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Comparing the Network Performance between the Installation of DG and Compensating Capacitor using EP

Abstract— 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 also voltage stability issues. This paper presents the performance improvement in distribution network with distributed generation (DG). Pre-developed sensitivity index was utilized to identify the suitable location of distributed generation installation; followed by optimization of the distributed generation output to obtain maximum benefits from its installation using EP. Consequently, installation of capacitor was also implemented to perform similar task. The compensating capacitor was installed at the bus location identified by the sensitivity analysis. The effectiveness of the proposed methodology was validated on the 33-Bus Distribution System. Results for loss minimization and voltage profile improvement produced by the distributed generator allocation with those obtained by installing the compensating capacitor in the system were compared accordingly in order to reveal the merit of each technique.

Keywords – Distributed Generation (DG), Sensitivity analysis, Evolutionary Programming (EP).

I. INTRODUCTION

Distributed or dispersed generation (DG) or embedded generation (EG) is small-scale power generation that is usually connected to or embedded in the distribution system. The term DG also implies the use of any modular technology that is sited throughout a utility's service area (interconnected to the distribution or sub-transmission system) to lower the cost of service [1,2]. It offers valuable alternative to the traditional sources of electrical power for industrial, commercial and residential applications. The purpose of these plants is to cope with the growing demand for electricity in certain areas and render certain activities self sufficient in terms of power production; thus achieving energy savings. Recent changes in the electric utility infrastructure created the opportunities for many technological innovations including the application of distributed generation to achieve various benefits. To achieve the benefits, many factors have to be considered such as the best technology to be used, the number and the capacity of the units, the best location and the network connection.

Therefore, the factors of the best location and sizing are the one of important issues in the implementation of distributed generation in the distribution system. With proper planning, the integration of distributed generations in a distribution system would lead to enhancement in the network performance in terms of voltage profile improvement, reduction in line losses and improve 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.

A new method for determining the optimal size of distributed generator is proposed using Evolutionary Programming optimization technique. Various loading conditions were tested in order to evaluate the effectiveness of the proposed technique in determining the optimal size of the distributed generator. In this study, the optimal allocations of distributed generator are identified based on the results obtained from the sensitivity analysis. This study also compares loss minimization and voltage improvement achieved by the distributed generator allocation to that gained by installing compensating capacitor in the system.

The effectiveness of the proposed methodology was validated using 33-Bus Distribution System [4].

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II. SENSITIVITY INDEX

In order to obtain maximum benefit from DG installation, a new technique was developed in order to determine the suitable location for the distributed generator based on sensitivity analysis. 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 distributed generation [5]. A program written in MATLAB programming language was developed in order to calculate the index. 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.

The following procedures were implemented in the sensitivity analysis to determine the suitable location of distributed generator in the test systems:

i. Run the load flow program in MATLAB programming language (Newton-Raphson method) at the base case
ii. Compute the no load voltage and no load angle for bus *i*
iii. Compute the sensitivity indices for injected active power P_i and injected reactive power Q_i using equation 3.2 and 3.3 respectively.
iv. Record the highest sensitivity index by taking the magnitude of the index.
v. Select the bus with highest sensitivity index value as the suitable location for the distributed generator.

Once the sets of optimal allocation of distributed generator have been identified, the size of distributed generator will be determined using Evolutionary Programming (EP) optimization technique.

III. META-EP

Meta EP [6] technique was employed for determining the optimal size of distributed generator (DG). This technique is different from the standard EP since the element of self adaptation is included in the mutation process. The algorithm of Evolutionary Programming for optimal sizing for this study is explained in the following procedural form:-

Step 1 Initialization of population

For the purpose of determining the optimal sizing of DG, the random numbers represent the kW output (P_g) of distributed generator as the variable to be optimized. The size of DG is to be set in the interval of 0MW-3MW. The number of variables depends on the number of distributed generators to be installed in the systems.

Step 2 Evaluation of the fitness value of each population

In order to minimize the network losses, the fitness of the EP is taken to be the total losses in the distribution system. The total loss was evaluated by solving the load flow program. It was done by calling the load flow program into the EP as a main program. The optimization also took the consideration of the voltage constraint in the system so that the minimum and maximum voltage would not be exceeded.

Step 3 Mutation process

A new population is formed by mutating the initial existing population by implementing the mutation operator. Mutation is the only variation operator used for generating the offspring from each parent. The fitness of the offspring was calculated by calling the load flow program.

Step 4 Selection process

The selection process was done by the tournament scheme. In this process, the offspring produced from the mutation process were combined with the parents to undergo the selection process. The individual is to compete with other randomly selected individuals and the winning criterion was based on fitness values. For each comparison, the individual that obtained the most numbers of wins will be prescribed for the new generation.

Step 5 Convergence test

This procedure is to determine the stopping criteria of the optimization. The convergence criterion is specified by the difference between the maximum and minimum fitness to be less than 0.0001. If the convergence condition is not satisfied, the processes will be repeated.

$$maximum_{fitness} - minimum_{fitness} \leq 0.0001 \quad (1)$$

IV. DETERMINING THE OPTIMAL DG SIZING USING EP

The optimal size of the distributed generator is determined by having the kW output (P_g) of the distributed generator as the variable to be optimized. The kVar output of the distributed generator was determined using equation (3) and the power factor of the system was set to be 0.85.

$$x_i = P_g \quad (2)$$

$$Q_g = P_g \times \tan^{-1}\theta \quad (3)$$

$\cos\theta = 0.85$

$\theta =$ Power factor angle

The operation of the distributed generator is considered to be at steady state and therefore, the distributed generator is modelled as injected active and reactive power, P_g and Q_g respectively [7]. The objective of the optimization is to minimize the network losses denoted by equation 1.10. Hence, the fitness for the EP was taken to be the total losses in the distribution system and evaluated by executing the load flow program 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 (5), so as to ensure that the maximum and minimum voltages would not be exceeded.

$$Minimise \quad \sum_{j=1}^{n} P_{loss} \quad (4)$$

n = number of lines in the system

Voltage constraint,

$$V_{i\,\min} < V_i < V_{i\,\max} \quad (5)$$

$V_{i\,min}$ = minimum allowable voltage level in the system at bus i

$V_{i\,max}$ = maximum allowable voltage level in the system at bus i

V_i = new voltage level at bus i

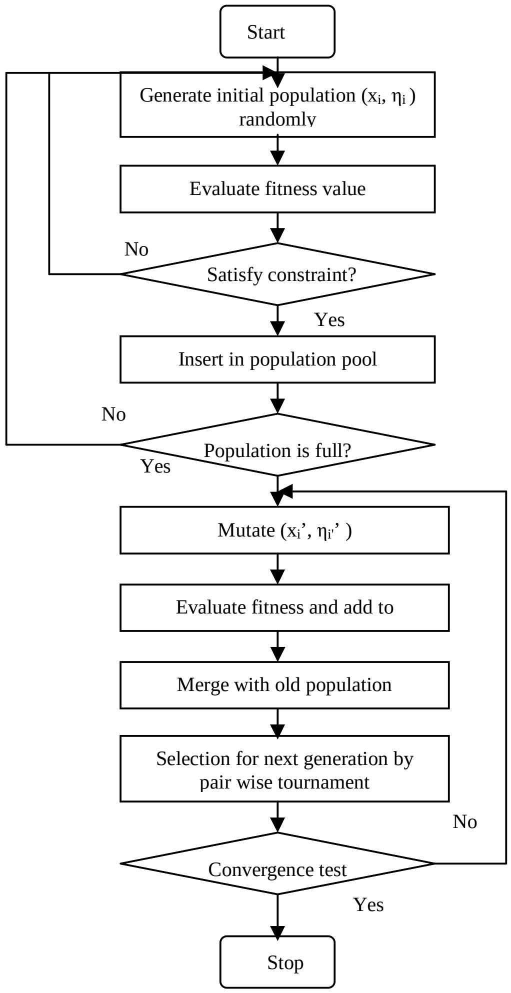

Fig 1: Flowchart for implementation of EP optimization method to determine the optimal size of the DG.

V. TEST SYSTEM

The proposed technique was tested on IEEE 33-Bus Distribution System. The schematic diagram for the test systems is shown in the Fig. 2. Similar study was performed to see the effect of compensating capacitor installed at the selected buses identified from the sensitivity analysis for loss minimization and voltage improvement for comparison. The optimal size of the compensating capacitor was also determined by the developed Evolutionary Programming optimization technique.

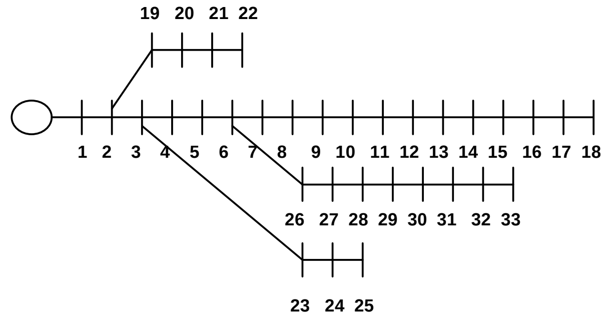

Fig 2: IEEE 33-Bus Distribution System

VI. RESULT FOR OPTIMAL LOCATION AND SIZING

The load flow analysis was conducted using the load flow program in MATLAB programming language software. Table I shows the result for initial total losses for the test system.

TABLE I
RESULT FOR TOTAL LOSS WITHOUT INSERTING DG FOR 33-BUS

	Total Loss (MW)	
	P_{Loss}	**Q_{Loss}**
Base Case	0.1714	0.1114

In order to determine the suitable location of the distributed generator, sensitivity analysis was conducted on the test system. The sensitivity indices were evaluated for every bus in the system and the results are tabulated in TABLE II. The bus with highest sensitivity index value is selected as the suitable location for the distributed generator. From TABLE II, it could be observed that bus 30 has the highest sensitivity index value and therefore it is chosen as the suitable location for distributed generator. Bus 32, 14, 31 and 25 were also selected for comparison of distributed generator allocation so that the improvement on the network performance in terms of loss minimization and voltage profile improvement could be compared.

TABLE II
FIRST 6 BUSES WITH HIGHEST SENSITIVITY INDEX VALUE

Bus No.	$\left\lvert\frac{\partial L_i}{\partial P_i}\right\rvert$	**Bus No.**	$\left\lvert\frac{\partial L_i}{\partial Q_i}\right\rvert$
32	0.45075	30	0.71067
30	0.32159	32	0.16505
31	0.3086	14	0.14965
14	0.29422	31	0.1083
25	0.27392	24	0.10282
24	0.23047	25	0.083065

The effect of optimal sizing and allocation of the distributed generator on the total losses and voltage profile in the system was observed by installing the distributed generator at the chosen busses individually.

Fig 3(a) shows the installation of distributed generator at the chosen bus has reduced the power losses in the system. Allocating the distributed generator at bus 30 resulted in better loss minimization as compared to other bus locations. Fig 3 (b) shows the minimum voltage in the system as a result of installing distributed generator at the respective buses.

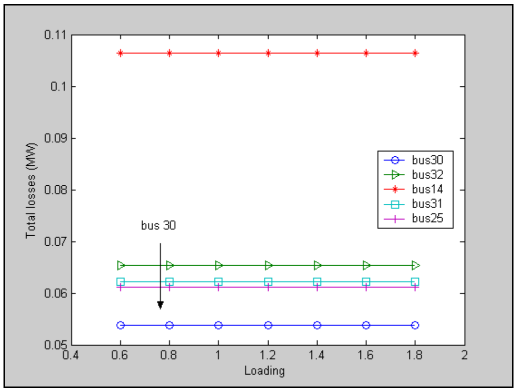

Fig 3 (a) Total losses in the system with installation of distributed generator for load increase at individual buses

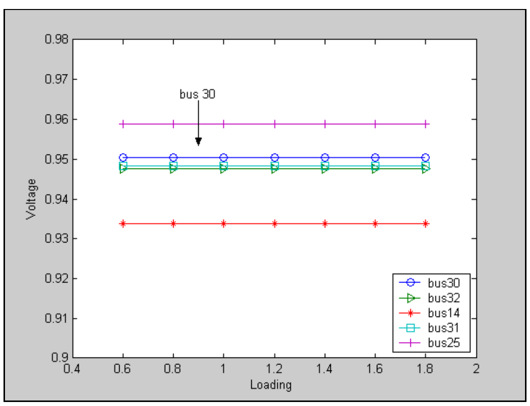

Fig 3 (b) Minimum voltage in the system with installation of distributed generator for load increase at individual buses.

The optimal output of the distributed generator in order to minimize the system losses at different loading condition identified by the proposed EP optimization technique are tabulated in TABLE III. The results reveal that, the optimal output of the distributed generator increased as the loading at a load bus was incremented.

TABLE III
OPTIMAL DISTRIBUTED GENERATOR OUTPUT FOR LOSS MINIMIZATION IN THE SYSTEM OF LOAD INCREASE AT INDIVIDUAL BUS

	Optimal output of distributed generator at each bus location (MW)				
Loading/times the nominal value	**30**	**32**	**14**	**31**	**25**
0.6	1.2654	1.0359	0.8689	1.1126	1.9508
0.8	1.3023	1.0742	0.8914	1.1423	2.0337
1.0	1.3428	1.1197	0.9189	1.1721	2.1207
1.2	1.3834	1.1611	0.941	1.2034	2.2
1.4	1.42	1.2023	0.9648	1.2437	2.2841
1.6	1.4606	1.2446	0.9883	1.2722	2.3693
1.8	1.4997	1.2889	1.0186	1.2912	2.4544

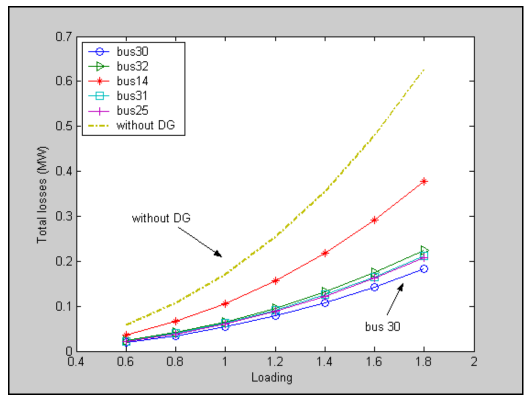

Fig 4 (a) Total losses with installation of distributed generator for overall load increase in the system.

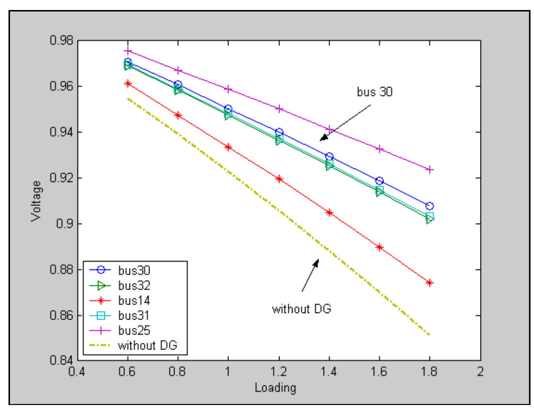

Fig 4 (b) Minimum voltage in the system with installation of distributed generator for overall load increase in the system.

The result obtained for overall load increase in the system was illustrated in Fig 4 (a) and Fig 4 (b). The graph in Fig 4 (a) shows the distribution losses with distributed generator installed at respective load buses for the overall increase in the loading conditions. The minimum total losses obtained when distributed generator was installed at bus 30 compared to the other buses. Fig 4 (b) shows the minimum voltage in the system as a result of installing of distributed generator at the respective bus. The optimal outputs of the DG are tabulated in TABLE IV. The results show that when the overall load was increased, the optimal size of distributed generators also increased.

TABLE IV
OPTIMAL DISTRIBUTED GENERATOR OUTPUT FOR LOSS MINIMIZATION IN THE SYSTEM FOR OVERALL LOAD INCREASE IN THE SYSTEM.

	Optimal output of distributed generator at each bus location (MW)				
Loading/times the nominal value	**30**	**32**	**14**	**31**	**25**
0.6	0.8011	0.6669	0.5458	0.7006	1.2604
0.8	1.071	0.8925	0.7297	0.9351	1.6886
1.0	1.3411	1.1194	0.9165	1.1732	2.1188
1.2	1.6124	1.3486	1.1052	1.411	2.553
1.4	1.8885	1.576	1.2914	1.651	2.9918
1.6	2.1635	1.8069	1.4889	1.8917	3.4344
1.8	2.4388	2.0386	1.6848	2.1344	3.8842

Similar study was performed to see the effect of compensating capacitor installed at the selected buses identified from the sensitivity analysis for loss minimization and voltage improvement. The optimal size of the compensating capacitor was also determined by the developed EP optimization technique. This study was conducted in order to compare the results obtained from the implementation of distributed generation. 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 5 a(i) and 5 b(i) respectively. The graph shows in Fig 5 a(i) illustrates that load increase at bus 30 has caused an increase in the total losses of the system significantly although compensating capacitor is located at this bus. At the same time, Fig 5 b(i) shows that increase in load at bus 30 has also reduced the minimum voltage appreciably as compared to the effect of load increase at the other load buses. Fig 5 a(ii) and Fig 5 b(ii) shows the variation in total power losses and minimum voltage with respect to increase in loading at each bus individually.

The optimal outputs of the compensating capacitor are tabulated in TABLE V. The results reveal that, the optimal output of the compensating capacitor increased as the loading at a load bus was incremented.

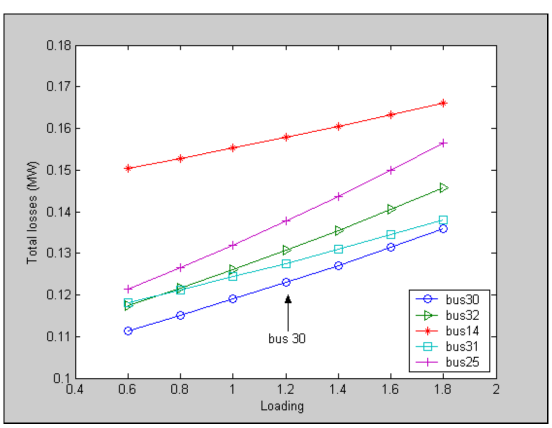

Fig 5 a(i) Total losses in the system with compensating capacitor for load increase at individual buses

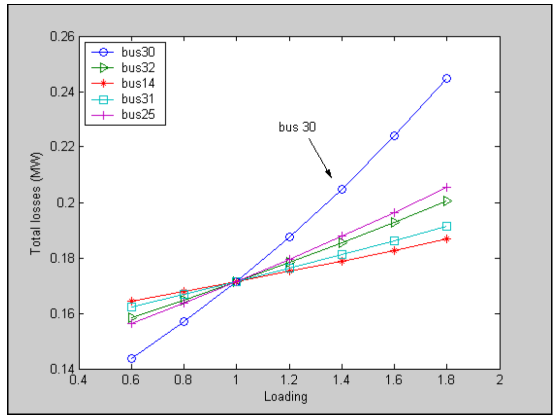

Fig 5 a(ii) Variation in total losses with respect to increase in loading at each bus individually.

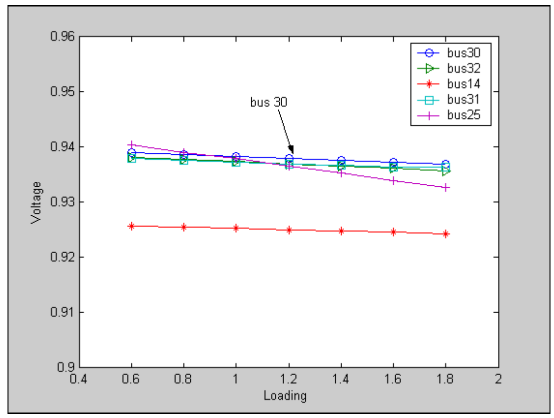

Fig 5 b (i) Minimum voltage in the system with compensating capacitor for load increase at individual buses.

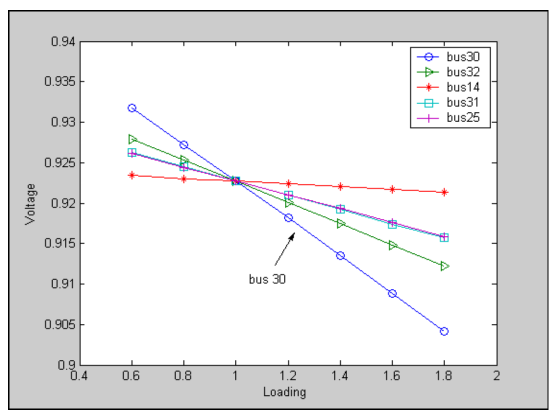

Fig 5: b (ii) Variation in minimum voltage in the system with respect to increase in loading at respective bus individually.

TABLE V
OPTIMAL COMPENSATING CAPACITOR OUTPUT FOR LOSS MINIMIZATION IN THE SYSTEM FOR LOAD INCREASE AT INDIVIDUAL BUSES

	Optimal output of compensating capacitor at each bus location (MVar)				
Loading/times the nominal value	**30**	**32**	**14**	**31**	**25**
0.6	0.9356	0.9394	0.504	0.9925	1.517
0.8	1.0597	0.9584	0.5244	1.0049	1.5543
1.0	1.1817	0.9773	0.5341	1.0242	1.6035
1.2	1.3016	0.9996	0.5501	1.0397	1.6431
1.4	1.4252	1.0197	0.5641	1.0507	1.6823
1.6	1.5492	1.0511	0.5851	1.0642	1.7211
1.8	1.6764	1.0622	0.6015	1.0816	1.7736

Fig 6(a) and Fig 6(b) shows the result of compensating capacitor installation on loss minimization and voltage improvement respectively when the overall load increase in the system. 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 30. The optimal outputs of the compensating capacitor are tabulated in TABLE VI. The results show that when the overall load was increased, the optimal size of compensating capacitors also increased.

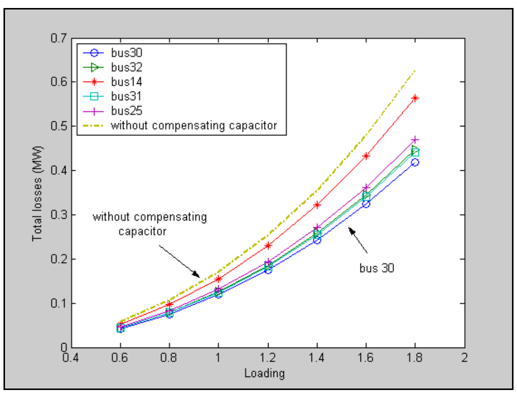

Fig 6: (a) Total losses in the system with and without compensating capacitor for overall load increase in the system.

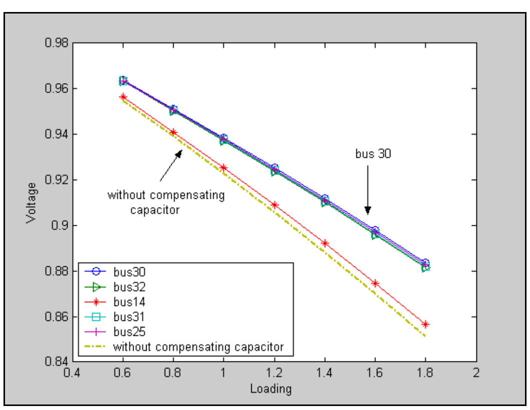

Fig 6 (b) Minimum voltage in the system with and without compensating capacitor for overall load increase in the system

TABLE VI
OPTIMAL COMPENSATING CAPACITOR OUTPUT FOR LOSS MINIMIZATION IN THE SYSTEM FOR OVERALL LOAD INCREASE IN THE SYSTEM.

	Optimal output of compensating capacitor at each bus location (MVar)				
Loading/times the nominal value	**30**	**32**	**14**	**31**	**25**
0.6	0.7023	0.5805	0.3203	0.6107	0.9293
0.8	0.9423	0.7916	0.4285	0.8156	1.2705
1.0	1.1831	0.9779	0.5362	1.0267	1.6017
1.2	1.4221	1.1786	0.6446	1.2286	1.9449
1.4	1.6667	1.3811	0.7561	1.4391	2.2983
1.6	1.9112	1.5777	0.8666	1.6503	2.6639
1.8	2.1612	1.7787	0.9773	1.8614	3.0411

VII. COMPARING THE NETWORK PERFORMANCE BETWEEN THE DG INSTALLATION AND COMPENSATING CAPACITOR

The comparison in the system performance in terms of loss minimization and voltage improvement between distributed generator and compensating capacitor installations at bus 30 could be observed in the graphs shown in Fig 7 (a) and Fig 7 (b) respectively for the case of load variations at bus 30. The load variation at bus 30 is considered because it would effect the change in system losses and voltage profile most.

Similar comparison was obtained in the graphs shown in Fig 8 (a) and Fig 8 (b) for the case of overall load increase and the distributed generation or compensating capacitor is located at bus 30. From these graphs, it shows that distributed generator installation gives better loss minimization and voltage improvement in the system as compared to compensating capacitor placement.

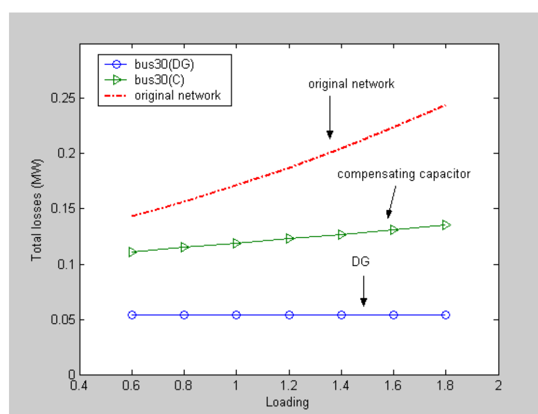

Fig 7: (a) Comparing the total losses between distributed generator (DG) and compensating capacitor installations for load increase at bus 30.

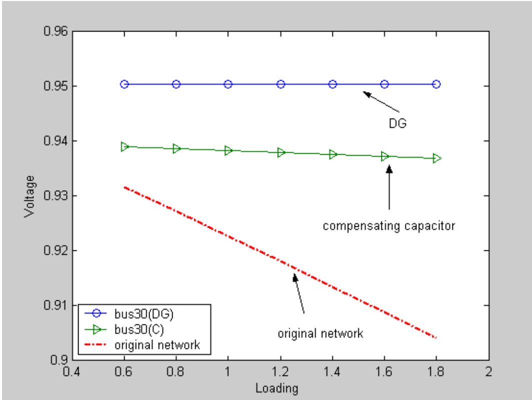

Fig 7: (b) Comparing the minimum voltage between distributed generator (DG) and compensating capacitor installations for load increase at bus 30.

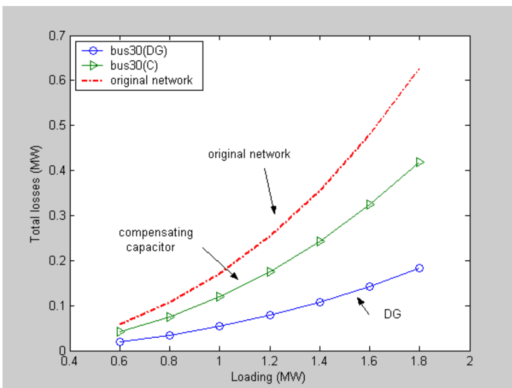

Fig 8: (a) Comparing total losses between distributed generator (DG) and compensating capacitor installations for overall load increase in the system.

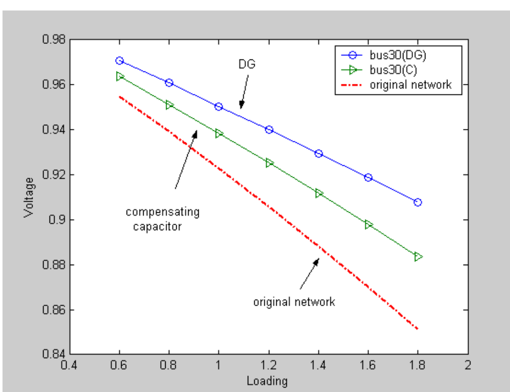

Fig 8: (b) Comparing minimum voltage between distributed generator (DG) and compensating capacitor installations for overall load increase in the system.

VIII. CONCLUSION

A new approach for determining the location and sizing of distributed generator in a distribution system is presented. The results revealed that the developed sensitivity analysis was successful in identifying the suitable location of distributed generation in a system. Meanwhile, the developed Evolutionary Programming optimization technique was used to identify the optimal sizing of distributed generator. From the results it shows that allocating and optimal sizing the distributed generation using the proposed technique has managed to minimize the total losses and also improve the voltage profile in the system.

The comparative study between distributed 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. The test was also performed looking into variation in loading conditions at the load buses ranging from 60% to 180% of the base load condition. The load variation was considered at each bus and all buses in the systems. The analysis also took into consideration of voltage constraint to ensure the voltage improvement in the systems is within the voltage limits. The objective of optimal location and sizing of distributed generation is to reduce the total power losses in the system. The voltage profile was also monitored to see the effect to the voltage at each load bus in the test systems.

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