard to strengthen and expand their networks. However, their effort could be hindered due to limited source from the grid and also restricted capital investment. Introducing embedded generation to the distribution network could be an answer to these problems.

In the recent years, embedded generation has shown an increasing growth in distribution networks around the world due to rise in promotion towards utilization of renewable energy resources and development of co-generation plants. With proper planning, the integration of embedded generations in a distribution system would lead to enhancement in the network performance in terms of voltage profile improvement, reduction in line losses and improved power quality [2,3]. As a result, the demand required from the grid could be reduced, thus cutting the need to strengthen the feeders connecting the network to the grid.

Many studies have been performed to identify the influence of embedded generation on the performance of a distribution network. The effect of embedded generation on the voltage profile in a distribution network was examined in reference 3 with respect to both distributed and lumped loads. The study revealed that the upper limit value of the power that can be injected into a line without causing over voltages are: the voltage at the beginning of the line, the upper voltage limit, the position of the injected point, the total current drawn by the feeder loads and the quantities related to the load current distribution. Study has shown that the inclusion of synchronous or induction embedded generators have modified the behavior of a distribution network during transient and steady state [1] conditions. The best advantage in term of voltage stability was gained through collective integration of both types of embedded generators. Reference 4 demonstrates the application of load control for voltage regulation in distribution feeders with embedded wind generation. This scheme is more attractive than the conventional voltage control techniques since it is capable to perform peak looping, alleviating under voltage problem and avoiding line current overloads. In addition, reference 5 shows that embedded generator operating on voltage control mode has able to control the voltage profile of the network. Besides improving the voltage along the feeder, a significant reduction in the line losses could be obtained when an embedded generator is properly sized to closely match and located to the local load [6]. Therefore determining the optimal sizing of the embedded generator is one of the aspects presented in this paper.

Many conventional optimization techniques such as the gradient methods, linear programming, quadratic programming and dynamic programming have been employed to solve power system optimization problems in system planning, operation and pricing. However, due to the complexity of the problems, these methods may fail to find the global optimal solutions [7].

Evolutionary computing techniques are emerging as efficient approaches for various search, classification and optimization problems. These classes of computing algorithms are called Evolutionary Algorithms (EAs) which are the computer-based problem-solving systems based on the principles of evolutionary theory. The most popular EAs developed are :-

a) Genetic Algorithms(GAs)
b) Evolutionary Programming(EP)
c) Evolutionary Strategies(ES)

The interest in these algorithms has been rising fast. The main strength of these innovative search algorithms lies in their global convergence, inherent parallel processing nature, problem independence and great robustness. Evolutionary computing has shown to be providing an impressive solution to VAR planning problems in transmission and distribution networks. Genetic Algorithms has been implemented to determine the size, location, type and number of capacitors to be placed in a radial distribution network in order to minimize the network losses [8,9].

In this paper, a new method for determining the suitable location for embedded generator is proposed based on new sensitivity indices derived from voltage stability improvement with respect to changes in injected active and reactive power at a bus. Evolutionary programming optimization technique has been developed in order to determine the optimal size of the embedded generation. The objective of the optimization was to minimize the losses in the network while maintaining the voltage profile at the acceptable level. The effectiveness of the proposed methodology was verified by the analysis on a 69-bus distribution system[10]. This study also compares loss minimization and voltage improvement achieved by the embedded generator allocation to that gained by installing compensating capacitor in the system. The compensating capacitor was installed at the bus location identified by the sensitivity analysis.

SENSITIVITY ANALYSIS

The suitable bus location for the embedded generator is determined from the sensitivity analysis. The proposed technique identifies the suitable location for the embedded generator by studying the pre-developed voltage stability index [11] variations with respect to changes in reactive and active power injections at a bus. Sensitivity indices that relate the changes in the voltage stability index with respect to changes in injected active and reactive power at a load bus were derived from the voltage stability index formulation. The sensitivity indices were computed for every load bus and those buses with highest sensitivity values were chosen for the embedded generation placement. The derivation of the sensitivity indices from the voltage stability index formulated in reference 11 is as follows:-

The voltage stability index at a load bus i is given by

$$L_i = 4[V_{o_i} V_{L_i} \cos\theta_i - V_{L_i}^2 \cos\theta_i^{\,2}] / V_{o_i}^2 \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

V_{L_i} = load voltage at bus i
V_{o_i} = no load voltage at bus i
$\theta_i = (\theta_{o_i} - \theta_{L_i})$
θ_{L_i} = load angle at bus i
θ_{o_i} = no load angle at bus i

The first sensitivity index was formulated from the change in L_i with respect to the change in injected P_i at bus i is given by

$$\frac{\partial L_i}{\partial P_i} = \frac{\partial L_i}{\partial V_{L_i}} x \frac{\partial V_{L_i}}{\partial P_i} + \frac{\partial L_i}{\partial \theta_{L_i}} x \frac{\partial \theta_{L_i}}{\partial P_i} \ldots\ldots\ldots\ldots(2)$$

Hence, the second sensitivity index was derived from the change in L with respect to the change in injected Q at bus i is given by

$$\frac{\partial L_i}{\partial Q_i} = \frac{\partial L_i}{\partial V_{L_i}} x \frac{\partial V_{L_i}}{\partial Q_i} + \frac{\partial L_i}{\partial \theta_{L_i}} x \frac{\partial \theta_{L_i}}{\partial Q_i} \ldots\ldots\ldots(3)$$

Expressing equations 2 and 3 into matrix form gives

$$\frac{\partial L_i}{\partial P_i} = \begin{bmatrix} \dfrac{\partial L_i}{\partial V_{L_i}} & \dfrac{\partial L}{\partial \theta_{L_i}} \end{bmatrix} \begin{bmatrix} \dfrac{\partial V_{L_i}}{\partial P_i} \\ \dfrac{\partial \theta_{L_i}}{\partial P_i} \end{bmatrix} \ldots\ldots\ldots\ldots(4)$$

$$\frac{\partial L_i}{\partial Q_i} = \begin{bmatrix} \dfrac{\partial L_i}{\partial V_{L_i}} & \dfrac{\partial L}{\partial \theta_{L_i}} \end{bmatrix} \begin{bmatrix} \dfrac{\partial V_{L_i}}{\partial Q_i} \\ \dfrac{\partial \theta_{L_i}}{\partial Q_i} \end{bmatrix} \ldots\ldots\ldots\ldots(5)$$

The elements of the row matrices in equations 4 and 5 are derived from equation 1 as follows,

$$\frac{\partial L_i}{\partial V_{L_i}} = 4 \frac{\left(V_{o_i} - 2V_{L_i}\right)}{V_{o_i}^2} \ldots\ldots\ldots\ldots(6)$$

$$\frac{\partial L_i}{\partial \theta_{L_i}} = \frac{4}{V_{o_i}^2}\left[-V_{o_i} V_{L_i} \sin\theta_i + 2V_{L_i}^2 \cos\theta_i \sin\theta_i\right] \ldots(7)$$

$\frac{\partial V_{L_i}}{\partial Q_i}, \frac{\partial \theta_{L_i}}{\partial Q_i}, \frac{\partial V_{L_i}}{\partial Q_i}$ and $\frac{\partial \theta_{L_i}}{\partial Q_i}$ are obtained from the inverse of loadflow jacobian matrix.

The sensitivity criterion was determined from the values of the sensitivity indices evaluated at each load bus in a system. Buses with highest sensitivity values are selected for the location of the embedded generators.

EVOLUTIONARY PROGRAMMING (EP)

Evolutionary Programming has been employed in the field of design search and optimization more thoroughly after the exposure from Fogel [12] when it was first implemented in the prediction of finite states machines. Since then, EP has undergone refinement process in which self-adaptation parameters and different mutation strategy has been implemented. EP searches for the optimal solution by evolving a population of candidate solutions over a number of generations. During each generation, a new population is formed from the existing population by implementing the mutation operator. The operator produces a new solution by perturbing each component of the current solution by a random amount. The strength of each of the candidate solution is determined by its fitness that is evaluated from the objective function of the optimization problem.

The selection process is done through the tournament scheme, in which individuals from a population compete with each other. The individuals that obtained the most numbers of wins will be selected for the new generation.

The competition scheme must be such that the fittest individuals will have a greater chance to survive, while weaker individuals will be eliminated. Through this, the population evolves towards the global optimal solution.

In the proposed approach, Meta EP [12] technique was employed for determining the optimal size of the embedded generator. This technique is different from the standard EP since element of self adaptation is included in the mutation process. The implementation of Meta EP was according to the following procedures:-

a. Generate the initial populations of α consisting of μ individuals and set generation $\kappa = 1$. Each individual will be from a pair of real valued vector (x_i, η_i), $\forall i \in \{1,\ldots,\mu\}$, where η_i is a strategy parameter.

b. Each α has n components $\alpha(j), j = 1,\ldots,n$

c. Evaluate the fitness score for each individual (x_i, η_i), $\forall i \in \{1,\ldots,\mu\}$, of the population according to the objective function, $f(x_i)$

d. For each parent (x_i, η_i), $i = \{1,\ldots,\mu\}$, a single offspring is created (x_i', η_i') using:

$$\eta_i'(j) = \eta_i(j)\exp(\tau' N(0,1) + \tau N_j(0,1)), \ldots\ldots\ldots\ldots(8)$$

$$x_i'(j) = x_i(j) + \eta_i'(j)\, N_j(0,1), \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

$x_i(j)$, $x_i'(j)$, $\eta_i(j)$ and $\eta_i'(j)$ is the jth component of the respective vector. $N(0,1)$ donates a normally distributed one-dimensional random number with mean 0 and 1. $N_j(0,1)$ indicates that the random number will be anew for each value of j.

$$\tau = \left(\left(2 (n)^{1/2}\right)^{1/2}\right)^{-1} \text{ and } \tau' = \left((2n)^{1/2}\right)^{-1} \qquad \ldots\ldots\ldots\ldots(10)$$

e. Calculate the fitness of each offspring (x_i', η_i') $i = \{1,\ldots,\mu\}$.

f. Pair wise comparison is conducted over the union of both parent and offspring. For each individual, q opponents are chosen randomly from the union with equal probability. In each comparison, an individual receives a "win" if its fitness number is not smaller than the opponents.

g. The μ individuals out of the union that have the most wins will be selected as parents of next generation.

h. Stop if the halting creation is satisfied, otherwise go the next generation, k = k + 1 and continue at step c.

The implementation of EP for determining the optimal size of embedded generator in order to minimize the line losses in a distribution system is explained in the next section.

OPTIMAL EMBEDDED GENERATOR SIZING VIA EVOLUTIONARY PROGRAMMING

The optimal size of the embedded generator is determined by having the kW output (Pg) of the embedded generator as the variable to be optimized in the EP optimisation. The kVar output of the embedded generator was determined using equation 12 and the power factor of the system is set to be 0.85.

$$x_i = P_g \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots (11)$$

$$Q_g = P_g \, x \tan^{-1} \phi \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots \ldots\ldots\ldots (12)$$

$\cos \phi = 0.85$

ϕ = power factor angle

The operation of the embedded generator is considered to be at steady state and therefore, the embedded generator is modeled as injected active and reactive power, P_g and Q_g respectively [13]. The objective of the optimization is to minimize the network losses denoted by equation 13. Hence, the fitness for the EP was taken to be the total losses in the distribution system and evaluated by executing the loadflow programme with the injected active and reactive power at the suitable location determined from the sensitivity analysis. The optimization also took into consideration the voltage constraint of the system as shown in equation 14, so as to ensure that the maximum and minimum voltages would not be exceeded.

$$Minimise \sum_{j=1}^{n} P_{loss} \quad ....(13\ )$$

n = number of lines in the system

Voltage constraint s, $V_{i_{\min}} < V_i < V_{i_{\max}}$ ....(14)

The population size is taken to be 20 and the mutation probability is 0.03. The procedure of the EP method to determine the optimal size of the embedded generator is summarized in the flowchart given in Figure A1 in Appendix A.

SIMULATION RESULTS AND DISCUSSION

This study investigated on the loss minimization and voltage improvement that could be achieved as a result of embedded generator installation at the chosen bus with optimal generation output identified by the EP optimization technique. The developed technique was tested on a 69-bus system[10]. This system contains 69 branches and 7 laterals as shown in Figure A2 in Appendix A. The loss minimization and voltage improvement obtained from the embedded generator installation at the identified bus location were also compared to those obtained from compensating capacitor placement at the same bus location.

In order to determine the suitable location of the embedded generator, sensitivity analysis was conducted on the 69-bus test system. The sensitivity indices given by equations 4 and 5 were evaluated for every bus in the system and the results are tabulated in Table 1. The bus with highest sensitivity index value is selected for allocating the embedded generator.

Table 1First 10 buses with highest sensitivity index value

Bus No.	$\left\|\frac{\partial L_i}{\partial P_i}\right\|$	Bus No.	$\left\|\frac{\partial L_i}{\partial Q_i}\right\|$
61	26.3958	61	10.2167
64	7.7781	64	2.8583
21	3.8323	50	1.2550
65	2.5544	49	1.0333
59	2.3896	21	1.0086
18	1.7960	65	0.9095
17	1.7946	59	0.8591
12	1.7144	12	0.5132
16	1.2811	11	0.3950
11	1.2367	18	0.3906

From Table 1, it could be observed that bus 61 has the highest sensitivity index value and therefore it is chosen as the suitable location for embedded generator. However, for comparison, buses 64, 21, 65 and 59 were also selected for embedded generator allocation so that the improvement on the network performance in terms of loss minimization and voltage profile improvement could be compared. The study also considered the effect of load increment at the chosen buses individually and also load increment at all buses in the system simultaneously on the network losses and also voltage profile. The EP optimization technique was implemented in order to determine the optimal output of the embedded generator located at the chosen site.

The graphs in Figures 1 and 2 show the variation of total losses and voltage profile in the system respectively with respect to individual load increase at buses 61, 64, 21, 65 and 59.

From the graph shown in Figure 1, it could be observed that load increase at bus 61 has caused an increase in the total losses of the system significantly. At the same time, Figure 2 shows that increase in load at bus 61 has also reduced the minimum voltage appreciably as compared to the effect of load increase at the other load buses.

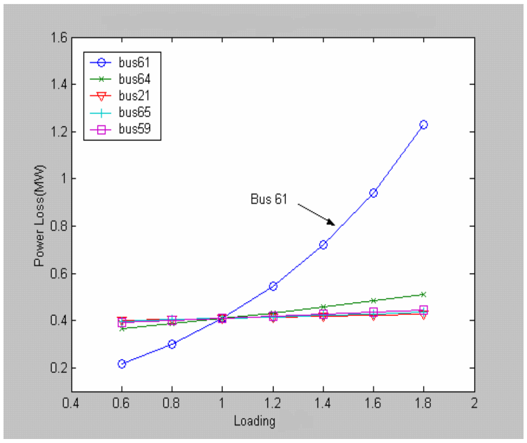

Fig. 1 Variation in total power losses with respect to increase in loading at each bus individually

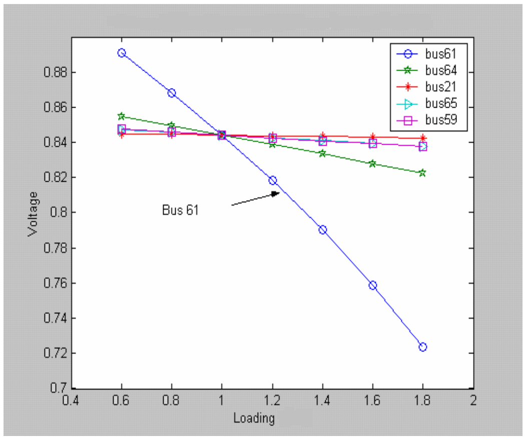

Fig.2 Variation in minimum voltage in the system with respect to increase in loading at respective bus individually.

In order to minimize the system losses, embedded generator was located at these respective buses individually. The loading at each load bus was varied and the EP optimization technique was implemented to determine the optimal embedded generator output in order to minimize the system losses at the various loading conditions. The graph in Figure 3, illustrates the distribution losses in the system with embedded generator installed at respective load buses for a range of loading conditions. Figure 4 shows the minimum voltage in the system as a result of installing embedded generator at the respective bus. The optimal output of the embedded generator in order to minimize the system losses at different loading condition identified by the proposed EP optimization technique are tabulated in Table 2.

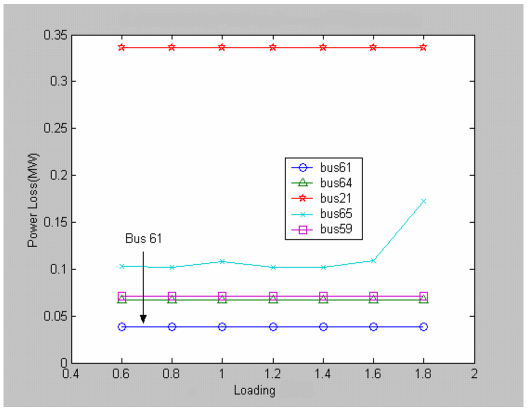

Fig. 3 Total losses in the system with installation of embedded generator for load increase at individual buses.

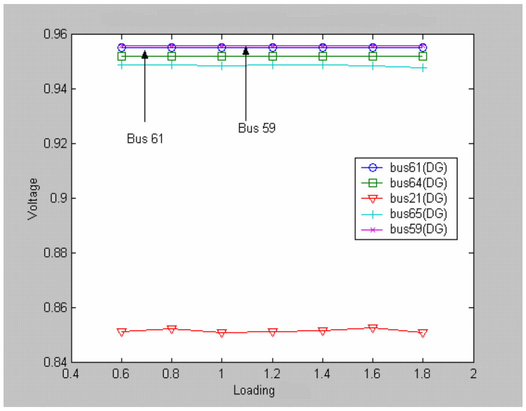

Fig. 4 Minimum voltage in the system with installation of embedded generator for load increase at individual buses.

Figure 3 shows that allocating the embedded generator at bus 61 has resulted in better loss minimization as compared to other bus location. The minimum voltage in the system has also been maintained at an acceptable value despite the increase in loading as shown in Figure 4. Therefore, the results demonstrate that the proposed EP optimization technique has able to search for the optimal output of the embedded generator in order to minimize the system losses while maintaining the voltage level at various loading conditions. The results tabulated in Table 2 also reveal that, as the loading at a load bus was incremented, the optimal output of the embedded generator has also increased. The power to be generated by the embedded generator located at bus 61 is higher as compared to other bus location. This is due to the high loading connected at this bus. However, allocating the embedded generator at bus 61 has resulted in the greatest loss minimization and voltage improvement.

Table 2. Optimal embedded generator output for loss minimization in the system or load increase at individual buses.

Loading	Optimal output of embedded generator at each bus location (MW)				
	61	64	59	65	21
0.6	1.3428	1.5263	1.8895	1.3901	0.7312
0.8	1.5910	1.5731	1.9086	1.3996	0.7525
1.0	1.8393	1.6172	1.9272	1.4144	0.7782
1.2	2.0878	1.6643	1.9482	1.4260	0.7970
1.4	2.3362	1.7096	1.9686	1.4364	0.8237
1.6	2.5856	1.7546	1.9856	1.4496	0.8450
1.8	2.8349	1.8008	2.0085	1.4609	0.8681

The capability of the proposed technique to determine the optimal output of the embedded generator in order to minimize the total losses in the system with overall load increase in the system was tested. A range of loading condition (60% - 180% of the nominal value) was used for the evaluation and the results are given in Figures 5, 6 and Table 3. The graph shown in Figure 5 compares the total losses in the system before and after the installation of embedded generator at the selected bus location. The graph also shows that the total losses in the system were reduced with the installation of embedded generator and the best loss minimization is obtained when the embedded generator was located at bus 61. Similarly, the graph in Figure 6 shows the variation in the minimum voltage with respect to overall load increase in the system when embedded generator was installed at the selected buses. It could be observed that allocating embedded generator at bus 61 has given better voltage improvement and hence the voltage profile of the system is maintained at an acceptable range. Finally the optimal active power to be generated by the embedded generator installed at the selected bus location for a range of loading conditions are tabulated in Table 3. It could be observed that more injected power is required from the embedded generator as the loading was increased in order to minimize the losses and also improving the voltage profile in the system.

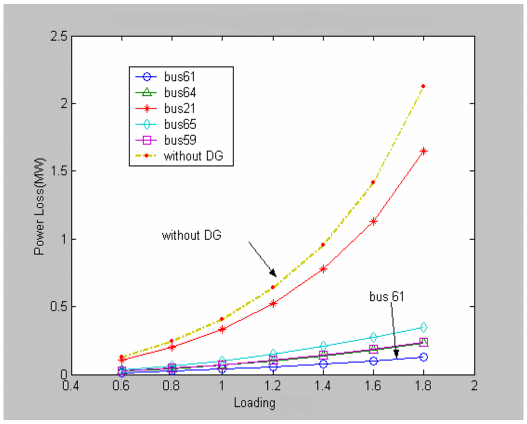

Fig. 5 Total system losses with installation of embedded generator for overall load increase in the system.

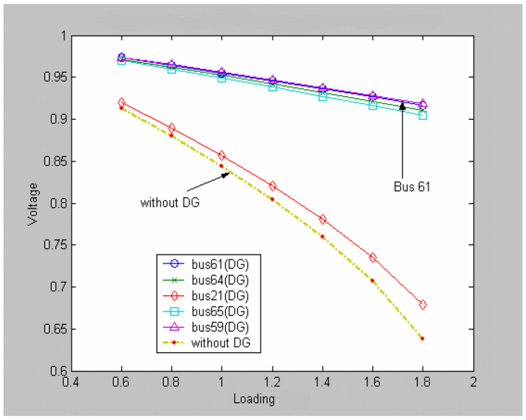

Fig. 6 Minimum voltage in the system with installation of embedded generator for overall load increase in the system.

Table 3. Optimal embedded generator output for loss minimization in the system for overall load increase in the system.

Loading	Optimal output of embedded generator at each bus location (MW)				
	61	64	59	65	21
0.6	1.1009	0.9632	1.1464	0.8369	0.4527
0.8	1.4699	1.2896	1.5340	1.1228	0.6125
1.0	1.8401	1.6181	1.9273	1.4148	0.7783
1.2	2.2091	1.9487	2.3245	1.7090	0.9475
1.4	2.5799	2.2823	2.7238	2.0074	1.1266
1.6	2.9509	2.6179	3.1294	2.3130	1.3184
1.8	3.3224	2.9560	3.5366	2.6223	1.5278

Similar study was performed to see the effect of compensating capacitor installed at the selected buses identified from the sensitivity analysis on loss minimization and voltage stability improvement. The optimal size of the compensating capacitor was also determined by the developed EP optimization technique. The total system losses and voltage profile as regards to load variation at individual bus with compensating capacitor installed at the selected buses are shown in the graphs given in Figures 7 and 8 respectively. Meanwhile, loss minimization and voltage improvement in the system as a result of compensating capacitor installation when the overall load condition is varied could be observed from the graphs given in Figures 9 and 10 respectively. Based on these graphs, the best performance in terms of loss minimization and voltage improvement was obtained when the compensating capacitor was also located at bus 61. Finally, comparison in the system performance in terms of loss minimization and voltage improvement between embedded generator and compensating capacitor installation could be observed in the graphs shown in Figures 11 and 12 respectively for the case of load variations at the individual bus. Similar comparison could also be observed in the graphs shown in Figures 13 and 14 for the case of overall load increase. From these graphs, it is obvious that embedded generator installation gives better loss minimization and voltage improvement in the system as compared to compensating capacitor placement.

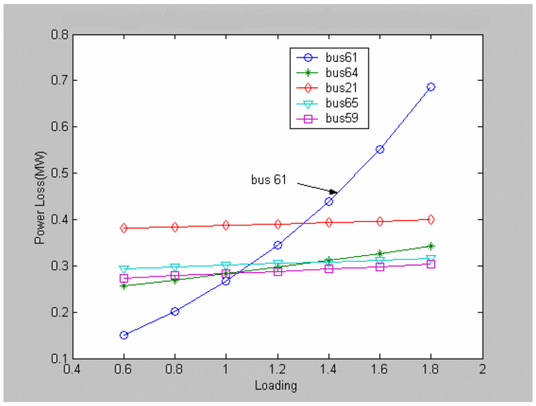

Fig. 7 Total losses in the system with compensating capacitor installed for load increase at individual buses.

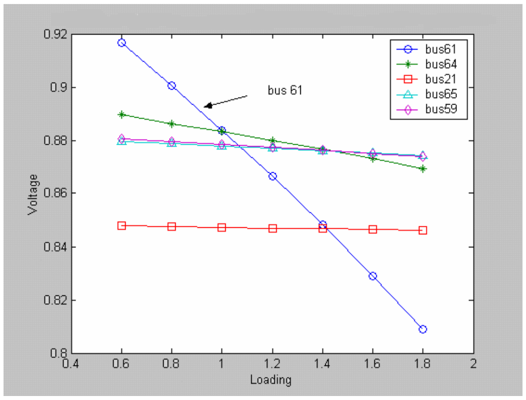

Fig. 8 Minimum voltage in the system with compensating capacitor installed for load increase at individual buses.

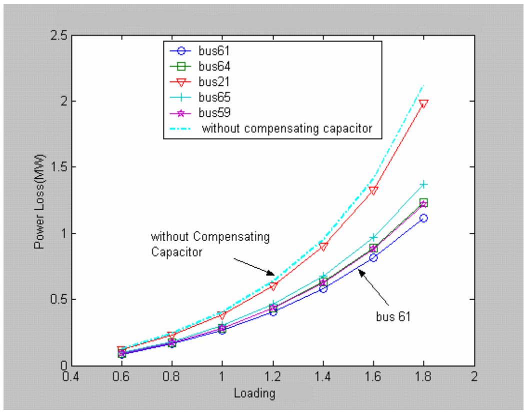

Fig. 9 Total system losses with compensating capacitor installed for overall load increase in the system.

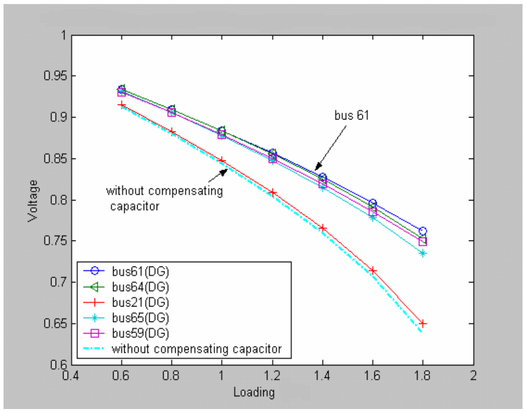

Fig. 10 Minimum voltage in the system with compensating capacitor installed for overall load increase in the system.

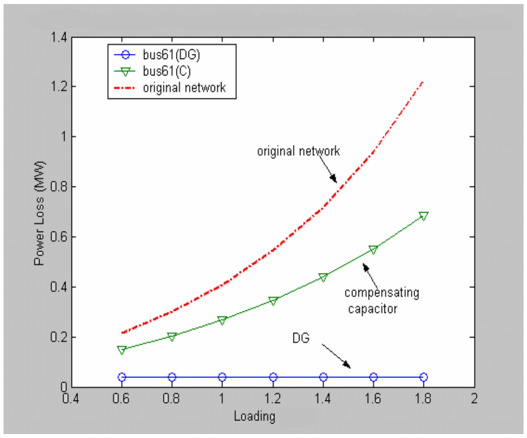

Fig. 11 Comparing the total system losses between embedded generator(DG) and compensating capacitor installations for load increase at individual buses.

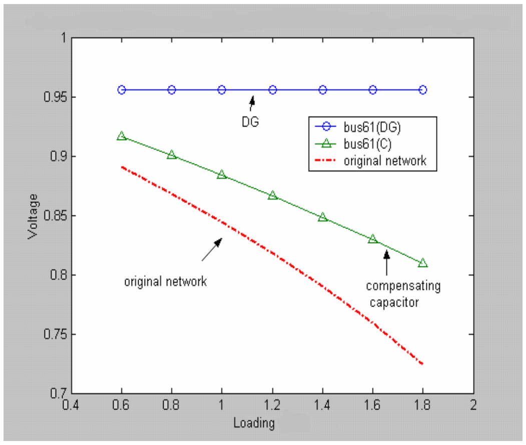

Fig. 12 Comparing the minimum voltage between embedded generator(DG) and compensating capacitor installations for load increase at individual buses.

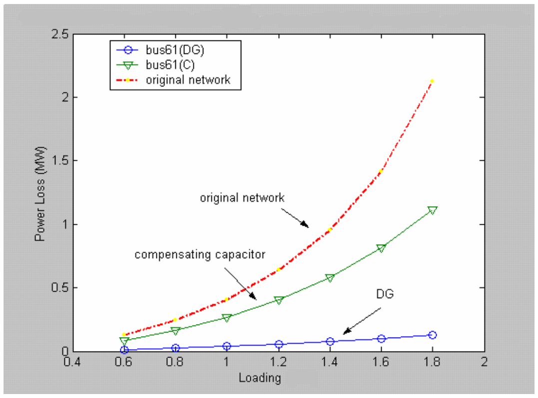

Fig. 13 Comparing total system losses between embedded generator(DG) and compensating capacitor installations for overall load increase in the system.

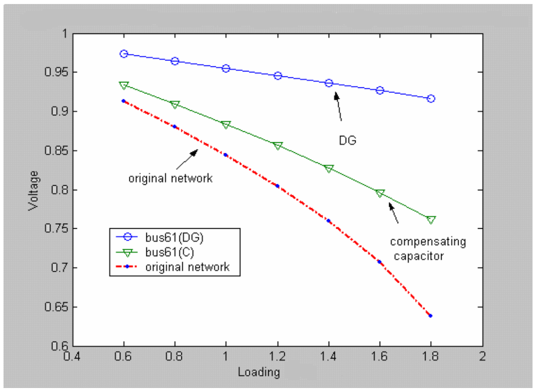

Fig. 14 Comparing minimum voltage between embedded generator(DG) and compensating capacitor installations for overall load increase in the system.

CONCLUSION

A new approach for determining the location and sizing of embedded generator in a distribution system is presented. Two sensitivity indices were formulated based on voltage stability improvement with respect to changes in active and reactive power injection at load bus. The sensitivity indices were evaluated for every load bus in a system and the bus with highest sensitivity index value was chosen to be the suitable location for the embedded generator. An EP optimization technique was developed to determine the optimal output of the embedded generator. From the numerical simulation, the combination of suitable location of the embedded generator identified from the sensitivity analysis and optimal generation output identified by the EP optimization technique has able to reduce the losses and improve the voltage profile in a distribution system. The comparative study between embedded generator and compensating capacitor installations has shown that the former has better capability in terms of loss minimization and voltage profile improvement in a system.

REFERENCES

1. J. V. Milanovic and T. M. David (2002) Stability of Distribution networks with Embedded Generators and Induction Motors, IEEE Power Engineering Society Winter Meeting 2002, Vol.2, pp 1023 – 1028.
2. D. Xu and A. A. Girgis (2001) Optimal load shedding strategy in power systems with distributed generation, IEEE Power Engineering Society Winter Meeting 2001, Vol.2, pp 788 – 793.
3. S. Conti, S. Raiti and G. Tina (2003) Small-scale embedded generation effect on voltage profile: an analytical method, Proc. IEE Gen. Trans. Dist., vol.150, no. 1, pp. 78 – 86.
4. N. G. Scot, D. J. Atkinson, J. E. Morrell (2002) Use of load control to regulate voltage on distribution networks with embedded generation, IEEE Trans. Power Syst., vol.17, no. 2, pp. 510 – 515.
5. K. Pandiaraj and B. Fox (2000) Novel voltage control for embedded generators in rural distribution networks, Proc. Int. Conference Power System Technology 2000 (PowerCon2000)., vol.1, pp. 457 – 462.
6. L. Kojovic (2002) Impact of DG on voltage regulation", IEEE Power Engineering Society Summer Meeting 2002,, Vol.1, pp 97 – 102.
7. K. P. Wong (2002) Recent development and application of evolutionary optimization techniques in power systems, Proceedings on International Conference on Power System Technology.
8. G. Boone and H. Chiang (1993) Optimal capacitor placement in distribution system by genetic algorithms", International Journal of Power and Energy Systems., Vol.15, pp. 155 – 162.
9. S. Sundharajan and A. Pahwa (1994) Optimal selection of capacitors for radial distribution systems using a genetic algorithm", IEEE Trans. Power Syst., vol.9, No. 3, pp. 1499 – 1507.
10. M.E. Baran and F.F. Wu (1989) Optimal Capacitor Placement on Radial Distribution Systems", IEEE Trans. on Power Delivery., vol.4, No.1, pp. 725 – 733.
11. T.K.A. Rahman and G.B. Jasmon (1997) A New Voltage Stability Index and Loadflow Technique for Power System Analysis, International Journal of Power and Energy Systems., vol.17, no.1, pp. 28 – 37.
12. L.J. Fogel (1966) Intelligence Through Simulated Evolution: Forty years of evolutionary programming, John Wiley & Sons, New York.
13. R. T. Guttromson (2002) Modelling distributed energy resources dynamics on the transmission system, IEEE Trans. Power Syst., vol.17, no. 4, pp. 1148 – 1153.

APPENDIX A

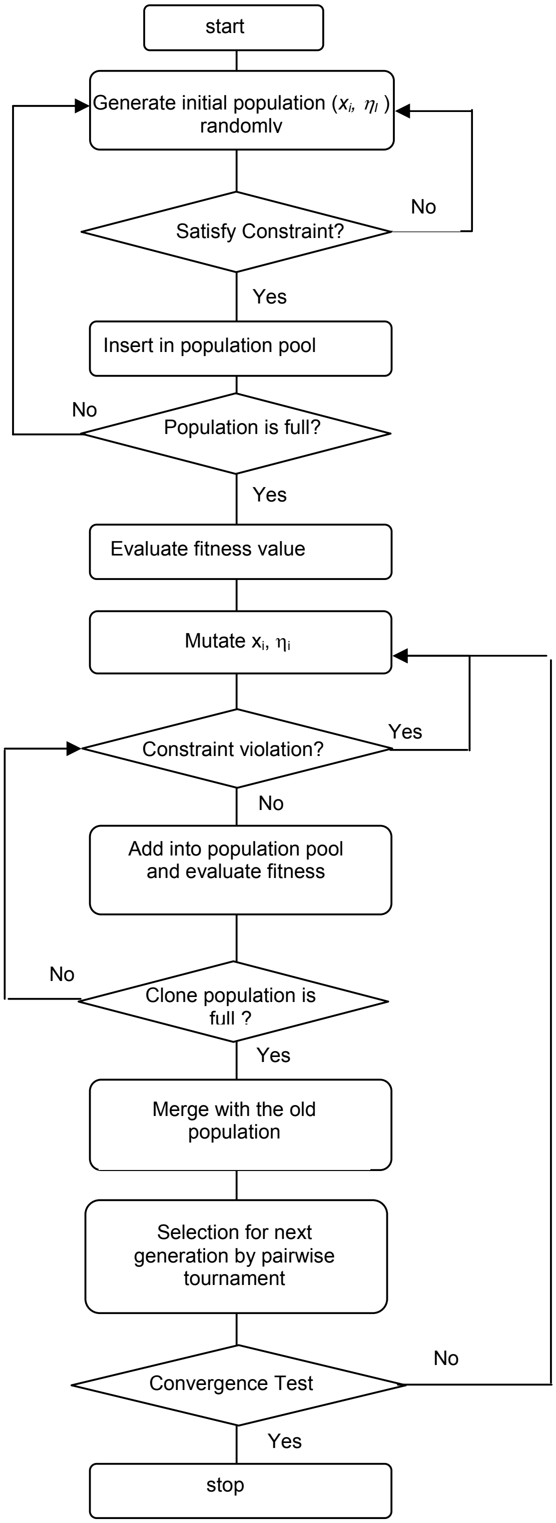

Fig. A1 Flowchart for implementation of EP

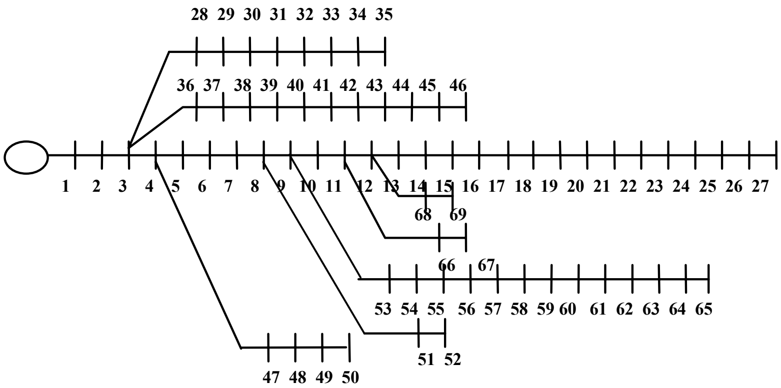

Fig. A2 The 69-bus Test System