Allocation and Sizing of Distributed Generation using Particle Swarm Optimization (PSO) Technique for Loss Minimization

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Abstract – **Distributed generator (DG) is playing major role to supply energy resources and also for the development of co-generation plant which is absolutely very important in the electric power systems of the near future. The study involved in this project is to determine the optimal allocation and sizing of the DG in order to minimize the losses in the system.**

Fast Voltage Stability Index (FVSI) technique has been used with the objective to identify the suitable location for the distributed generation in the networks. FVSI is used as the measuring instrument in predicting the sensitive lines which will be used to identify the location for DG installation. Once the locations are determined, Particle Swarm Optimization (PSO) technique is developed to identify the optimal size of the DG. It is an algorithm that represents the behavior of a flock of birds or a school of fish.

The feasibility of the proposed method is considered by using the fitness function in PSO technique to solve the load flow calculations for decision-making. In order to realize all the proposed technique, MATLAB programming software is used to develop the programming codes. The effectiveness of the proposed technique has been validated on standard IEEE 12-bus distribution system.

The obtained results show that the choice of the optimal locations and sizing of the DGs in the distribution system had minimized the total loss.

Keywords – **Fast Voltage Stability Index (FVSI), Optimal allocation of DG units, Particle Swarm Optimization (PSO)**

I. INTRODUCTION

Power system deregulation and the shortage of transmission capacities have also led to the increased demand in distributed generation sources. 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].

Due to the DG technologies, their benefit and concepts, and their valuable effect on the electricity market make DG a credible alternative in the distribution system planning. Therefore, since the importance of DG now being increasingly accepted and realized, it is challenging to determine the optimal location of DG for planning engineer [3]. Furthermore, recent changes in the electric utility infrastructure created the opportunities for many technological innovations including the application of distributed generation to achieve a variety of benefits. Many factors should be considered to achieve the benefits such as the best technology to be used, the number and the capacity of the units, the best location and network connection. Thus, the factors of the best location and sizing are the one of the important issues in the implementation of distributed generation in the distribution system. With optimal placement and sizing of distributed generation, maximum potential benefits could be obtained especially to improve the performance and to reduce the system loss [2].

Various techniques have been studied and proposed to solve the optimal allocation and sizing problem in distribution network since many years before. In [3], genetic algorithms (GA) have been employed to search for suitable and acceptable value to implement in distribution system. In [4], a Multiobjective Evolutionary (MO) method has been applied in order to obtain a feasible decision. In this project paper, particle swarm optimization (PSO) algorithms is presented and being applied to solve this allocation sizing problem in distribution system.

Particle Swarm Optimization (PSO) technique has been used with an objective to derive and identify the suitable location for the distributed generation in networks. It is an algorithm that represents the behavior of a flock of birds or a school of fish. The PSO algorithm is an adaptive algorithm based on a social-psychological metaphor, and the technique is probably best presented by explaining its conceptual development [5,6]. It is proven that PSO gives better results compared with the other methods.

At the present stage of research, special technique of Fast Voltage Stability Index (FVSI) with MATLAB program has been used in order to identify selected locations based on the sensitivity index analysis. The line that exhibits the highest rate of change of FVSI is considered as the critical line referred to a bus while the value of maximum reactive load at FVSI value closed to 1.00 is assigned as the maximum permissible load [7]. The procedure presented has been tested on standard IEEE 12-bus distribution system. The results show the efficiency of this approach.

In this study, DG allocation is addressed in order to reduce loss in a distribution system.

II. DISTRIBUTED GENERATION

Distributed generation, or DG, includes the application of small generators, typically ranging in capacity from 5KW to 10MW, at or near to the end-user to provide the electric power needed. In general, DG could be defined as a small electric power source usually connected to distribution networks or even in the consumers' side of the meter. Regarding the primary fuel, DG could be classified into two general categories: fossil DG (Combined Heat and Power (CHP), micro-turbines, fuel cells, etc.) and renewal DG [3].

DG units are usually connected at the substation, distribution feeder or customer load levels, and placed in urban area or perhaps in the same building as the load in order to reduce the losses in transmitting the energy. Employing DG in a distribution network has several advantages and a few disadvantages to the system [8,9]. In Malaysia, generations of electricity are provided by generators that are mostly being placed far from the load. Then the electricity will be transferred to load via national grid in Malaysia. The reasons why these power plants are placed far away are because of the source of energy and affect to human being. Therefore long and costly transmission lines have to be built in order to dispatch the energy. Thus the losses in the transmission lines arise because the longer the line is proportional to the higher resistance value in the lines.

Therefore to avoid the energy being wasted during the transmission, research has been done and a practical and logical solution has been achieved. As mentioned before, distributed or dispersed generation (DG) or embedded generation (EG) generation is designed and placed close to load or perhaps within the load itself as a solution to reduce losses and avoid wasted so many energy. 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 desired [10]. As part of it, it is challenging to determine the optimal location of DG for planning engineer. It is important to obtain the best sit and size of DG due to ensure the effectiveness of the technique so as a result we can fulfill the objectives to reduce the losses in the distribution system.

III. OBJECTIVES

The main objective of this project is to be able to explain the basic ideas or theories of PSO technique and FVSI analysis by installing the distributed generation (DG) at the most sensitive line which referred to the bus with suitable value. The proposed procedures and methodology will be successfully obtained when the results show the distribution loss in the distribution system is minimizing after installing the DG compared to the loss before installing the DG. It is also to ensure the capability of the DGs to be able to reduce the loss but still can withstand the extra load and support the system.

IV. METHODOLOGY

This project based on two main objectives which are to identify the suitable location and also the optimal size for the DG units in order to minimize the loss in the system. Therefore, the utilization of Fast Voltage Stability Index (FVSI) technique is being used in order to determine the location of DG installation. On the other hand, the development of PSO algorithm and PSO engine has been used in order to optimize the sizing of DG for loss minimization. The routine of FVSI and PSO algorithm is programmed by MATLAB software.

The methodology implemented for this paper work is shown in the flowchart in Fig. 1 and Fig. 3.

A. *FVSI Technique*

Fast Voltage Stability Index abbreviated by FVSI is developed by Dr. Ismail Musirin from Universiti Teknologi MARA, Shah Alam from Malaysia. FVSI is formulated in this study as the measuring instrument in predicting the sensitivity lines by using the sensitivity index analysis. The line that exhibits the highest rate of change of FVSI is considered as the critical line referred to a bus while the value of maximum reactive load at FVSI value closed to 1.00 is assigned as the maximum permissible load [7]. If the discriminant is small than zero, the roots for the voltage or power quadratic equations will have imaginary roots that could cause instability in the system [7].

The mathematical equation for FVSI was formulated from a line model given by:-

$$FVSI = \frac{4Z^2 Q_j}{V_i^2 X} \qquad (1)$$

Where:

Z is the line impedance

X is the line reactance

Q_j is the reactive power at the receiving end

V_i is the sending end voltage

FVSI will sort all the data calculated based on the most sensitive line which is has the highest FVSI value. Then the top three of the most sensitive line will be selected as the best candidates to perform the PSO technique and minimize the loss. The following procedures were implemented in order to form the sensitive line:-

1. Run the load flow program using Newton Raphson method for the base case.
2. Evaluate the FVSI value for every line in the system.
3. Gradually increase the reactive power loading at a chosen bus until the load flow solution fails to give the results. Calculate the percentages of loss for every load variation.

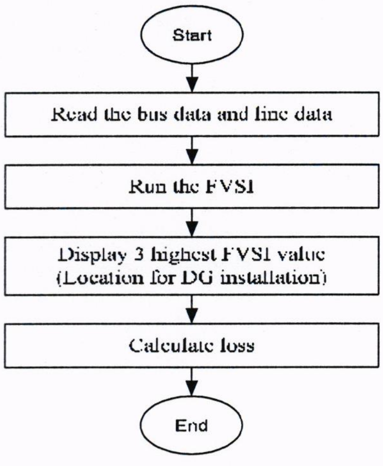

Fig. 1 Flow chart of FVSI technique

B. PSO Algorithm

Particle Swarm Optimization (PSO) algorithm is one of the Evolutionary Computation (EC) techniques. It was first introduced by Kennedy and Eberhart in 1995. Since the method is based on a simple concept and can be easily implemented by computer codes, it has attracted many researchers' attention and has been applied with great success to broad engineering problems. The PSO algorithm is an adaptive algorithm based on a social–psychological metaphor [5].

The development of its idea was based on simulation of social behavior of animals such as a flock of birds, a school of fish or a group of people who pursue a common goal in their lives. Like other stochastic searching techniques, the PSO is initialized with generating a population of random solutions, which is called a swarm. Each individual is referred to as a particle and presents a candidate solution to the optimization problem. A particle in PSO, like any living object has a memory in which retains the best experience, which is gained in the meanwhile of searching solution area. In this technique, each candidate solution is associated with a velocity vector [5,6]. The velocity vector is constantly adjusted according to the corresponding particle's experience and also the particle's companions' experiences. Accordingly in PSO algorithm, the best experiences of the groups are always shared with all particles and hence, it is expected that the particles move toward better solution areas. The *Gbest* PSO is an implementation where the neighborhood is the entire swarm, while *Pbest* PSO refers to the implementation where a smaller neighborhood size is used. This characteristic accentuates PSO method among other existing evolutionary optimization technique.

According to the above-mentioned concepts, *Gbest* PSO operation can be represents in mathematical expressions as following:

$$v_i^{(k+1)} = \omega v_i^k + C_1 Rand()' (Pbest_i^k - x_i^k) + C_2 Rand()' (Gbest^k - x_i^k) \quad (2)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (3)$$

Where:

v^k & v^{k+1}	= velocity
ω	= inertial weight (constant)
C_1 & C_2	= acceleration constant
Rand	= random number between [0-1]
Pbest	= best particle's position in the swarm
Gbest	= best position from the neighbor
x^k & x^{k+1}	= position of the particle

In these equations $i=1,2,...,m$ is the index of each particle, while k is the number of iteration. The constants C_1 & C_2 are the weighting factors of the stochastic acceleration terms, which pull each particle toward *Pbest* and *Gbest* positions. They represent a "cognitive" and a "social" component, respectively, in that they affect how much the particle's personal best and the global best influence its movement. Hence, the learning factors C_1 & C_2 are often set to 1.47 as a recommended value [5,11]. Pointing out, the PSO has been found to be robust and fast in solving nonlinear, non-differentiable, multi-objective problem, reference[12] has introduced the parameter ω into the PSO's equation to improve its performance. Suitable selection of inertia weight,ω, in equation (2) provides a balance between global and local explorations. The recommended value for inertia weight,ω, is 0.7.

In general, the inertia weight ω is set according to the following equation:

$$\omega^{(k+1)} = \frac{\omega^{\max} - \omega^{\min}}{k_{\max}} \times k \quad (4)$$

From equation (4), $k_{\max}$ is the maximum number of iterations and k is current iteration number. Fig.2 represents the basic idea of particle swarm optimizer graphically.

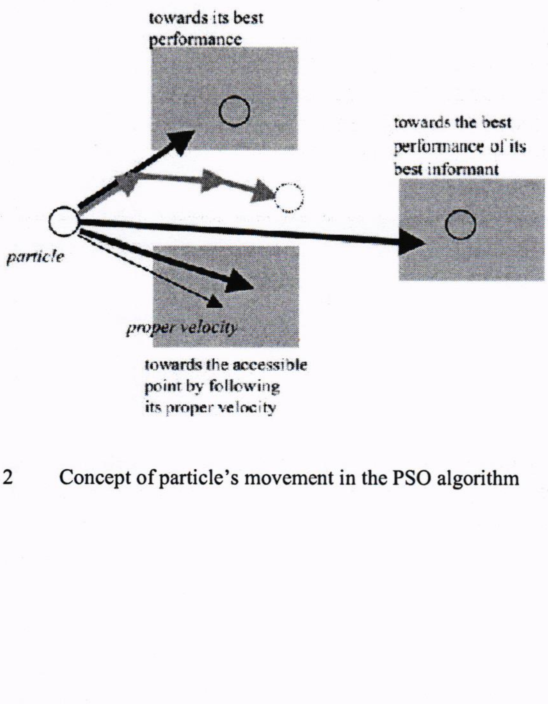

Fig. 2 Concept of particle's movement in the PSO algorithm

The solution methodology for the PSO technique is outlined in the general flow chart below:

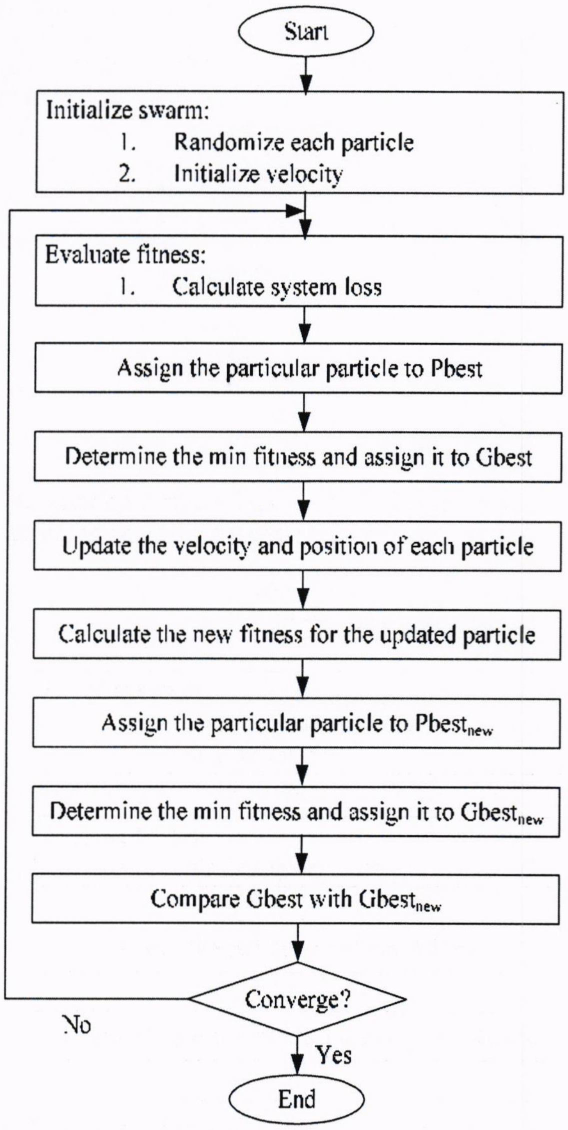

Fig. 3 General Flow chart of PSO

V. RESULTS AND DISCUSSION

A. FVSI Technique

Table 4.1 below tabulated the result of three buses with the highest sensitivity index value. These buses are the best locations for the DG installation. This is the base case condition when no reactive power load is injected at the distribution system. The results show that the buses with the highest sensitivity index values are Bus 4, Bus 5 and Bus 6.

TABLE I
THREE BUSES WITH THE HIGHEST SENSITIVY INDEX VALUE
(LOCATION FOR DG INSTALLATION)

CANDIDATES FOR PSO	
Bus Number	FVSI value
5	0.7988
4	0.5143
6	0.2917

B. PSO Algorithm

Once the locations are determined, Particle Swarm Optimization (PSO) technique was developed to identify the optimize size of the Distributed Generation (DG). Calculation of loss is applied for every reactive power that is being injected in the selected bus in the system. As for this project, loading condition is injected at Bus 4, Bus 5 and Bus 6 (best position with highest FVSI value). All data and characteristics are observed closely and were taken in a table while graphs were plotted to differentiate the loss before and after DGs are installed.

A. Analysis of the losses with three swarm sizes before and after DGs is installed.

Based on the program designed, PSO algorithm is set to use three swarm sizes (x_1, x_2, x_3) with 20 populations for each swarm size. The result will show three optimal locations of Distributed Generations (DGs) in the standard IEEE-12 bus distribution system.

- At Bus 4

Fig. 4 illustrates the comparison of the losses at Bus 4 before and after DGs is installed regarding swarm size of three.

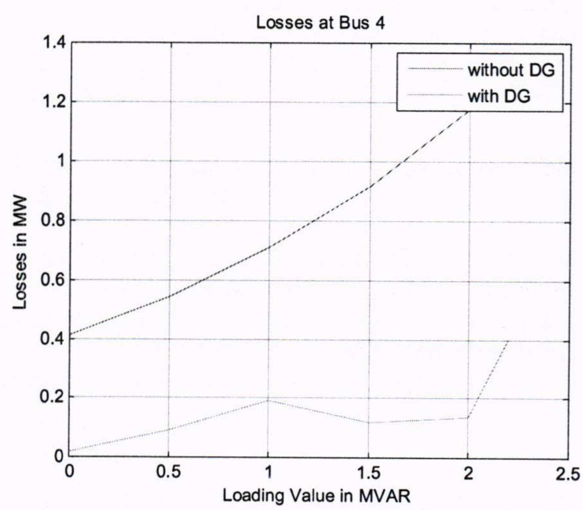

Fig.4 Comparison of the losses at Bus 4 before and after DGs is installed regarding swarm size of three.

The data obtain from the analysis of the losses at Bus 4, when injected with five selected load values before and after DGs is installed is tabulated below:

TABLE II

THE DATA OF THE LOSSES AND THE PERCENTAGE OF DECREASED IN LOSS AT BUS 4 BEFORE AND AFTER INSTALLATION OF DGs

BUS NUMBER: 4					
Load value (MVAR)	Loss without DG (MW)	Loss with DG (MW)	Percentage decreased (%)	Particles	BUS
Base Case = 0.001	0.4140	0.0149	96.40	x_1 = 0.9648	5
				x_2 = 0.1753	4
				x_3 = 0.8617	6
0.5	0.5438	0.0893	83.58	x_1 = 0.9051	5
				x_2 = 1.3605	4
				x_3 = 0.6196	3
1.0	0.7099	0.1913	73.05	x_1 = 0.7484	5
				x_2 = 0.6780	4
				x_3 = 0.4684	3
1.5	0.9174	0.1204	86.88	x_1 = 1.0289	4
				x_2 = 1.2318	5
				x_3 = 0.3327	3
2.0	1.1736	0.1355	88.45	x_1 = 1.5082	4
				x_2 = 1.5338	5
				x_3 = -0.6511	3
2.2	1.2919	0.4027	68.83	x_1 = 0.6225	4
				x_2 = 0.9879	5
				x_3 = 0.1704	3

- At Bus 5

Fig. 5 illustrates the comparison of the losses at Bus 5 before and after DGs is installed regarding swarm size of three.

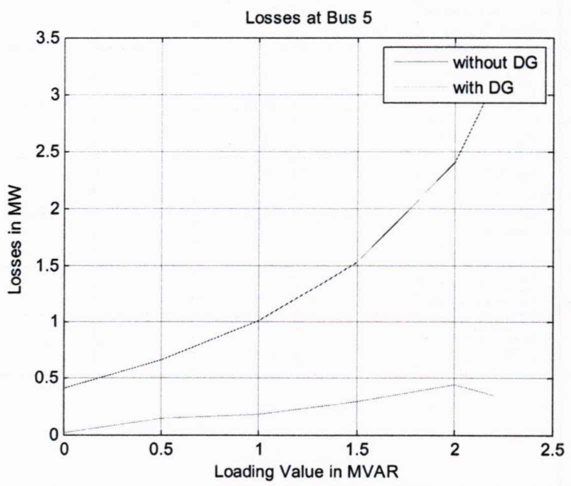

Fig. 5 Comparison of the losses at Bus 5 before and after DGs is installed regarding swarm size of three.

The data obtain from the analysis of the losses at Bus 5, when injected with five selected load values before and after DGs is installed is tabulated below:

TABLE III

THE DATA OF THE LOSSES AND THE PERCENTAGE OF DECREASED IN LOSS AT BUS 5 BEFORE AND AFTER INSTALLATION OF DGs

BUS NUMBER: 5					
Load value (MVAR)	Loss without DG (MW)	Loss with DG (MW)	Percentage decreased (%)	Particles	BUS
Base Case = 0.002	0.4140	0.0134	96.76	x_1 = 0.6467	5
				x_2 = 0.4628	4
				x_3 = 1.0749	6
0.5	0.6617	0.1413	78.65	x_1 = 0.9575	5
				x_2 = 0.8928	4
				x_3 = 0.3565	3
1.0	1.0143	0.1748	82.77	x_1 = 1.5489	5
				x_2 = 0.0327	4
				x_3 = 0.9096	3
1.5	1.5309	0.2940	80.80	x_1 = 1.1244	5
				x_2 = 1.2632	4
				x_3 = 0.8067	3
2.0	2.4077	0.4512	81.26	x_1 = 1.2815	5
				x_2 = 0.9970	4
				x_3 = 0.7791	3
2.2	3.1044	0.3485	88.77	x_1 = 1.7729	5
				x_2 = 0.8909	4
				x_3 = 0.8769	3

- At Bus 6

Fig. 6 illustrates the comparison of the losses at Bus 6 before and after DGs is installed regarding swarm size of three.

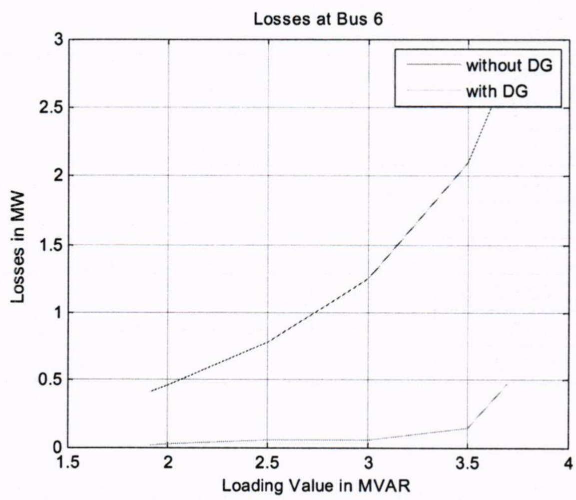

Fig. 6 Comparison of the losses at Bus 6 before and after DGs is installed regarding swarm size of three.

The data obtain from the analysis of the losses at Bus 6, when injected with five selected load values before and after DGs is installed is tabulated below:

TABLE IV
THE DATA OF THE LOSSES AND THE PERCENTAGE OF DECREASED IN LOSS AT BUS 6 BEFORE AND AFTER INSTALLATION OF DGs

BUS NUMBER: 6					
Load value (MVAR)	Loss without DG (MW)	Loss with DG (MW)	Percentage decreased (%)	Particles	BUS
Base Case = 1.910	0.4140	0.0188	95.46	x_1 = 0.8754	5
				x_2 = 0.5181	4
				x_3 = 0.9436	6
2.0	0.4591	0.0216	95.30	x_1 = 0.6233	5
				x_2 = 0.5038	4
				x_3 = 0.9577	6
2.5	0.7764	0.0572	92.63	x_1 = 0.8902	5
				x_2 = 0.4208	4
				x_3 = 0.9129	6
3.0	1.2565	0.0586	95.34	x_1 = 1.3862	5
				x_2 = 1.0118	4
				x_3 = 1.2105	6
3.5	2.0969	0.1464	93.02	x_1 = 0.7855	5
				x_2 = 1.6130	4
				x_3 = 1.2557	6
3.7	2.7957	0.4688	83.23	x_1 = 1.0027	5
				x_2 = 0.7664	4
				x_3 = 0.5517	6

B. Analysis of the losses with four swarm sizes before and after DGs is installed.

- At Bus 4

Fig. 7 illustrates the comparison of the losses at Bus 4 regarding swarm size of four.

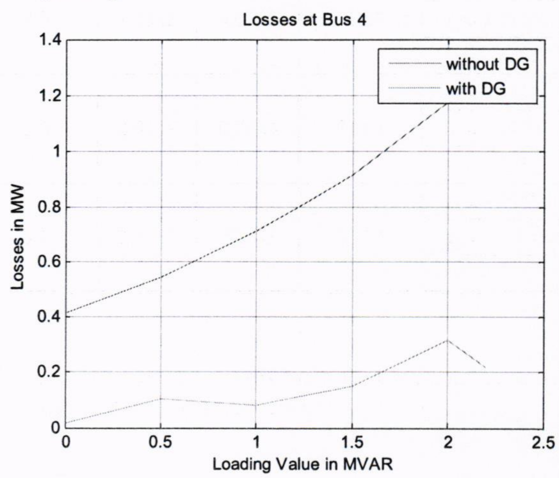

Fig. 7 Comparison of the losses at Bus 4 before and after DGs is installed regarding swarm size of four.

The data obtain from the analysis of the losses at Bus 4 is tabulated below:

TABLE V
THE DATA OF THE LOSSES AND THE PERCENTAGE OF DECREASED IN LOSS AT BUS 4 BEFORE AND AFTER INSTALLATION OF DGs

BUS NUMBER: 4					
Load value (MVAR)	Loss without DG (MW)	Loss with DG (MW)	Percentage decreased (%)	Particles	BUS
Base Case = 0.001	0.4140	0.0142	96.57	x_1 = 0.6653	5
				x_2 = 0.2502	4
				x_3 = 1.0159	6
				x_4 = 0.2390	3
0.5	0.5438	0.1039	80.89	x_1 = 0.9635	5
				x_2 = 0.6071	4
				x_3 = 0.5704	3
				X_4 = 0.1263	2
1.0	0.7099	0.0831	88.29	x_1 = 1.4259	5
				x_2 = 0.5871	4
				x_3 = 1.0121	3
				x_4 = 0.7600	2
1.5	0.9174	0.1507	83.57	x_1 = 0.9716	4
				x_2 = 0.9453	5
				x_3 = 0.7848	3
				x_4 = 0.5963	2
2.0	1.1736	0.3181	72.90	x_1 = 0.7360	4
				x_2 = 0.7947	5
				x_3 = 0.5449	3
				x_4 = 0.6862	2
2.2	1.2919	0.2203	82.95	x_1 = 1.0213	4
				x_2 = 1.0467	5
				x_3 = 0.6718	3
				x_4 = 0.7041	2

- At Bus 5

Fig. 8 illustrates the comparison of the losses at Bus 5 regarding swarm size of four.

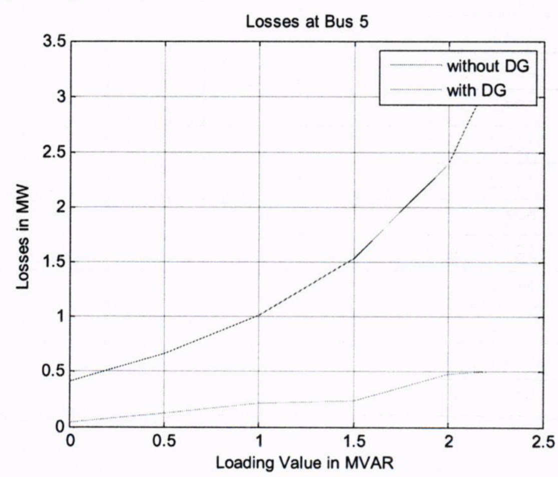

Fig. 8 Comparison of the losses at Bus 5 before and after DGs is installed regarding swarm size of four.

The data obtain from the analysis of the losses at Bus 5 is tabulated below:

TABLE VI

THE DATA OF THE LOSSES AND THE PERCENTAGE OF DECREASED IN LOSS AT BUS 5 BEFORE AND AFTER INSTALLATION OF DGs

BUS NUMBER: 5					
Load value (MVAR)	Loss without DG (MW)	Loss with DG (MW)	Percentage decreased (%)	Particles	BUS
Base Case = 0.002	0.4140	0.0390	90.58	x_1 = 0.9462	5
				x_2 = 0.3472	4
				x_3 = 0.5181	6
				x_4 = 0.6727	3
0.5	0.6617	0.1222	81.53	x_1 = 1.1816	5
				x_2 = 0.7293	4
				x_3 = 0.5760	3
				x_4 = 1.0112	2
1.0	1.0143	0.2117	79.13	x_1 = 1.1865	5
				x_2 = 0.4699	4
				x_3 = 1.0056	3
				x_4 = 0.9377	2
1.5	1.5309	0.2327	84.80	x_1 = 1.3243	5
				x_2 = 1.5020	4
				x_3 = 0.3654	3
				x_4 = 0.2055	2
2.0	2.4077	0.4855	79.84	x_1 = 1.4587	5
				x_2 = 0.6739	4
				x_3 = -0.0085	3
				x_4 = 0.3742	2
2.2	3.1044	0.4993	83.92	x_1 = 1.3634	5
				x_2 = 0.8772	4
				x_3 = 1.0817	3
				x_4 = 0.2338	2

- At Bus 6

Fig. 8 illustrates the comparison of the losses at Bus 6 regarding swarm size of four.

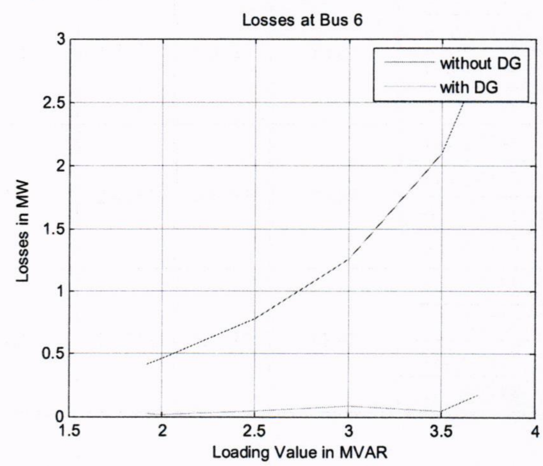

Fig. 9 Comparison of the losses at Bus 6 before and after DGs is installed regarding swarm size of four.

The data obtain from the analysis of the losses at Bus 5 is tabulated below:

TABLE VII

THE DATA OF THE LOSSES AND THE PERCENTAGE OF DECREASED IN LOSS AT BUS 6 BEFORE AND AFTER INSTALLATION OF DGs

BUS NUMBER: 6					
Load value (MVAR)	Loss without DG (MW)	Loss with DG (MW)	Percentage decreased (%)	Particles	BUS
Base Case = 1.910	0.4140	0.0260	93.72	x_1 = 0.9173	5
				x_2 = 0.1616	4
				x_3 = 0.7156	6
				x_4 = 0.5777	3
2.0	0.4591	0.0121	97.36	x_1 = 0.9781	5
				x_2 = 0.1494	4
				x_3 = 1.0725	6
				x_4 = -0.0189	3
2.5	0.7764	0.0422	94.56	x_1 = 0.9752	5
				x_2 = 0.6022	4
				x_3 = 0.9715	6
				x_4 = -0.0559	3
3.0	1.2565	0.0853	93.21	x_1 = 1.2654	5
				x_2 = 0.5466	4
				x_3 = 0.9348	6
				x_4 = 0.7708	3
3.5	2.0969	0.0491	97.66	x_1 = 1.4415	5
				x_2 = 0.5596	4
				x_3 = 1.6880	6
				x_4 = -0.3786	3
3.7	2.7957	0.1716	93.86	x_1 = 0.9903	5
				x_2 = 1.0721	4
				x_3 = 1.2405	6
				x_4 = 0.9319	3

From the figures showed and the tabulated data, it is observed that total losses increase accordingly as reactive power loading is increased. DGs are installed in an objective to withstand the extra load and support the system.

The installation of DG in the system has proved that the DGs are capable to reduce loss and support the system.

VI. CONCLUSIONS

This paper has presented allocation and sizing of Distributed Generation (DG) using Particle Swarm Optimization (PSO) technique for loss minimization. The study involved in this project is to determine the optimal allocation and sizing of the DG in order to minimize the losses in the system. The possibility to solve the optimal allocation and sizing of DG through a suitable PSO algorithm has been the approach in this thesis. The important characteristic to determine the suitable and acceptable locations and values of the objective function with respect to minimizing the loss is considered.

Since the number of DGs will be increasing and also their efficiency in transmitting energy have been chosen as a factor in objective function, installation of a few number of DGs with respect to avoid and reduce the wasted energy while transmitting energy is mandatory. For the extension of this work, economic factor will be taken into consideration. Even though minimization of loss is part of the cost benefit, other issues will occur which lead to the optimal cost benefit to the consumers and country. However this thesis only introduces a method towards giving the most best and cost efficient of electricity to the country.

By using these FVSI technique and PSO algorithm as a proposed methodology we can see that the objectives are achieved due to the results presented. With the installation of DGs at optimal allocation and sizing at the distribution system has proved that DGs are capable to reduce loss and support the system. As a result, these proposed techniques are versatile and efficient to be used.

VII. FUTURE DEVELOPMENT

In the near future, many expansion and further studies can be done. PSO algorithm can be applied to the real bus system that is being use in the country or other country in the world. Since PSO capable of producing excellent and promising result, therefore it can be said that it is the most reliable optimization technique. As for Distributed Generators, these DGs can be part of the back up power for the certain area or city. Moreover if the country has a big potential of renewable energy, maybe DGs can be the main source of energy to the city. Even though the first cost will be very high, but for long term benefits is great and proven. Other than using this algorithm to determine location and sizing DG in the bus system, PSO can be used for other sort of problem solving in our daily life.

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