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Development of Improved Particle Swarm Optimization Algorithm Based on Success Rate for Optimal Placement of DG on Distribution Network

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ABSTRACT

The increase in load demand of distribution networks, made the role of distribution systems (DSs) difficult for the power utilities. However, thoughtful planning for supplementary power reimbursement are necessary on DSs for power loss and voltage deviation minimization which is done by optimization techniques. An Improved Particle Swarm Optimization algorithm Based on Success Rate (IPSO-SR) was introduced for the optimal allocation of Distributed Generation (DG) due its robust convergence. The work is implemented on IEEE 33 Bus system. Newton Raphson Power Flow (NRPF) is used in MATLAB R2018a environment. The average voltage achieved from the simulation results at base case is 0.9488pu. . However, when two DGs were located optimally using PSO algorithm, the average voltage achieved was 0.9669pu, in the case of IPSO-SR algorithm is found to be 0.9792pu, which shows enhancement of 3.20%. Whereas when three DGs was applied the result obtained is 3.52% as related to PSO where the average voltage achieved was 0.9669pu. The average voltage was upgraded to 0.9822pu using IPSO-SR. The total real power loss gained from the simulation result of 2-DG is 202.7071MW for base case, but reduced to 123.4201MW using PSO and found to be 122.496MW using IPSO-SR which is equivalent to 39.79%. While for 3 DGs, decreased to 119.2670MW using PSO, but with IPSO-SR was 113.9630MW which demonstrated reduction of 43.77%. The results established a minimized system loss while enhancing voltage profile.

1.0 INTRODUCTION

Deregulated Energy Market (DEM) offers a powerful backing to the distribution companies (DISCOs) to withstand a resourceful, consistent, and secure electric services. However, endless increment in load demand has made the operation of distribution system (DS) a hard and complex task for the power utilities for the power utilities which leads to voltage instability, speedy increase in power loss and poor power factor. However, cautious planning for additional active and reactive power reimbursement are obviously required on DSs, which can be done via optimization techniques. Nevertheless, in reforming and reorganization of the electricity market, intensifying the capacity of generating stations, transmission lines and distribution systems, there are clear limitations like scarcity of conservative resources, improved transmission, circulation costs, and environment factor [1]. Hence, any method that can advance the state of affairs of the distribution system should be precisely and carefully considered. The introduction of renewable Distributed Generation (DG) technology or Flexible AC Transmission System (FACTS) devices like Distribution Static Synchronous Compensator (DSTATCOM) in RDS is a smart substitute for the planning engineers of DISCOs to improve the distribution system performance [2]. Distributed Generations can intensify system voltage magnitude, decrease power system losses, and lessen environmental pollution as a result of generation emission [3]. [4], presented a research article titled "Cost–Benefit Analysis for Optimal DG Placement in Distribution Systems by using Elephant Herding Optimization algorithm. The results have been obtained for real and reactive power losses, voltage profile, cost component for real power and reactive power obtained from DGs, and their sizes. Similarly [5], worked on Optimal Sizing and Siting of Distributed Generation for Power Quality Improvement of Distribution Network in Niger State, Nigeria. Considering objective function that computes at hand percentage losses in 11kV feeder, Abuja Electricity Distribution Company (AEDC), Suleja Distribution Network, Nigeria. Buses with poor voltage profile were reported at base case and later incorporated optimal sizing and siting of DGs. But as a result of DGs installation, it is observed that 8.10% and 7.20% active and reactive power loss diminution was achieved while bus voltage enhanced by 0.4% and [6] present a work on the ''effect of distributed generator injection with different numbers of units on power quality in the electric power system'' where the (DG) is usually located on buses that are linked directly to the load to decrease voltage drop and power losses in the network. The results of power losses after adding distributed generation were the best in the fifth experiment on bus 149, where the network experienced a total loss of active power (P) previously of 720,822 kW, to 682,939 kW and total loss of reactive power (Q) formerly of 530.02 kVar, to 405.835 kVar. From the results of the calculation of the power flow using ETAP software (Electrical Transient Analyzer Program).. Nevertheless, manual based intuition placement approach of DG device, which pilot to optimal minimal solution instead of global optimal.

Several research works have been carried out on DG allocation issue on Radial Distributed System (RDS), incorrect allocation can collapse the entire system operation. Hence, optimal placement of the device has significant impacts on the potential benefits of the system [7]. DG shares technical performance regarding voltage profile improvement and power loss reduction in the perspective of DEM [8].

This research work presents an Improved Particle Swarm Optimization Based on Success Rate (IPSO-SR) as metaheuristic optimization approach for optimal sizing and siting of DG for power loss reduction and Voltage Profile (VP) improvement. The work was applied on IEEE 33 Bus test system. Newton Raphson Power Flow technique was used in MATLAB R2018a environment for the load flow analysis**.** The results display the optimal effects of DG in provisions of technical impacts that reduced the system losses while improving voltage profile of the bus voltages resulting from optimal siting and sizing of the DG.

1.1 Distribution network

Distribution system is vigorous to offer reliable and prominent quality power to consumer loads which are irregular and intermittently unbalanced. Radial distribution network mainly experiences high R/X ratio which results in huge power losses, high voltage aberrations and poor voltage stability. Including DGs in distribution networks can improve these tribulations to a huge extent [9].

1.2 Load flow analysis

Load flow study is the study of several numerical methods for resolving power system steady-state non-linear equations formulation. It is very significant in planning, economic operation, load preparation and exchange of power between utilities. The attainable in any load flow study are as follows;

i. Real and Reactive power injected at each bus
ii. Line flows and the losses across any branch

iii. Voltage magnitude and voltage phase angle at each bus. [10].

At each bus of the system, two of the above-mentioned quantities will be specified and the outstanding two will be unknown.

1.2.1 Problem formulation of load flow analysis

Considering i_{th} bus of a power system, the lines are represented by their equivalent pi models with charging admittance at bus *i*.

The net injected current I_i, real power P_i and reactive power Q_i into bus *i* can be written as [10].

The net injected current I_i is calculated as

$$I_i = Y_{ii}V_i + \sum_{k=1}^{n} Y_{ik} V_k \quad (1)$$

$$k \neq i$$

Where

I_i represent net injected current, Y_{ii} is the admittance matrix, V_i is the sending end bus voltage, Y_{ik} is the line admittance matrix, V_k is the receiving end bus voltage real power P_i and reactive power Q_i into bus *i*

But

$$P_i = JQ_i = V_i * I_i \quad (2)$$

P_i represent real power and reactive power stand for Q_i into bus *i*.

Therefore,

$$I_i = \frac{P_i - JQ_i}{V_{i^*}} \quad (3)$$

Substituting equation 1 into 3 yields

$$V_i = \frac{1}{Yii}\left[\frac{P_i - jQ_i}{V^*_i} - \sum_{k=1}^{n} Y_{ik}V_k\right] \quad (4)$$

$$k \neq i$$

Now, the real P_i and reactive Q_i power injected at bus *i* is given by

$$P_i - jQ_i = V_i^*[Y_{ii}V_i + \sum_{k=1}^{n} Y_{ik}V_k] \quad (5)$$

$$k \neq i$$

Converting equation (5) to rectangular form and separating real and imaginary terms gives [10].

Real injected power as follows

$$P_i = \sum_{k=1}^{n} |V_i|\,|V_k||y_{ik}|\cos(\theta_{ik} - \delta_i + \delta_k) \quad (6)$$

Whereas,

θ_{ik} depicts phase angle between sending and receiving end bus, δ_i is the phase angle of sending bus and δ_k is the phase angle of receiving bus

Reactive injected power as

$$Q_i = \sum_{k=1}^{n} |V_i|\,|V_k||y_{ik}|\sin(\theta_{ik} - \delta_i + \delta_k) \quad (7)$$

The line flows from bus *i* to *k* and vice-versa can be computed as [11].

$$P_{ik} - JQ_{ik} = |V_i|^2 Y_{ik} - V_t^* V_k y_{ik} + |V_i|^2 Y_{ik} \quad (8)$$

Converting equation (8) to rectangular form and separating real and imaginary terms gives:

The Real power line flow as:

$$P_{ik} = -|V_i|^2|Y_{ik}|\cos\theta_{ik} + |V_i|\,|V_k||Y_{ik}|\cos(\theta_{ik} - \delta_i + \delta_k) \quad (9)$$

Reactive power line flow as:

$$Q_{ik} = |V_i|^2|Y_{ik}|\sin\theta_{ik} - |V_i|\,|V_k||Y_{ik}|\sin(\theta_{ik} - \delta_i + \delta_k) \quad (10)$$

Presently, the summation of line flows from bus *i* to *k* and vice versa will determine the real and reactive line losses as follows [10].

Real line losses

$$PLoss_{ik} = P_{ik} + P_{ki} \quad (11)$$

Whereas, P_{ik} is real power from sending end bus to receiving end bus while P_{ki} is the real power from receiving end bus to sending end bus

Reactive line losses

$$QLoss_{ik} = Q_{ik} + Q_{ki} \quad (12)$$

Q_{ik} is the reactive power from sending end bus to receiving end bus and Q_{ki} is the reactive power from receiving end bus to sending end bus.

1.3 Overview of distributed generation (DG)

DG is the power generation at the distribution system with renewable or near to the ground carbon emission source. There are numerous factors of trepidation which leads to endlessly growing demands of DGs [8]. DGs are mainly located next to the load to lower the distribution losses and to enhance the bus voltages. The DG location problem is a difficult combinatorial problem having nonlinear objective(s) and constrictions. In literature, few methods based on analytical such as - mixed integer nonlinear programming (MINLP), numerical and heuristic methods have been used to assimilate DG optimally in distribution systems.

1.3.1 Classifications of DG

DGs are classified mainly on the root of fuel used, renewable energy and otherwise, competence of generation, energy production etc.

The DG Types based on real and reactive power liberation capability, these types of DGs are categorized into four main types.

TYPE 1: DGs capable of supplying only active power.
TYPE 2: DGs skillful of generating real and reactive power mutually.
TYPE 3: DGs talented to generate only reactive power.
TYPE 4: DGs competence of supplying active power but consuming reactive power [8].

2. OUTLINE OF IPSO-SR

In this technique, the conventional cognitive speeding up coefficient in the PSO algorithm is divided into two different parts, c1band c1w where c1b refers to the cognitive coefficient, which speeds up the particle on the way to the finest position, however c1wrefers to the cognitive constituent that speeds up the particle away from the worst position. To determine the updated value of the velocity, the particle cogitates both its earlier best and worst positions. The addition of the worst particle in the algorithm takes care of better exploration of the search space

$$V_{id}^{t+1} = w * V_{id}^{t} + C_{ib} * r\ and\ (pbest_{id}^{t} - S_{id}^{t}) + C_{iw} * r\ and\ (S_{id}^{t} - pworst_{id}^{t}) + C_2 * r\ and\ (gbest_{id}^{t} - S_{id}^{t}) \quad (15)$$

$$S_{id}^{t+1} = S_{id}^{t} + V_{id}^{t+1} \quad (16)$$

To assure a proper inertia weight, a novel adaptive inertia weight idea was planned based on the rate of success of the particle in attaining the best solution. In this method, the rate of success is introduced to decide the location of the swarm in each iteration. A high success rate (SR) indicates that the particles require a large value of the inertia weight to accelerate them toward the desired optimum point. A low value shows that the particles are oscillating around the optimum point and need a small value of inertia weight in order to converge to an optimum solution. The number of successes of particle i (NS (i)) at the current iteration t and SR of the particles in an intensification problem can be evaluated in equations (17) and (18). [11]

$$\mathrm{NS(i)} = \begin{cases} 1 \\ 0 \end{cases} \text{otherwise if } \mathrm{OF}_{i}^{t} > \mathrm{OF}_{\mathrm{pb\ esti}}^{t+1} \quad (17)$$

$$SR = \frac{1}{p}\sum_{i=1}^{p} NS(i) \quad (18)$$

3. STRUCTURE OF 33-BUS IEEE TEST SYSTEM

IEEE 33-Bus test system in figure 2, comprises of 33 buses and 32 lines and has a voltage of 12.66kV, load size of 3.715MW and 2.3MV [5].

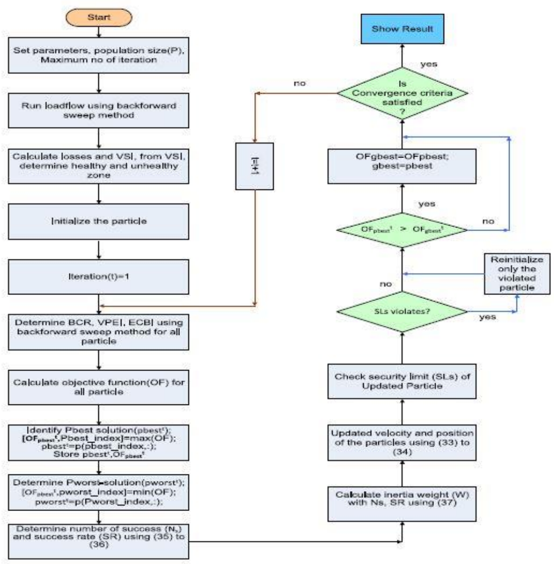

Figure 1. Flow Chart of IPSO-SR

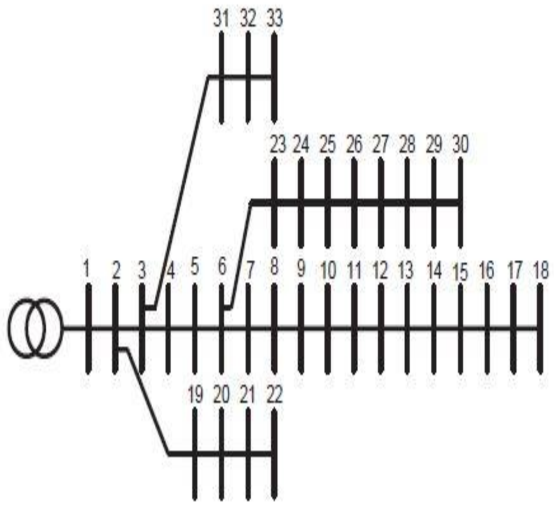

Figure 2. Line Diagram of 33-Bus IEEE Test System.

4. PROBLEM FORMULATION OF THE WORK

The objective function of this research is to reduce the power losses and increase the voltage profiles of the distribution system

Minimize $f = \sum_{i=1}^{Nbr} I_i^2 R + \sum_{k=1}^{Nb} (V_k - V_k^{sp})^2$ (19)

Subject to:

$V_k \leq V_{kmax}$ (20)

$0 \leq P_{DG} \leq P_{DG}^{max}$ (21)

$0 \leq Q_{DG} \leq Q_{DG}^{max}$ (22)

$I_i \leq I_i^{max}$ (23)

Where, I_i^{max} and I_i are the current in i[th] branch, I_i^2 thermal limit of i[th] branch and R resistance of i[th] branch of the system respectively. V_k is the voltage at k[th] bus and V_k^{sp} is the specified voltage of k[th] bus. P_{DG} and Q_{DGS} are the active power and reactive power injection, P_{DG}^{max} and Q_{DG}^{max} are the maximum permissible active and reactive DG power injections, separately. V_{kmax} is the upper voltage limits of k[th] bus. Nbr and Nb are the number of branches and buses of the system, correspondingly.

5. RESULTS AND DISCUSSION

The reduction of power losses for various simulation cases was conducted on IEEE 33-bus distribution network. The first case analyzed the initial total power losses and voltage profile at base case. The second case optimized the power losses and voltage profile as well through DGs connection. IPSO-SR algorithm and the power flow analysis were demonstrated and simulated in MATLAB software R2018b.

5.1 IEEE 33-bus network with 2-DG using PSO

Power flow analysis was attained using Newton Raphson method to achieve the parameters used in determining the Performance of the network. Figure 3 illustrate the results for first situation with 2-DG using PSO. The power flow results at base case illustrated that the voltage magnitudes of buses 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 26, 27, 28, 29, 30, 31, 32 and 33 are outside the steady state acceptable limits (0. 95 – 1.05 p.u), as such the system is in threshold of instability which may breakdown. This problem of instability can be talked through effective voltage control and hence via reconfiguration of the system, by optimal sizing and sitting of distributed generator. Two DGs with optimal size 1.0e[06] +j1.7062 and 1.0e[06] +j1.5214 were positioned at buses 23 and 25. Resulting from the allocation of the device, the total system voltage is enhanced except buses 11, 25, 31and 32 are still not within the limit. The average voltage acquired from the simulation results at base case is 0.9488pu. However, when two DGs were located optimally using PSO algorithm, the average voltage achieved was 0.9669pu.

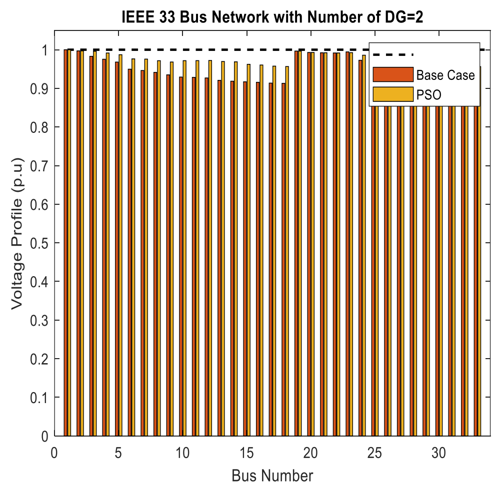

Figure 3: IEEE 33-bus network with 2-DG using PSO

5.2 IEEE 33-bus network with 2-DG using IPSO-SR

Figure 4 displays the results for first scenario with 2-DG using IPSO-SR. Two DGs with optimal size $1.0e^{06}$ +j 1.7389 and $1.0e^{06}$ +j1.7628 each were situated at buses 11and 15. Following the device allocation, the average voltage was enhanced from 0.9669pu to 0.9792pu using IPSO-SR. The entire buses voltage profile are within the stable acceptable limit, therefore the system is considered to be stable.

5. 3 Comparison of voltage profile for IEEE 33-bus network with 2-DG

The comparison of voltage profile simulation results with 2-DG for both base case and optimal case when PSO and IPSO-SR were applied are presented in Figure 5. For the base case the average voltage was found to be 0.9488pu but finally increased to 0.9669pu due to DGs application using PSO optimization method. Yet, the system is still in verge of voltage instability until IPSO-SR was introduced as a result of optimal placement of the DGs when the system become stable, with an average voltage of 0.9792pu.

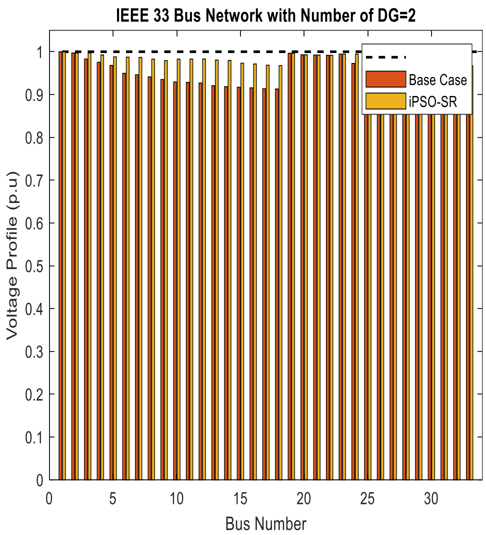

Figure 4: IEEE 33-bus network with 2-DG using IPSO-SR

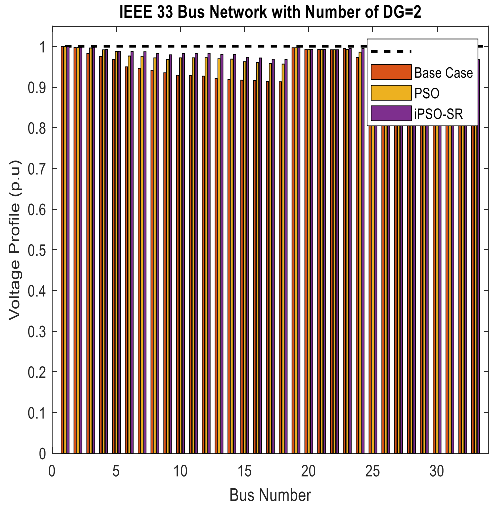

Figure 5: Comparison of Voltage Profile for IEEE 33-bus network with 2 -DG

5.4 Comparison of real power loss on IEEE 33-bus network with 2-DG

Figure 6 shows the complete system real power loss acquired from the simulation result to be 202.7071MW at base case. The real power loss is found to be 123.4201MW following DG application using PSO which shows a reduction of 79.87MW that is 39.11% when equated to base case result. Resulting from the application 2 DGs using IPSO-SR, the real power loss becomes 122.496MW which displays a reduction of 80.6575MW which is equivalent to 39.79% when compared to base case. These demonstrated that IPSO-SR technique performed better than PSO.

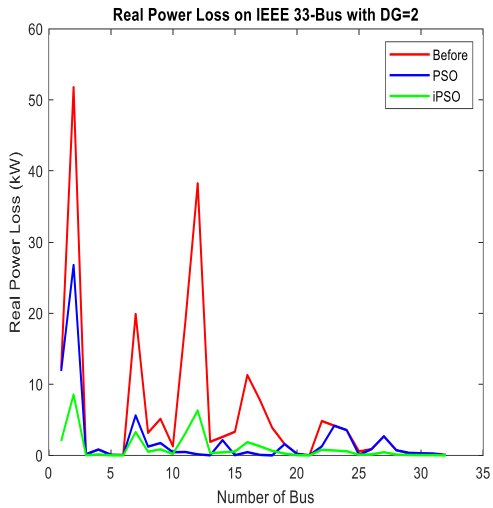

Figure 6 Comparison of Real Power Loss on IEEE 33-bus Network With 2-DG

5.5 Convergence characteristics of PSO and IPSO-SR on IEEE 33-bus network with 2-DG

Figure 7 present the convergence curves for PSO and IPSO-SR on IEEE 33-bus network with 2-DG, when PSO was introduced it converges after 9 iterations. Also, when IPSO-SR was placed optimally, the convergence occurred after 4 iterations.

5.6 IEEE 33-bus network with 3-DG using PSO

The second scenario is application of 3-DG using PSO as shown in Figure 8. Three DGs with optimal sizes $1.0e^{06}$+j 1.7613, $1.0e^{06}$ +j2.1260 and $1.0e^{06}$ +j 2.2001, were positioned at buses 11, 17 and 28. Subsequent from the allocation of the device, the total system voltage is improved from 0.9488pu to 0.9669pu except buses10, 11 and 32 are still not within the limit. This illustrated that the system is unstable and if not properly talked through voltage control it may lead to breakdown of the system.

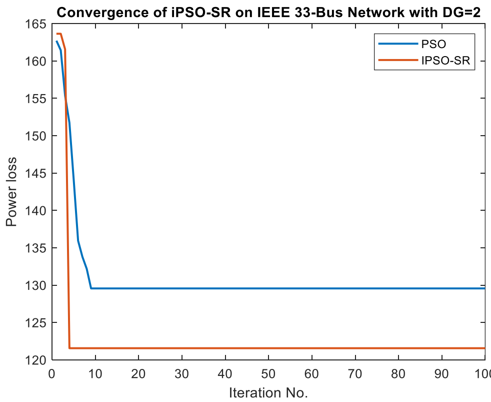

Figure 7: Convergence Characteristics of PSO and IPSO-SR on IEEE 33-bus Network With 2-DG

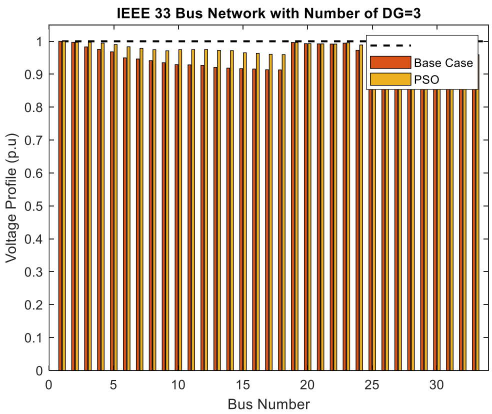

Figure 8: IEEE 33-bus network with 3-DG using PSO

5.7 IEEE 33-bus network with 3-DG using IPSO-SR

Figure 9 also revealed the results for second scenario with 3-DG using IPSO -SR. Three DGs with optimal sizes $1.0e^{06}$ +j2.2760, $1.0e^{06}$ +j 2.6499 and $1.0e^{06}$ +j2.7526 were positioned optimally at buses 23, 27 and 32. The average voltage was upgraded from 0.9488pu to 0.9822pu when IPSO-SR was used optimally. Observing the result, all the buses are within the acceptable limit, which shows the effectiveness of IPSO-SR over PSO algorithm in system voltage control.

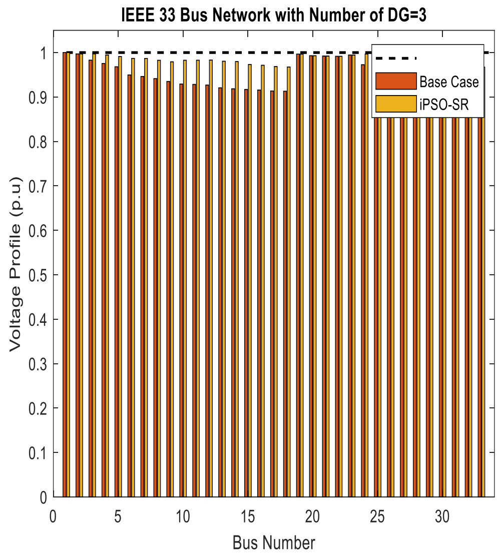

Figure 9: IEEE 33-bus network with 3-DG using IPSO-SR

5.8 Comparison of voltage profile for IEEE 33-bus network with 3-DG

The comparison of simulation results acquired with 3-DG for base case, PSO and IPSO-SR are shown in Figure 10. In the case of base case the average voltage was found to be 0.9488pu but improved to 0.9669pu and lastly to 0.9792pu due to DGs application using IPSO-SR optimization method. Consequently, the system is found to be stable.

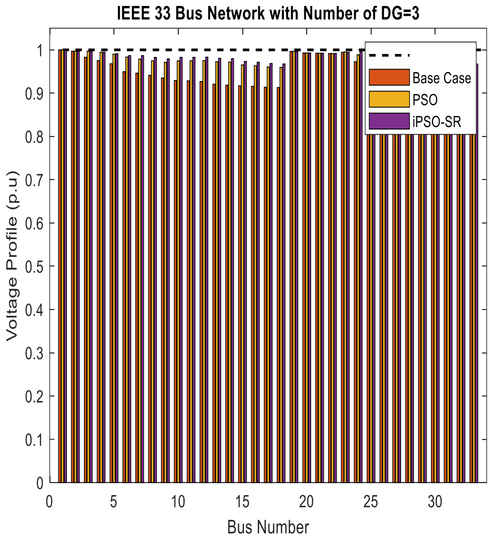

Figure 10 Comparison of Voltage Profile for IEEE 33-bus Network With 3-DG

5.9 Comparison of real power loss on IEEE 33-bus network with 3-DG

The whole system real power loss attained from the simulation result is found to be 202.7071MW at base case, as shown in figure 11. The real power loss is found to be 119.2670MW due to the outcome of DG application using PSO which shows a decrease of 83.4401MW that is 41.16% as compared to base case result. Also when 3 DGs using IPSO-SR was applied, the real power loss is found to be 113.9630MW which shows a reduction of 88.441MW which is equivalent to 43.77% as related to base case. These indicate that IPSO-SR technique performed better than PSO in the optimal sitting and sizing of the device.

5.10 Convergence characteristics of PSO and IPSO-SR on IEEE 33-bus network with 3-DG

The convergence curves for PSO and IPSO-SR on IEEE 33-bus network with 3-DG are presented in figure 12, when PSO was applied the convergence occur after 6 iterations. Similarly, when IPSO-SR was applied in the optimal placement of the devices, the convergence is attained after 5 iterations.

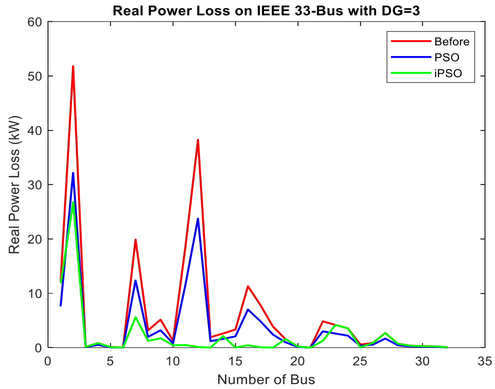

Figure 11: Comparison of Real Power Loss on IEEE 33-bus Network With 3-DG

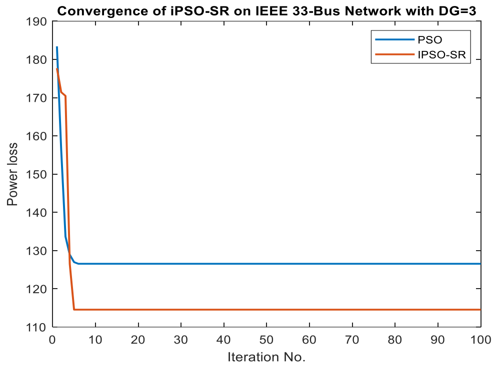

Figure 12 Convergence of PSO and IPSO-SR on IEEE 33-bus Network With 3-DG

Table 1: Summary of Simulation Results

Parameter	**Base case**	**2DG**		**3DG**	
		PSO	**IPSO-SR**	**PSO**	**IPSO-SR**
Average voltage (p.u)	0.9488	0.9669	0.9792	0.9699	0.9822
Real power loss (KW)	202.7071	123.420	122.0496	119.2670	113.9630
Convergence rate (No.)	-	9	4	6	5

6. CONCLUSION

An Improved Particle Swarm Optimization Based on Success Rate (IPSO-SR) was employed to determine the optimal allocation of Distributed Generation (DG). The work is implemented on standard IEEE 33 Bus test systems. Newton Raphson Power Flow (NRPF) method was used in MATLAB R2018b environment for the power flow analysis. On successful completion of the work, the results reduced the system losses while increasing voltage profile of the bus voltages significantly as a result of optimal siting and sizing of the DG. These show that IPSO-SR technique outperformed PSO.

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