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IMPLEMENTATION OF PSO-BASED OPTIMAL DISTRIBUTED GENERATORS (DG) SIZING AND LOCATION USING MATLAB

Ibekwe, I. K. Ph. D and Prof Eneh. I.I.
Department of Electrical and Electronic Engineering. Enugu State University of Science and Technology, ESUT, Enugu.

Keywords: *Particle Swarm Optimization (PSO), Distributed generators (DG), Sizing and Location, Implementation*

Abstract: *This paper is on Implementation of the Particle Swarm Optimization (PSO)-based Optimal Distributed generators (DG) Sizing and Location using Matlab. The implemented PSO was executed to obtain the optimum size(s) and optimum location(s) of the DGs. Having determined the optimum size(s) and location(s), the optimally sized DGs were integrated into their optimum locations for network loss reduction. The number of DGs was three; the locations are buses 5, 9, and 11 while the corresponding optimum DG sizes are: 0.495+ j0.264, 759 + j0.172 MW, and 0.641 + j0.264 MW. The optimum loss obtained represents a 9.055pureduction in loss relative to the network with no DG connected. It is not surprising that the type-two DGs performed better than the type-one DGs. This is because, by supplying both active and reactive power at the load points, the network is offered efficient active and reactive power support.*

1.0 INTRODUCTION

Losses in transmission and distribution networks represent the single largest consumption in any power system. Due to the rapid increase in the demand for electricity, environmental constraints, and competitive energy market scenario, the transmission and distribution systems are often being operated under heavily loaded conditions and distribution system loss has become more and more of a concern. It is estimated that electricity losses account for 6.6% of the total energy used in most power systems around the world. A huge proportion of these losses are attributed to the medium voltage distribution network, (Pecas, *et al.,* 2017). With typical power factor and energy cost in Nigeria, this amounts to power losses running into millions of dollars for the Nigerian Discos. This surely reduces the return on investment for the system operators. Due to thermal stresses, power loss impacts the life span of grid equipment thus it increases the cost of maintenance and the total cost of system operation. Hence power loss reduction is one of the vital areas of power system planning, design, and operation.

The requirement to provide acceptable power quality and enhanced efficiency to achieve all possible economic benefits will create a very favourable climate for the need for loss minimization techniques and innovative operating practices, (Kennedy and Eberhart,

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1995). Also to enhance the efficiency of a distribution system, loss minimization is the only alternative. The potency of a distributed generation when optimally deployed can be exploited towards the mitigation of losses in the Imo distribution network in South-eastern Nigeria. Southeast Nigeria is an economic hub in dire need of electrical power for business sustainability and development of the region. Therefore, it is imperative to find a remote remedial technique to boost the power distribution within the zone pending when there will be further expansion of the overstretched distribution network.

In this research, Implementation of the particle swarm optimization (PSO)-based Optimal DG Sizing and Location using Matlab is presented.

2.0 LITERATURE REVIEW

Sadiq, *et al.,* (2013) conducted studies on the placement of dispersed generation systems for reduced losses in System Sciences. The Near-optimal determination algorithm was used for the computation of the placement decision. This work demonstrates a methodology for deploying dispersed fuel cell generators throughout a power system to allow for more efficient operation. The results show the importance of placement for minimizing losses and maximizing capacity savings. Furthermore, the work was not validated from the point of view of the effect of load variation on performance.

Jokojeje, *et al.,* (2015) carried out research studies on optimal distributed generation allocation in sub-transmission systems employing ant colonies to reduce losses. Ant colony search algorithm (ACSA) was the computational technique used. Simulations were used to validate the work. The impact of loss reduction on the voltage profile was reported. The result evaluation showed that the proposed scheme achieved about a 17.23% reduction in active loss, using the base power system as a baseline. The algorithm suffered from slow convergence, and the authors did not carry out a comparative evaluation of the performance of the proposed method.

Satish, *et al.,* (2011) proposed an optimal renewable resources mix for active loss minimization. The mixed integer nonlinear programming (MINLP) method was used for the computation. The authors proposed a methodology for optimally allocating different types of renewable distributed generation (DG) units in the distribution system to minimize annual energy loss. The results show that a significant reduction in annual energy losses is achieved for all the proposed scenarios. Results were obtained for loss reduction in terms of comparison with the base case of the power system. However, the work was not properly validated in terms of variation of load distribution on losses.

Kandil, *et al.*, (2012) carried out studies on the optimization of Loss Minimization Using FACTS in Deregulated Power Systems. The authors proposed the optimal allocation of TCSC based on real power loss. Power Flow studies were carried out by using Power World Simulator and MATLAB. First Base Case data were obtained for 9 – Bus, 14-Bus, and 30 – Bus. The One-Line diagram of 9-Bus and 14-Bus. The lines having maximum losses were identified. TCSC FACTS device was placed in these lines. TCSC was implemented by increasing the reactance of the line by 20 % to 70%. After placing TCSC power flow data was obtained and compared with the

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base case values. The percentage reduction of losses was computed. A drawback is that the work did not address the control of the FACTS device.

Karayat, *et al.,* (2018) proposed the minimization of power losses using distributed generation approach. The load flow analysis method was followed to calculate the loss in the system in conjunction with the line flows. A simple 5-bus system with the main bus of the substation as the slack bus, three Plant generators at the generator bus, and three load buses are taken for analysis. For loss minimization two distributed generators at two load buses were connected. The work was validated using simulation, and from the result obtained, the reduction in power loss is 58.21%. Although there was found a bit increase in real power loss, the overall loss decreased significantly. The work did not clarify the objective functions for the placement and control of the DGs in achieving loss minimization.

Amanifar, (2019) proposed a loss reduction technique that involved the development of analytical Expressions for DG Allocation in Primary Distribution Networks. Results show that the proposed method requires less computation, but can lead to the optimal solution as verified by the exhaustive load flow method. The evaluation carried out did not include sensitivity analysis of variation in DG configuration to variation in losses obtained.

Sedighi, *et al.,*(2017) carried out studies on power loss minimization that involved the development of a novel objective function for optimal DG allocation in distribution systems using meta-heuristic algorithms. The method used was a hybrid meta-heuristic algorithm consisting of Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Imperialist Competitive Algorithm (ICA). A detailed performance analysis was done on 13 bus radial distribution systems. The performances of the three algorithms were compared with each other and the results showed that the PSO was the fastest; and had the best solution and optimum results. The loss minimization performance of the proposed solution was not evaluated under diverse load variations and the sensitivity analysis of the impact of the load variation and DG penetration on the variation of losses was not carried out.

Kai, *et al.,*(2017) proposed a power loss reduction technique that is based on optimal planning of distributed generation with an application of a multi-objective algorithm including economic, environmental, and technical issues with considering uncertainties. To validate the effectiveness of the proposed scheme, simulations are carried out on a 33-bus distribution network and finally, the attained results are discussed. The evaluation carried out did not show a sensitivity of DG configuration to less variation in the system.

Varesi, (2017) carried out research studies on electric power components and systems swarm-intelligence-based optimal planning of distributed generators in the distribution network for minimizing energy loss swarm-intelligence-based optimal planning of minimizing energy loss. The work developed a heuristic approach for the planning of Distributed generators (DG) to minimize annual system energy loss. The effectiveness of the proposed approach was validated on 16-, 33-, and 69-bus radial distribution networks. The

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results are compared with those of already existing methods as suggested in the literature. But, the work did not include control of the DG.

3.0 MATERIALS AND METHOD

3.1 DG Size Problem Formulations

To be able to successfully implement a PSO search system for optimizing the DG size and location for minimum total network loss, there is a need to obtain the mathematical expressions that represent the problem to be solved by the PSO system. The problem formulations presented in Bhumkittipich (2013) are adopted for this research and are presented thus:

3.2 Problem Formulation

For efficient and effective power system operation, the distribution system must be guarded against overtly high losses that have always characterized the system. There is need for the reduction of real power loss in the distribution system. The loss in the system can be ascertained through equation (1) according to (Elgerd, 1971) giving the system operating condition,

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij}\left(P_iP_j + Q_iQ_j\right) + B_{ij}\left(Q_iP_j - P_iQ_j\right) \quad (1)$$

where

$$A_{ij} = \frac{R_{ij}\cos(\delta_i - \delta_j)}{V_iV_j}$$

$$B_{ij} = \frac{R_{ij}\sin(\delta_i - \delta_j)}{V_iV_j}$$

Note that P_i and Q_i are the net real and reactive power injection in bus "i" respectively, R_{ij} is the line resistance between bus i and j and δ_i are the voltage and angle at bus "i" respectively.

The technique seeks to minimize the total real power loss. Thus, the objective function can mathematically be written as:

$$\text{Minimize } P_L = \sum_{K=1}^{N_{sc}} \text{Loss}_k \quad (2)$$

Subject to power balance constraints

$$\sum_{i=1}^{N} P_{DGi} = \sum_{k=1}^{N} P_{Di} + P_L \quad (3)$$

Voltage constraints: $|V_i|^{min} \leq |V_i| \leq |V_i|^{max}$ (4)

$$\left|I_{ij}\right| \leq \left|I_{ij}\right|^{max} \quad (5)$$

Note that: $Loss_k$ is the distribution loss at section k, N_{sc} is the total number of sections, P_L is the real power loss in the system, P_{DGi} is the real power generation DG at the bus i, P_{Di} is the power demand at bus i.

3.3 DG Type and Heuristic Methodology

a. DG Type 1

It is a worthy note that some types of DGs such as photovoltaic cells produce real power only. To evaluate the optimal DG size at bus i, when it supplies only real power, the required condition for minimum loss is

$$P_i = P_{DGi} - P_{Di} = -\frac{1}{A_{ij}}\sum_{\substack{j=1 \\ j\neq i}}^{n}\left(A_{ij}P_j - B_{ij}Q_j\right) \quad (6)$$

The following relationship holds:

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$$P_{DGi} = P_{Di} - \frac{1}{A_{ii}}\sum_{\substack{j=1\\j\neq i}}^{n}\left(A_{ij}P_j - B_{ij}Q_j\right) \quad (7)$$

Equation (7) reflects the optimal size of DG for each bus to mitigate the real power loss.

b. DG Type 2

Unlike photovoltaic DGs, synchronous DGs provide only reactive power to enhance the voltage profile. To evaluate the optimal location of the DG, the loss equation is once more differentiated on either side with respect to Q_i. Equation (8) below gives the optimal DG size for every bus in the system.

$$Q_{DGi} = Q_{Di} - \frac{i}{A_{ij}}\sum_{\substack{j=1\\j\neq i}}^{N}\left(A_{ij}Q_j + B_{ij}P_j\right) \quad (8)$$

c. DG Type 3

In this scenario, the DG will supply real power and absorb reactive power in turn. In the case of a wind turbine, an induction generator is employed to provide real power and the reactive power will be consumed in the process (Saribatir et al., 1992). The amount of reactive power that they need is an ever-increasing subject of the active power output. The amount of reactive power consumed by the DG (the wind generator) in simple form can be denoted by the equation (9) as in the case of (DTI, 2004)

$$Q_{DG} = -(0.5 + P_{DG}^2) \quad (9)$$

The loss equation is subject to modification. Having followed through the same methodology for the first two DG types, the optimal DG size can be obtained by evaluating equation (10).

$$0.0032\ A_{ij}P_{DGi}^3 + P_{DGi}[1.004A_{ii} + 0.8A_{ii}Q_{Di} - 0.08Y_i] + (X_i - A_{ii}P_{Di}) = 0 \quad (10)$$

Equation (10) depicts the amount of real power that a DG supplies when connected to bus "i" to obtain the least system loss while the equation gives the amount of reactive power that is consumed.

d. Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is an optimization method based on population. This method was first proposed by Eberhart in 1995 having been inspired by the social behavior of birds flocking or fish schooling (Kennedy and Eberhart, 1995). PSO as a tool for optimization enables population-based search procedures in which individuals known as particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During the flight, each particle amends its position in accordance with its own experience (this value is referred to as Pbest), and in accordance with the experience of the neighboring particle (this value is referred to Gbest). Thus, each particle makes use of the best position it encountered and that of its neighbor as depicted in figure 1.

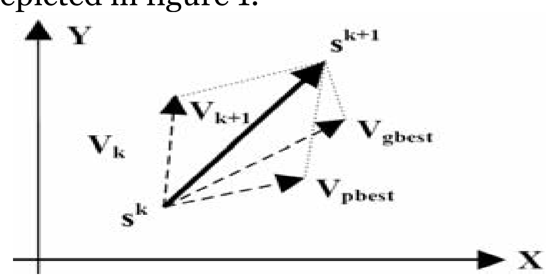

Figure 1: Concept of a searching point by PSO

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The concept of velocity can be utilized to represent this modification. The following equation can be used to modify the velocity of each agent.

$$V_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand \times \left(Pbest_{id} - S_{id}^{k}\right) C_2 rand \times \left(gbest_d - s_{id}^{k}\right) \qquad (11)$$

With the help of the equation (11) above, a specific velocity that gradually gets nearer to pbest and gbest can be calculated. The following equation can be used to modify the current position (searching point in the solution space).

$$S_{id}^{k+1} = S_{id}^{k} + v_{id}^{k+1}, \quad i = 1, 2, \ldots . n, \quad d = 1, 2 \ldots , m \qquad (12)$$

Note that S^k is the present searching point, S^{k+1} is the modified searching point, v^k is the present velocity, v^{k+1} is the modified velocity of agent i v_{pbest} is the velocity based on pbest, v_{gbest} is the velocity based on g_{best}, n is the sum total of a particle in a group, m is the number of members in a particle, pbest_i is Pbest of agent i, $gbest_i$ is the gbest of the group, ω_i is the weight function for a velocity of agent i, c_i is weight coefficients for each term.

The weight function below is employed:

$$\omega_i = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{K_{max}} . K \qquad (13)$$

note that ω_{min} and ω_{max} are the respective minimum and maximum weights. K and k_{max} are the present and peak iterations. The appropriate value ranges for C_1 and C_2 are 1 to 2, however, 2 is the most suitable in many scenarios. Suitable values for ω_{min} and ω_{max} are 0.4 and 0.9 respectively (Eberhart, and Shi, 2000).

3.4 Implementation of the PSO-based Optimal DG Sizing and Location in Matlab

The flow chart of figure 2 was implemented in Matlab using source codes obtained from Gilt Hub (2015).

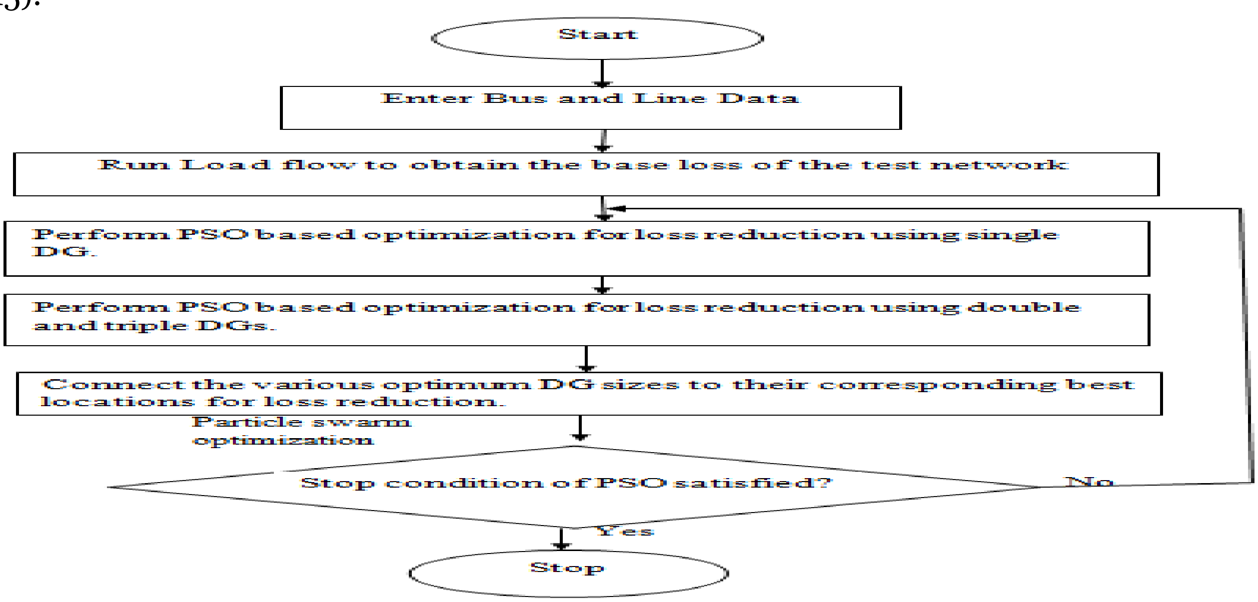

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Figure 2: Flow chart of GA-based optimal Sizing and Location of DG's

As provided in the system algorithm and flow chart of figure 2, the first step in this implementation is to create the code for accessing the line and bus data of the test network by the PSO system. This was achieved in lines 6 and 7 of the screenshot showing a section of file main Dg Sizing Placement.m presented in figure 3. The bus and line data named NetworkData.xlsx is contained in an excel (xlsx) file located in the same folder containing all the PSO code files. The remaining lines in figure 3 are used to identify the various columns of the bus and line data. Inputting the bus and line data into the PSO system is important as the system will perform a series of load flow studies as it searches for the size and location of DGs that achieves minimum total network loss in the case study network.

mainDgSIzingPlacement.m

```
1       %% DG Location
2       clear, clc, close all
3       %% Required input data
4
5       % System data
6       Busdata = xlsread('NetworkData.xlsx', 'Busdata');
7       Linedata = xlsread('NetworkData.xlsx', 'Linedata');
8
9       %% Data retrieval from Linedata
10
11      Nbr = Linedata(:,1);      % Line number
12      Nl = Linedata(:,2);       % Nl, From bus
13      Nr = Linedata(:,3);       % Nr, To bus
14      R = Linedata(:,4);        % R(i), Line resistance
15      X = Linedata(:,5);        % X(i), Line reactance
16      Imax = Linedata(:,6);     % Maximum current
17
18      %% Data retrieval from Busdata
19
20      Busn = Busdata(:,1);      % Bus number
21      Btype = Busdata(:,2);     % Type of bus 1-Slack, 2-PV, 3-PQ
22      Pl = Busdata(:,4);        % Pl(i):Load of bus i
23      Ql = Busdata(:,5);        % Ql(i):Load of bus i
24
25
```

Command Window

Figure 3: A screenshot of the section of main Dg Sizing Placement. m calling the bus and line data from the excel files.

The next instruction on the activity box (Create base network loss) is implemented in figure 4. Here, the base voltage and apparent power (KV and MVA) values are specified. To compute the total network real power loss before optimization, the power flow program is called in line 48. It is important to obtain this initial network real power loss as it will serve as the initial reference power loss during optimization.

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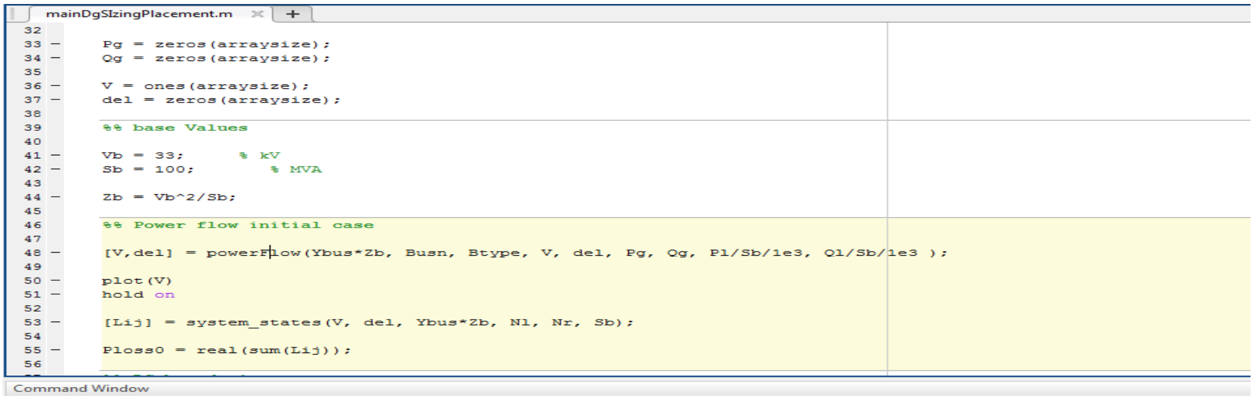
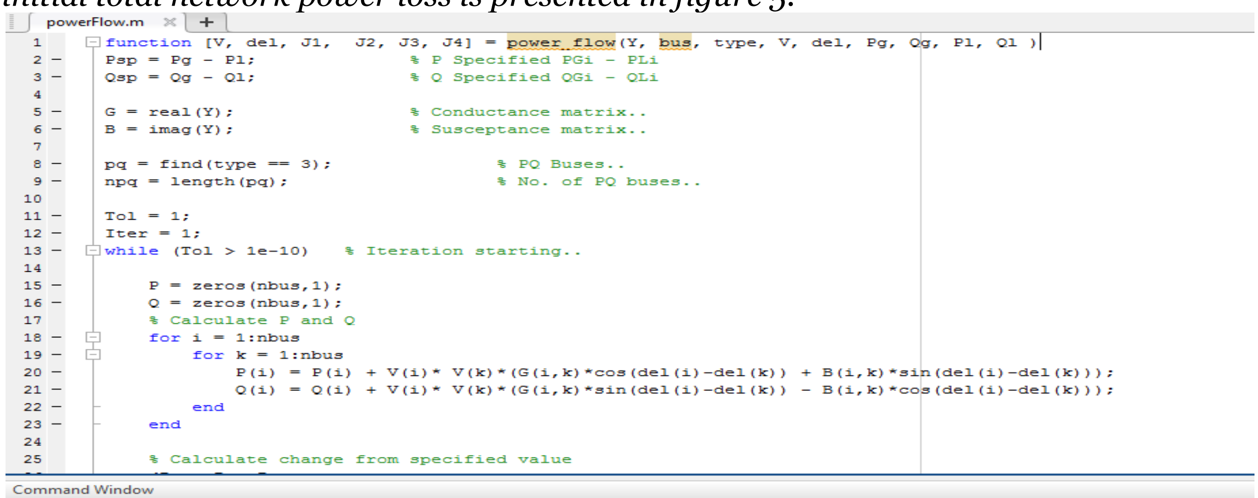


```
mainDgSIzingPlacement.m

Pg = zeros(arraysize);
Qg = zeros(arraysize);

V = ones(arraysize);
del = zeros(arraysize);

%% base Values

Vb = 33;       % kV
Sb = 100;         % MVA

Zb = Vb^2/Sb;

%% Power flow initial case

[V,del] = powerFlow(Ybus*Zb, Busn, Btype, V, del, Pg, Qg, Pl/Sb/1e3, Ql/Sb/1e3 );

plot(V)
hold on

[Lij] = system_states(V, del, Ybus*Zb, Nl, Nr, Sb);

Ploss0 = real(sum(Lij));
```

Figure 4: A screenshot of the section of main Dg Sizing Placement.mcalling the powerFlow.m file for power loss computation

A section of the program file, powerFlow.m that perform load flow studies for the realization of the initial total network power loss is presented in figure 5.



```
powerFlow.m

function [V, del, J1,  J2, J3, J4] = power_flow(Y, bus, type, V, del, Pg, Qg, Pl, Ql )
Psp = Pg - Pl;                 % P Specified PGi - PLi
Qsp = Qg - Ql;                 % Q Specified QGi - QLi

G = real(Y);                   % Conductance matrix..
B = imag(Y);                   % Susceptance matrix..

pq = find(type == 3);                  % PQ Buses..
npq = length(pq);                      % No. of PQ buses..

Tol = 1;
Iter = 1;
while (Tol > 1e-10)   % Iteration starting..

    P = zeros(nbus,1);
    Q = zeros(nbus,1);
    % Calculate P and Q
    for i = 1:nbus
        for k = 1:nbus
            P(i) = P(i) + V(i)* V(k)*(G(i,k)*cos(del(i)-del(k)) + B(i,k)*sin(del(i)-del(k)));
            Q(i) = Q(i) + V(i)* V(k)*(G(i,k)*sin(del(i)-del(k)) - B(i,k)*cos(del(i)-del(k)));
        end
    end

    % Calculate change from specified value
```

Figure 5: Screenshot of a section of the program file for performing load flow studies

The next step in the algorithm is to optimize the objective function to obtain the optimum DG sizes and their locations for the various DG numbers and types. Recall that eigenvalue analysis revealed that three DGs working together are likely to offer the minimum total network loss when installed in their best position and with appropriate size. To achieve the objective of this step, the optimal Sizing.m program file was called to optimize the objective function for the realization of the optimum DG sizes and locations. The section of main DgSizingPlacement.m for calling the optimalSizing.m program file is shown in figure 6.

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mainDgSIzingPlacement.m

```
%% Handle functions
% Handle function to genererate several study cases

SizingDg = @(DGType, ndg) optimalSizing(...
                        ndg, DGType, MinP, MaxP, MinQ, MaxQ,...
                        Ybus*Zb, Busn, Btype, V, del, Pg, Qg, Pl/Sb/1e3, Ql/Sb/1e3 , ...
                        Nl, Nr, Sb,...
                        Ploss0);

% Handle function to genererate several reports
SystemReport = @(dgtype, Ndg, xf, Pf, Qf) general_report(...
                     dgtype, Ndg,...
                     xf, Pf,Qf,...
                     Ybus*Zb, Busn, Btype, V, del, Pg, Qg, Pl/Sb/1e3, Ql/Sb/1e3 ,...
                     Nl, Nr, Sb);
```

Figure 6: Section of mainDgSizingPlacement.m for calling the optimalSizing.m program file

The optimization of the objective function for the determination of the optimal sizes of the various DG's and their locations in the test network was implemented in the program file, optimalSizing.m. As can be seen from figure 7, the optimization process was implemented using Particles Swarm optimization (PSO).

The first step in the PSO optimization process is to generate an initial particle population in form of an array. This population is randomly generated such that the particles possess random velocities and positions in relation to the set of possible solutions. The next is to evaluate the fitness of the position (p) for each particle. The old position of each particle is then updated with new better positions. The best position (pbest) among the particles is made the global best position for the entire group (gbest). The final step is the updating of velocities and positions of particles using equations and the subsequent output of the optimal solution (best global position) which is the optimal sizes and locations of DGs for minimum loss reduction. The PSO optimization algorithm is summarised in the flow chart of figure 7.

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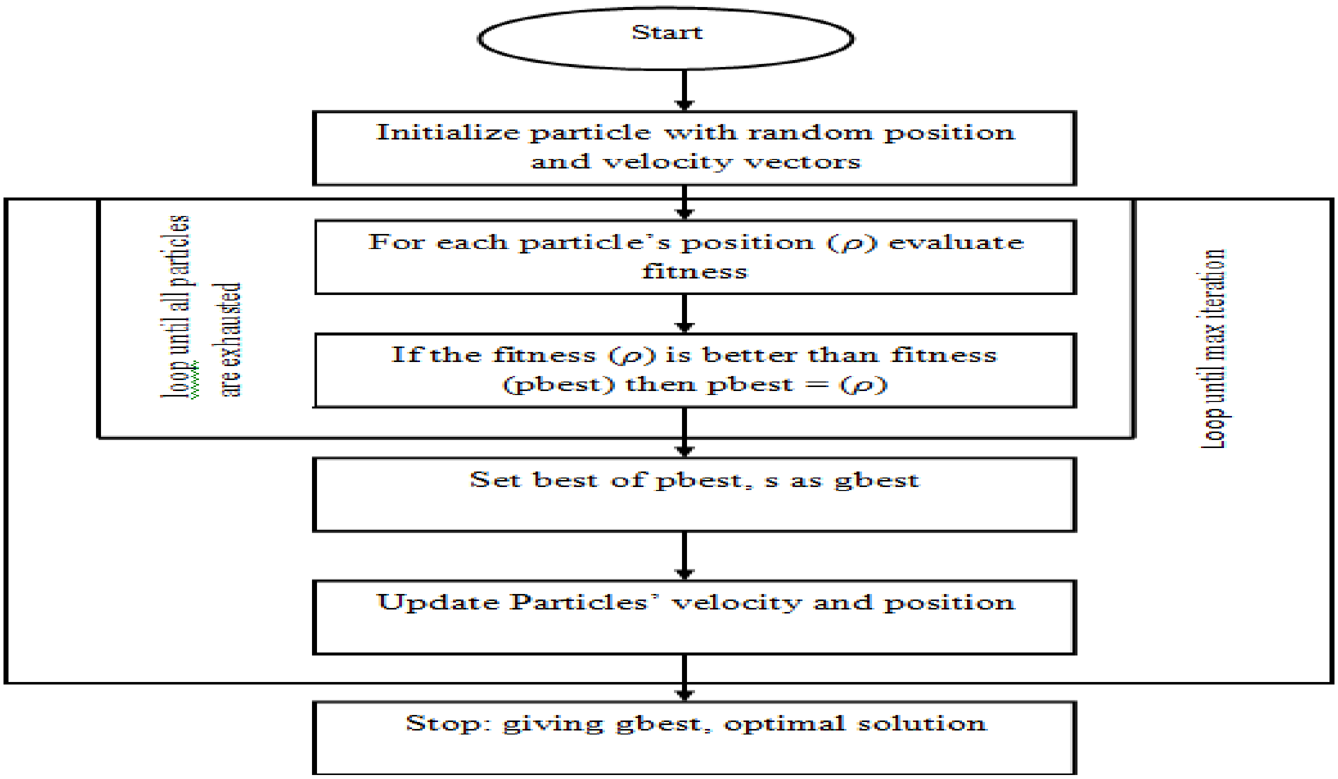

Figure 7: The PSO optimization algorithm flow chat

4.0 Results and Discussion

The aim of this is to obtain the optimal size(s) of DG unit(s) and their corresponding optimal locations (bus of installation) that will give minimum total network power loss during load flow. Obtaining the optimum sizes of DG units requires tedious computations while searching for the optimum DG locations is also an onerous task. The idea of employing an intelligent search and computational algorithm like PSO is to make these difficult searches and computations easier. One of the key parameters required for the effective implementation of the PSO based optimization system is the number of DG's to be used. The PSO based optimization system for determining the optimal sizes and locations of GDs for minimum realm power losses was then implemented to carry out the optimization using a maximum of 3 DGs.

The result obtained from each scenario/case are compared with the characterization result to determine the impact of optimum DG size and location on network loss reduction, the impact of a number of DGs installed and the type of DG used.

After obtaining the optimum sizes of the various DG types and their corresponding best locations, there is a need to connect the DGs to their respective best locations so that load flow can be performed to determine the level of total network real power loss obtained for each DG scenario and case. This was achieved using the AddDG.m

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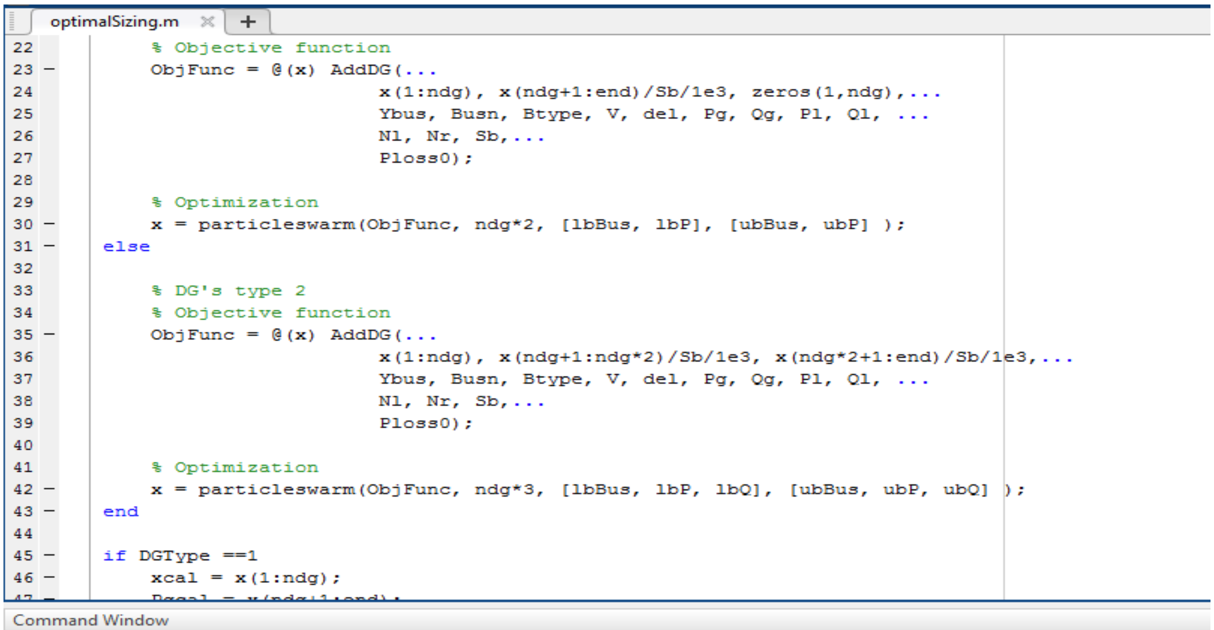
code. A section of the code is presented in figure 8.



```
optimalSizing.m
        % Objective function
        ObjFunc = @(x) AddDG(...
                            x(1:ndg), x(ndg+1:end)/Sb/1e3, zeros(1,ndg),...
                            Ybus, Busn, Btype, V, del, Pg, Qg, Pl, Ql, ...
                            Nl, Nr, Sb,...
                            Ploss0);

        % Optimization
        x = particleswarm(ObjFunc, ndg*2, [lbBus, lbP], [ubBus, ubP] );
    else

        % DG's type 2
        % Objective function
        ObjFunc = @(x) AddDG(...
                            x(1:ndg), x(ndg+1:ndg*2)/Sb/1e3, x(ndg*2+1:end)/Sb/1e3,...
                            Ybus, Busn, Btype, V, del, Pg, Qg, Pl, Ql, ...
                            Nl, Nr, Sb,...
                            Ploss0);

        % Optimization
        x = particleswarm(ObjFunc, ndg*3, [lbBus, lbP, lbQ], [ubBus, ubP, ubQ] );
    end

    if DGType ==1
        xcal = x(1:ndg);
Command Window
```

Figure 8: AddDG.m code

Table 1: Summary of Total Network Real Power Loss given by various cases of the two Scenarios

Scenario/Case	DG Number	Optimum DG Locations	Optimum	Real Power Loss MW
Scenario A (Type-One DG)	1	9		1.23
	2	7, 10		0.719
	2	5, 7, 11		0.549
Scenario A (Type-Two DG)	1	9		0.87
	2	7, 10		0.319
	3	5, 9, 11		0.154
Base Case	0			9.209

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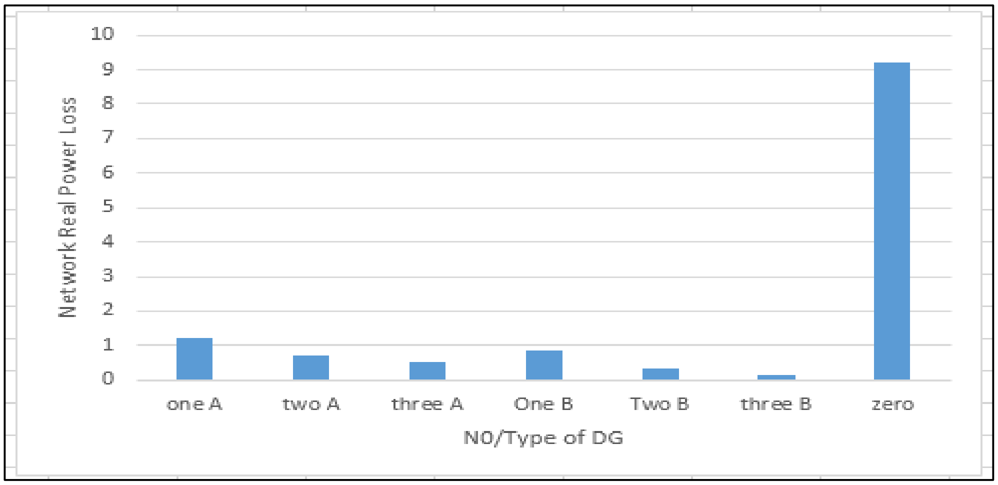

Figure 9: Load flow result performed on the test network after Type-two triple DG optimization.

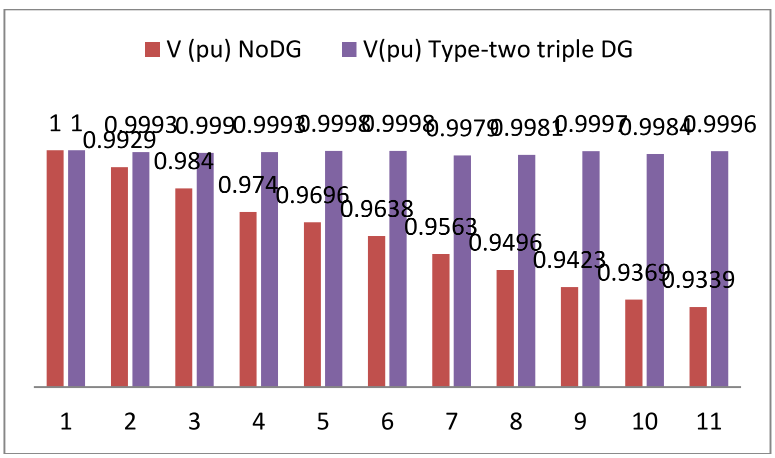

Figure 10: Voltage profile of buses without DG and with DG Type 1

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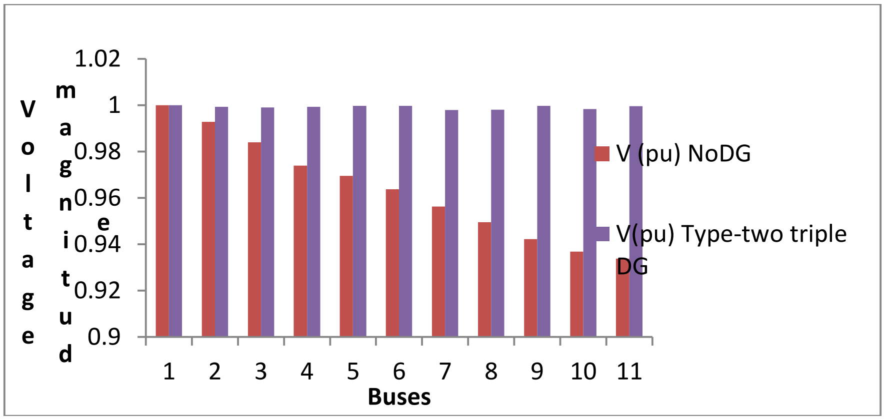

Figure 11: Voltage profile without DG and with Type-Two triple DG

4.1 Analysis of Scenario B (Type-two sizing and location)

From figure 9 and table 1, it can be seen that the type-two DG, case of 3 DG with a total network real power loss of 0.154pu becomes the optimum loss reduction obtained out of the six cases. The number of DGs was three, the locations are buses 5, 9, and 11 while the corresponding optimum DG sizes are: 0.495+ j0.264, 759 + j0.172 MW, and 0.641 + j0.264 MW. The optimum loss obtained represents a 9.055pureduction in loss relative to the network with no DG connected. It is not surprising that the type-two DGs performed better than the type-one DGs. This is because, by supplying both active and reactive power at the load points, the network is offered efficient active and reactive power support. The type-one DGs supply only active power at load points. Its compensation capacity is therefore limited as it offers no reactive power support.

5.0 CONCLUSION

In this research, Implementation of the PSO-based Optimal DG Sizing and Location using Matlab has been presented. The aim of this was to obtain the optimal size(s) of DG unit(s) and their corresponding optimal locations (bus of installation) that will give minimum total network power loss during load flow. Obtaining the optimum sizes of DG units requires tedious computations while searching for the optimum DG locations is also an onerous task. The idea of employing an intelligent search and computational algorithm like PSO was to make these difficult searches and computations easier. The research was able to implement PSO to obtain the optimum size(s) and optimum location(s) of the DGs.

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