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Hybrid Optimization for Optimal Distributed Generation Unit Placement in Radial Distribution System

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***Abstract**: In recent years, the demand for electric power is growing at a faster rate. This makes present time power system into a more composite one in structure and in terms of placing utility elements, operation, maintenance and control of power system to deliver the electric power to customers. To satisfy the demand for electricity is necessitate more generating units nearer to customer points and need of proper operational planning. The power loss is a major concern towards distribution system performance. Hence, minimization of losses in the system is a major consideration. The distributed generation plays significant role in satisfying the need for electricity demand and also helps in minimization of system losses by adopting intelligent algorithm technique. Among all its advantages, power losses, voltage enhancement and cost benefits are the prime areas of study in distributed generation units. So, placing and allocation of distributed generation acquire more attention towards distribution system. In this paper, an intelligent hybrid optimization technique is proposed for optimal distributed generating unit for minimizing the losses in radial distribution system. The proposed optimization technique is implemented for IEEE 33-bus system radial distribution system. The obtained simulated results provide the good applicability and enhancement in execution of the proposed hybrid method.*

***Keywords** : Binary Particle Swarm Algorithm, Cuckoo Search Algorithm, Distributed Generation, Power Loss Reduction, Voltage Stability Index.*

I. INTRODUCTION

The distributed generation is emerging as very significant and easy solution for power demand.

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It provides generated power which is placing very close to the consumers and comprises the installation and operation of compact, smaller in size and clean generating units very close to load points. The word Dispersed Generation refers to typically smaller scale of range 1kW-50kW power generation. And, these are connected to satisfy the consumer load demand in electric power distribution system.

The proposed optimization technique is made to place DG unit suitably in reducing system power losses and to enhancing voltage magnitude. In this proposed work, DG placement is found by voltage sensitivity factor by meta-heuristic technique. From this, the priority is made for all busses and is arranged in descending form. The most sensitive locations are identified and chosen for locating DG in system. The results obtained from proposed optimization have enhanced the convergence rate and execution time.

Zhu, et.al [1] considers two aspects for optimal insertion of DG for time varying loads i.e., to achieve higher reliability and to minimize losses. Willis [2] elucidated analytical methods and thumb rules method in evaluating the ODGP. The two methods “zero point analysis” and “2/3 rule are used. This method is employed for loss reduction, voltage effects and for uniform load services. Parizad et.al [3] described two outline of ODGP. The first outcome gives the reduction of system losses. Secondly, stability index is taken for optimal placement. Two line stability index is used to improve power transfer capability. It uses branch-current to bus-voltage (BCBV) and bus-injection to branch-current (BIBC) matrices.

Caisheng Wang, M. Hashem Nehrir [4], describes the analytical approach for DG unit allocation to improve the performance. Rau and Wan [5] have described a technique for optimum allocation of DG in mesh network for enhancing the potential. Thereby, reducing network loss, reactive power requirement and line loadings. Payyala and Green [6] explain the method of merging techno-economic assessment of biomass-fuelled generators. It focuses on optimum size and placement based on technical and economic conditions.

Khattam et.al [7] have analyzed Monte Carlo power flow algorithm which combines the stochastic and deterministic features of DG. The algorithm includes unreliability of both the location and on or off state of DG using Newton raphson method of load flow. Khanabadi, Doostizadeh et.al, [8] proposed optimum sitting and seizing of DG to eliminate clogging of power system using AC optimal power flow (ACOPF) along with binary variables and elucidated by mixed integer programming.

Silvestri, Berizzi et.al, [9] have presented a technique on GA to reduce the cost of energy production, power loss and network reinforcement. And this method is conducted on 43 and 93 bus system and found to be efficient. Karuppasamy Muthulakshmi et.al [10], has presented PSO and line flow sensitivity factor for obtaining optimum location and size of multiple distributed generation units thereby reducing the system power loss and power flow in the system.

W. S. Tan, et.al [11], presents cuckoo search algorithm for optimum allocation and sizing of DG to minimize real power loss, enhance the voltage stability and to enhance voltage profile. M. Afzalan et.al [12], presented HBMO and hybrid PSO algorithm for optimum placement and size of DG in distribution system which minimizes the loss and improve voltage profile. D.B. Prakash et.al [13], describes a PSO algorithm for optimum allocation and sizing of DG and is tested on IEEE 33 and 69 bus systems and efficiency is tested by comparing the results with different cases and it is found that there is minimization of power losses.

Banka Jyothsna Rani et.al [14], proposes binary PSO in the paper for optimal placement and size of DG units. The presented technique is tested on 69 bus test system and showed increase in voltage profile and minimization of system power loss. M. Padmalatha et.al [15], presented PSO for optimal allocation and size of distribution system to reduce the real power loss and improve voltage profile. The described technique is tested on 33 bus bench system and comparison is done with exciting method which showed better results. In [16], explains the impacts and effects of DG placement operational planning on feeder configuration using hybrid intelligent algorithm.

In this paper, section II represents the problem formulation of the optimization technique. Section III describes the voltage sensitivity factor for locating DG in distribution system. Section IV discussed on two algorithms on BPSO and CSA. In Section V, explaining the proposed hybrid optimization technique to overcome the system problem for minimizing the losses. At last Section VI presents the conclusions of work.

II. PROBLEM FORMULATION

The main agenda of the described optimization technique is to obtain the optimum allocation of distributed generation that reduces the system power loss of distribution system by considering various DG constraints and distribution system operational constraints.

A. The Load Flow Equation

The system load flow analysis of a single generation system is resolved by iterative method. There are two recursive equations in solving iteratively. The first equation is for calculating branch power from the end branch and proceeding backward mode towards starting node. The second equation is to calculate the bus voltage and angle of all buses starts from first node to last node.

The active power flows through the line from node *k* to *k+1* can be evaluated from backward method and is expressed as

$$P_{k,k+1} = P'_{k+1} + r_{k,k+1}\left(\frac{(P'_{k+1})^2 + (Q'_{k+1})^2}{V_{k+1}^2}\right) \quad (1)$$

where

$$P'_{k+1} = P'_{k+1,eff} + P_{k+1}$$

P_{k+1} = active power load connected at bus $k+1$.

The current, magnitude of bus voltage and angle are expressed as,

$$I_k = \left(\frac{(V_k * angle(\delta_k) - V_{k+1} * angle(\delta_{k+1})}{(R_k + jX_{k+1})}\right) \quad (2)$$

$$I_k = \left(\frac{(P_k - j * Q_k}{(V_k angle(-\delta_k)}\right) \quad (3)$$

Refer to (2) and (3),

$$V_{k+1} = \Big(V_k^2 - 2\big(P_{k,k+1}R_{k,k+1} + Q_{k,k+1}X_{k,k+1}\big) + (R_{k,k+1}^2 + X_{k,k+1}^2) * \left(\frac{P_{k,k+1}^2 + Q_{k,k+1}^2}{V_k^2}\right) \quad (4)$$

Then the real power loss at branch is calculated as,

$$P_{loss(k,k+1)} = R_{k,k+1} * \left(\frac{P_{k,k+1}^2 + Q_{k,k+1}^2}{V_k^2}\right) \quad (5)$$

Therefore, the total real power loss can be calculated as,

$$P_{TotalLoss} = \sum_{k=1}^{n} P_{loss(k,k+1)} \quad (6)$$

B. Determination of Power Loss with DG

The power loss is reduced by placing DG unit optimally in distribution system improves the voltage and reduce system cost. This achieves in improving security of power delivery and reliability. The system losses with DG can be calculated as,

$$P_{DG,loss(k,k+1)} = R_{k,k+1} * \left(\frac{P_{DG,i,k+1}^2 + Q_{DG,k,k+1}^2}{|V_k|^2}\right) \quad (7)$$

The total active power loss in the system with DG penetration is expressed as,

$$P_{DG,TotalLoss(k,k+1)} = \sum_{k=1}^{n} P_{DG,loss(k,k+1)} \quad (8)$$

C. Real Power Loss Reduction

The losses are reduces by penetrating DGs in distribution system. The power loss index ($\Delta PLoss_{DG}$) is the ratio of total real power loss with DG to the total real power loss without DG and is expressed as,

$$\Delta PLoss_{DG} = \frac{P_{DG,TotalLoss}}{P_{TotalLoss}} \quad (9)$$

From equation (9), power loss reduction is made by reducing the power loss index, $\Delta PLoss_{DG.}$

III. OBJECTIVE FUNCTION

The prime work of the proposed method is to minimize system power losses and to improve the voltage magnitude at all buses.

$$F_{\min imize} = \min(\beta_1 \Delta PLoss_{DG}) \quad (10)$$

where

$$\sum_{l}^{2} \beta_l = 1, \beta_l \in [0,1] \quad (11)$$

IV. SYSTEM OPERATIONAL CONSTRAINTS

The system is subjected to many operational constraints when DG unit are allocating in the system and are discussed as follows.

A. Bus Voltage Limits

The real power flows through the lines have an impact on system voltage level due to the distribution system resistive parameters of the lines are more than other lines. This leads the reactance to resistance ratio to one unit than that of transmission lines.

So, the bus voltage level must kept within the limits as

$$V_k^{\min} < V_k < V_k^{\max} \quad (12)$$

B. Load Balance Constraint

The system should always be in balanced condition. So, the load balance constraint to be considered as one of the important aspect and is expressed as;

$$P_{gk} - P_{dk} - V_k \sum_{l=1}^{N} V_l Y_l \cos(\delta_l - \delta l - \theta_l) = 0 \quad (13)$$

$$Q_{gk} - Q_{dk} - V_k \sum_{l=1}^{N} V_l Y_l \sin(\delta_l - \delta_l - \theta_l) = 0$$

(14)

where

k=1, 2,………, N

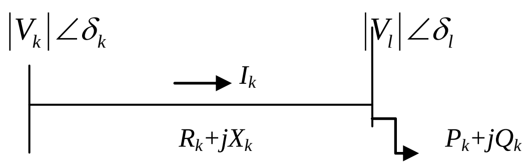

Fig. 1.Representation of a simple radial distribution system

C. Thermal Constraint

The thermal limits on any system lines should be in function within the limits and are expressed as,

$$S_k < S_k^{\max} \quad (15)$$

D. Technical Constraint for DG Capacity

DG has its own capacity and is inherently limited for any given location. So, the DG capacity to be defines and operates between the limits. The DG limits are given by,

$$P_{gk}^{\min} < P_{gk} < P_{gk}^{\max} \quad (16)$$

V. PROPOSED SOLUTION METHODOLOGY

The nature inspired hybrid PSO and CS algorithm for DG placement is discussed in this paper. This reduces the system losses and improves the bus voltage magnitude at all buses.

A. Particle Swarm Optimization

The velocity v_n^d , the position x_n^d of d^{th} dimension of the n^{th} particle is updated by PSO [13] is expressed in following equations:

$$V_n^d = w.V_n^d + c_1.r_1.(p_{best\,n}{}^d - x_n^d) + c_2.r_2.(g_{best\,n}{}^d - x_n^d) \quad (17)$$

$$x_n^{d+1} = x_n^d + v_n^d \quad (18)$$

where, $\boldsymbol{x_i}$ **:** position or place of n^{th} particle in search space

V_n **:** n^{th} particle velocity in a given search space

pbest n **:** best location of n^{th} particle in a given search space

gbest **:** globally best location in a given search space

w **:** inertia weight of the particle

r1, r2 **:** random variables which are independently uniformly ranges varies from zero and one

$\boldsymbol{C_1, C_2}$ **:** the positive coefficients of acceleration

Equation (17) refers new velocity from past velocity of swarms, and varies [-v_{max}, v_{max}]. The inertial weight [13], is expressed in equation (19) and is decreased from w_{max} to minimum value w_{min}.

$$w^k = w_{\max} - \frac{w_{\max} - w_{\min}}{k_{\max}}.k \quad (19)$$

where, K_{max} is last iteration number

B. The CSA for DG Placement

The CSA is nature inspired algorithm and the process of this for distributed generation placement are discussed below:

1. Initialize and define parameters, constraints, bounding conditions and random population host next of cuckoo search.
2. Read system line and load data.
3. Load flow to be run for base case.
4. Note down initial voltage magnitudes of all buses and system losses.
5. DG is located using voltage profile with lowest value and fix up the size the DG.
6. Initialize and define parameters, constraints, bounding conditions and random population host next of cuckoo search.

7. By levy flight, get a random cuckoo and evaluate the fitness function.
8. If the fitness condition found then replace with new solution.
9. Remove 'pa' for bad nests and new one is built and retained and best solution is passed.
10. Once all the conditions are satisfied and save best solution for DG placement.

C. Hybrid PSO-CSA Optimization Technique

The presented hybrid algorithm steps are mentioned below:

1. Initialize the control parameters of hybrid algorithm (both PSO and CSA).
2. Read out the branch data and bus data.
3. Run power flow for random particle occurs in the system.
4. Evaluate the fitness function like voltage profile at each buses and power loss reduction.
5. Find out the best fitness function value that are given to system, and proceed to next iteration count.
6. By considering proposed algorithm with DG unit, run the load flow and check for best fitness function.
7. If the fitness function will be found then place DG unit randomly to evaluating the power loss.
8. From obtained best fitness function value, DG unit will be place optimally by proposed hybrid algorithm and objective of the test case system will be evaluated.

VI. SIMULAION RESULTS AND DISCUSSION

This hybrid technique employed on 33-bus system having operating 12.66kV with the demand of active power is 3.715MW. The demand 2.295MVAr is reactive power and test is taken for analysis is shown in Fig.2 [17]. The algorithm is developed on MATLAB R2013a.

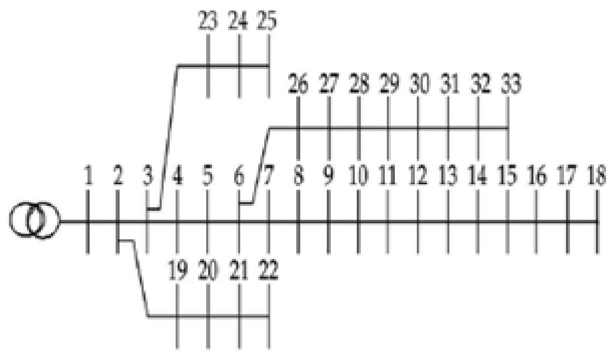

Fig.2. One line diagram of IEEE 33 bus test system

The test case is simulated by considering single and two type-I and type-III DG units with 50%, 75% and 100% penetration level with constant load. The proposed intelligent technique is verified for DG placement. This technique adopts the backward/forward sweep algorithm for power loss in evaluating the voltage magnitude at each buses and power loss in the system. From load flow, least voltage profile bus identified at bus 18 with 0.9036 per unit for DG place.

The complete results discussed in Table I and Table II for type-I and type-II respectively. This paper proposed the new intelligent technique for distribution system proper operational planning scheme to enhance the system performance with DG unit placement.

Table I shows the simulation results of 33-bus system with type-I DG placement with 100% penetration level. The base case power loss 202.418kW is reduced to 111.1928kW power with 91.2252kW of power. The total loss reduction in percentage is about 45.138 and loss reduction index is 0.45138. This result clears that, the new intelligent technique with hybrid meta-heuristic employed and confirms the minimization of power loss, voltage profile and enhances the system stability.

Table- I: Results for type-I DG placement of 33 bus

Particular	*Base Case*	*After Type-1 DG Place*
Total real power loss in kW	202.418	111.1928
Power loss reduction in kW	----	91.2252
Percentage power loss reduction	----	45.138
Minimum Voltage in p.u and bus number	0.9043 Bus 18	0.9206 Bus 18
Power loss reduction index	----	0.45138
Total real power loss index and bus number	----	0.351 Bus 30

per unit as p.u. kilo Watt as kW

Table II shows the simulation results of 33-bus system with type-III DG placement with full penetration level. The base case power loss 202.418kW is reduced to 117.0628kW power with 85.3552kW of power. The total loss reduction in percentage is about 42.242 and loss reduction index is 0.4224. In these results also concluding this technique employed for the minimization of power loss, voltage.

Table- II: Results for type-III DG placement of 33 bus

Particular	*Base Case*	*After Type-3 DG Place*
Power loss in kW	202.418	117.0628
Power loss reduction in %	----	42.2425
Minimum voltage in p.u and bus number	0.9043 Bus 18	0.9248 Bus 18
Power loss reduction index	----	0.422425
Total real power loss index and bus number	----	0.345 Bus 30

per unit as p.u. kilo Watt as kW

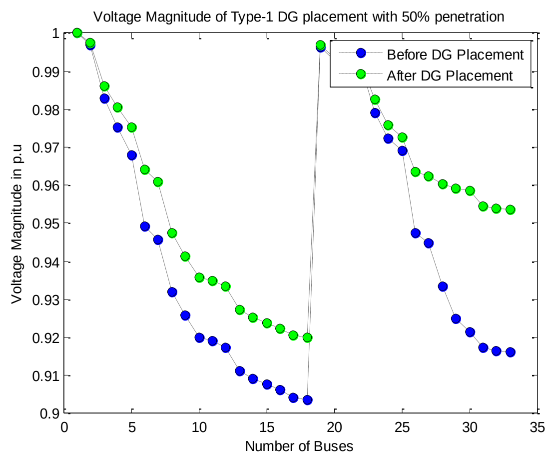

Fig.3. Voltage in p.u of Type-I DG at 50% penetration

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Fig.3. shows voltage magnitude of type-I DG unit with 50% penetration level. And found least voltage magnitude at bus 18.

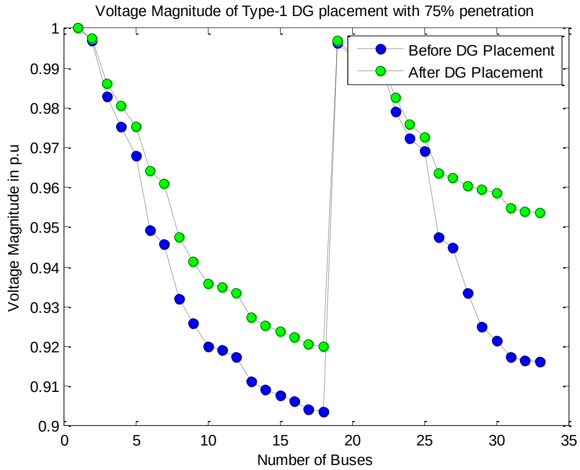

Fig.4. Voltage in p.u of Type-I DG at 75% penetration

Fig.4. shows voltage magnitude in per unit with and without type-I DG unit with 75% penetration level.

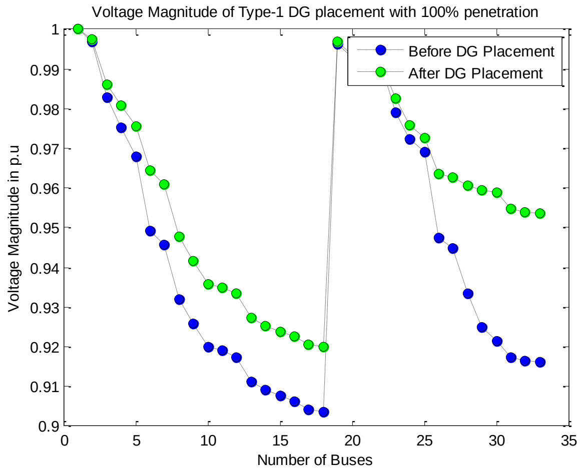

Fig.5. Voltage in p.u of Type-I DG at 100% penetration

Fig.5. shows voltage magnitude in per unit with and without type-I DG unit with 100% penetration level.

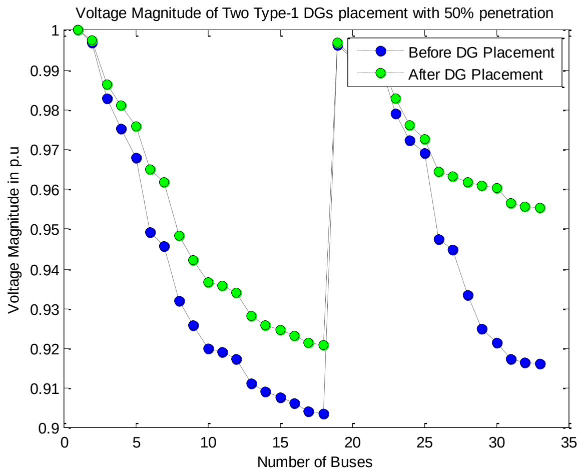

Fig.6. Voltage in p.u of two Type-I DG at 50% penetration

Fig.6. shows voltage magnitude of two type-I DG unit with 50% penetration level.

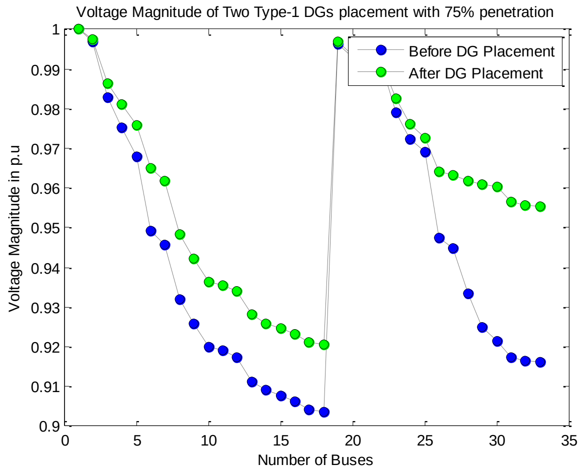

Fig.7. Voltage in p.u of two Type-I DG at 75% penetration

Fig.7. shows voltage magnitude in per unit with and without two type-I DG unit with 75% penetration level.

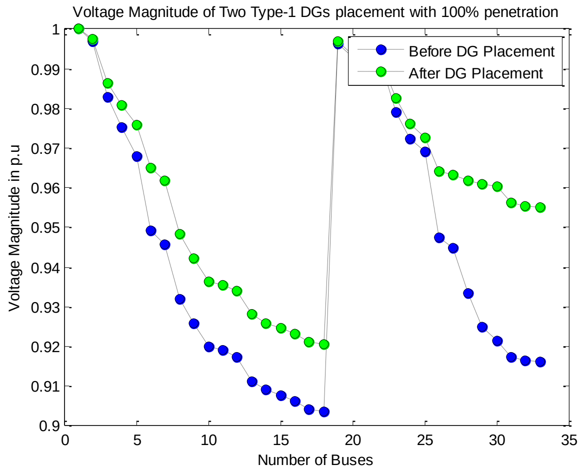

Fig.8. Voltage in p.u of two Type-I DG at 100% penetration

Fig.8. shows voltage magnitude in per unit with and without two type-I DG unit with 100% penetration level.

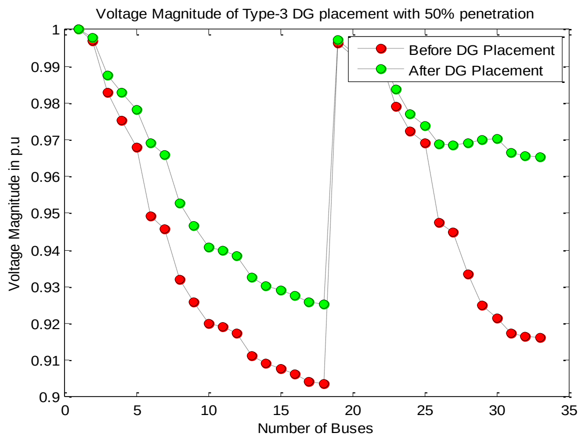

Fig.9. Voltage in p.u of Type-III DG at 50% penetration

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Fig.9. shows the voltage magnitude of type-III DG unit with 50% penetration level. And found least voltage magnitude at bus 18.

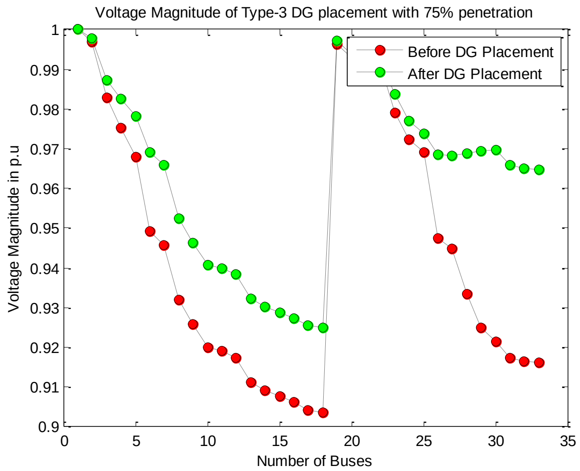

Fig.10. Voltage in p.u of Type-III DG at 75% penetration

Fig.10. shows voltage magnitude in per unit with and without type-III DG unit with 75% penetration level.

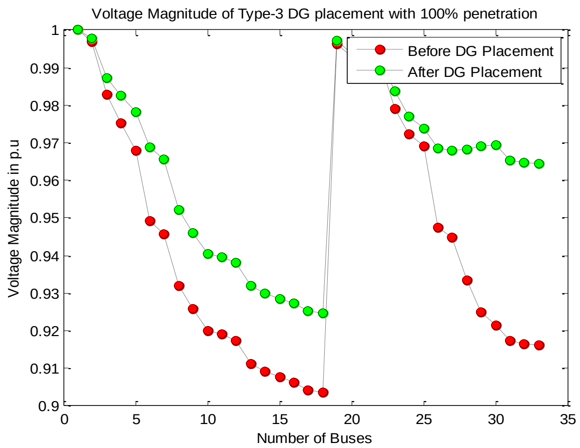

Fig.11. Voltage in p.u of Type-III DG at 100% penetration

Fig.11. shows voltage magnitude in per unit with and without type-III DG unit with 100% penetration level.

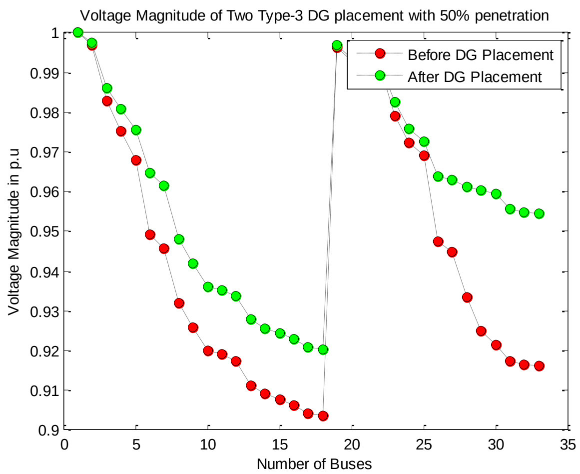

Fig.12. Voltage in p.u of two Type-III DG at 50% penetration

Fig.12. shows voltage magnitude of two type-III DG unit with 50% penetration level.

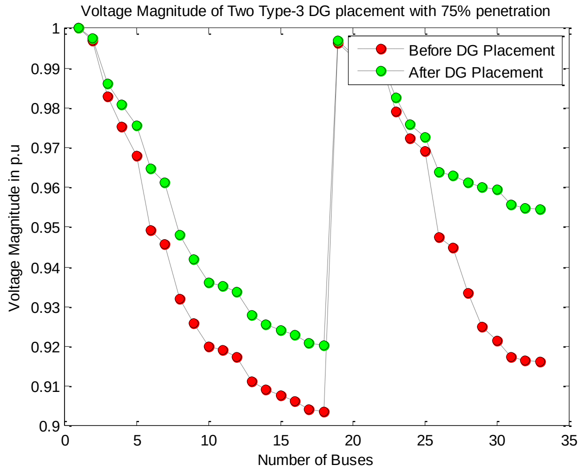

Fig.13. Voltage in p.u of two Type-III DG at 75% penetration

Fig.13. shows voltage magnitude of two type-III DG units with 75% penetration level.

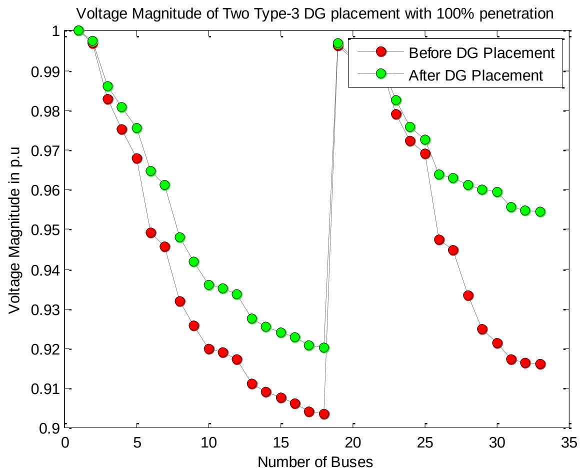

Fig.14. Voltage magnitude in p.u of two Type-III DG at 100% penetration

In Fig.14. shows the voltage magnitude of two type-III DG units with 100% penetration level.

VII. CONCLUSION

The proposed hybrid intelligent meta-heuristic BPSO and CSA technique is tested on standard bench mark IEEE 33-bus system. This work is evaluated with constant loading condition. The optimum placement of type-I and type-III DG units are identified by determining the power loss reduction as objective function with single and two distributed generation consideration also with different penetration levels and found improvement in the voltage magnitude as discussed in section VI.

The results obtained by proposed technique for optimum placement of DG seen improved voltage magnitude at each buses and loss reduction of the system than previous methods.

Hence, the objective function of the proposed work is achieved. So, power loss reduction problem, and improving voltage profile are achieved from the results and it can be concluding that the proposed hybrid algorithm gives better solution for system enhancement in radial distribution system by suitably placing DG planning.

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