

Statistical Assessment of Whale Optimization Algorithm for Sizing and Placement of DG Considering Multi-Objective Function with PSO and CSA Algorithm



J P Sridhar, R Prakash

Abstract: Distributed or decentralized power generation (DGEN) technology is popularized in the 21st century and it emerged has an effective alternative solution to meet the forecasted energy demand for restructured power system by putting restriction on power plants and transmission lines of the of the next decade generation. Modified state policies and increased technological innovation for low-capacity production promotes increased development and investment of DGEN. The use of distributed renewable energy generation has been driven by environmental concerns. DGEN's incorporation into the distribution side of the network offers critical system advantages such as voltage assistance support, reduction in loss, transmission power increase, strengthened system performance, etc. This paper presents the optimized DG placement (ODGP) and sizing solution in distribution side of the network for the multi-objective formulation includes the objective of minimizing the losses, maximization of voltage stability and also includes the cost requirement. The new Meta-heuristic based Approach named as Whale optimization algorithm is used for optimal placement and Sizing of DGEN is considered in this work and the solution of the proposed optimization algorithm is compared with two most popular optimization techniques such as Particle Swarm Optimization (PSOA), Cuckoo Search Algorithm (CSOA). The comparative analysis of these above said optimization techniques is developed and compared for performance comparison can be done with 69 bus IEEE standard radial system to validate the results of the proposed multi objective problem.

Keywords: Distributed Generation (DGEN), Whale optimization algorithm (WHA), Particle swarm optimization (PSOA), Cuckoo Search Algorithm (CSOA).

I. INTRODUCTION

In the 21st century clean Energy and clean water are very important in advanced life and these are basic necessary elements for sustained economic development. Energy is very essential commodities for economic growth, development and livelihood of the people. Energy is considered as one of the major and important financial sector for the development of any country. As concerns about climate change, depletion of fossil fuels, increasing operation and maintenance cost and rising of fossil fuel prices etc.,

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there is a growing interest in energy sector towards the alternate sources of energy. Due to above said limitations in the coming years renewable or non-conventional energy sources are plays a vital role in the power sector. All the developed and developing countries are showing keen interest in generate more power from non-conventional energy sources. Due to liberalization of electricity market and incentives from governments will accelerates the renewable energy growth and it also attracts the independent power producers to start generating power from larger extent. The government of India also set the target of world largest renewable energy expansion program of 175GW of installed capacity by 2022 from the current installed capacity of 75 GW [1] [2]. In the coming five years we have to generate an additional power generation of 100GW from the renewable energy sources especially from solar and wind energy systems. Hence it very important to design, sizing and optimal placement is very important to integrating these renewable energy sources to the existing network. It also important to maintain the constraints like voltage, current, power quality issues etc. within the acceptable limits.

II. DISTRIBUTED GENERATION

Due to various limitations of centralized power stations such as increasing cost, aging infrastructure, higher rate of power losses, environmental issues etc. leads to utility companies and customers to think of alternative energy production technologies to meet the growing demand of electricity. Distributed Generation is a new concept of power generation method here we can produce electricity close to the load centres or directly at the consumption point. According to IEEE standards DGEN can be defined as “generation of electrical power in a smaller scale as compare to conventional power plants and also facilitate interconnection at any suitable place in power system network” [3]. According to T Ackermann DG can be classified under various categories as per the table shown below.

Table-I: Classification of various categories of DG

DG Capacities	Range
Micro	1 to 5 KW
Small	5 KW to 5 MW
Medium	5 MW to 50 MW
Large	50 MW to 300 MW

A. Types of DGEN Technologies

Most of the times Distributed generation is referred as Distributed Energy Resources (DER's). The classification of Distributed Energy Resources are described as shown in fig.1 below. According to their ratings, DG resources can be divided as micro, small scale, medium and large scale DG sources [4]. Several types of DG's are according to their construction and technology point of view. According to this DG can be classified as conventional and non-conventional generator shown in fig. 8 below.

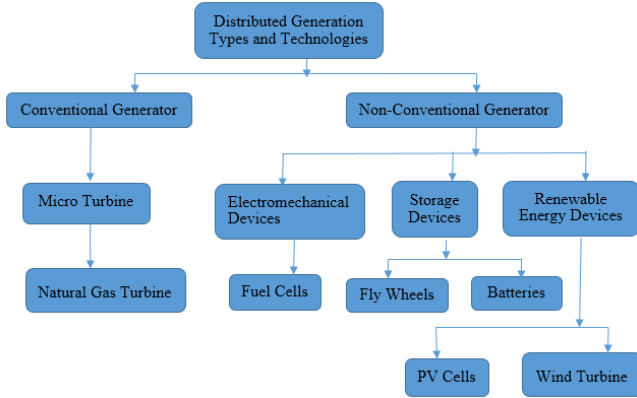


Fig.1: Classification of DGEN sources

III. MULTI OBJECTIVE PROBLEM FORMULATION

The prime objective this proposed work is placement and sizing of DGEN sources with multi objective problem formulation. Because many of the researchers worked already only by considering the single objective function such as to minimize either power loss or else improving the voltage profile for the placement and sizing of DGEN sources.

Multii-objective optimization is also carried out by many researchers in the area of ODGP problem for improving the voltage profile and minimizing losses, but the cost based analysis has not yet been carried out. Therefore, in this paper the cost of the DGEN and the cost of the tariff both are considered along with improving the voltage profile and minimizing losses in the RDS.

A. Mathematical Modelling Solar PV as DGEN

In the proposed optimization problem one of the most popular DGEN sources like solar PV is considered for the sizing and placement problem. The power which the PV module generates depends on the characteristics of solar radiance, module features and ambient temperature. Based on the solar irradiance, the PV array output power can be computed as [5].

$$P^{PV} = N.FF.V_y.I_y \dots\dots\dots (1)$$

$$V_y = V_{oc} - K_v.T_{cy} \dots\dots\dots (2)$$

$$I_y = s[I_{isc} + K_i(T_{cy} - 25)] \dots\dots\dots (3)$$

$$FF = V_{MPPT} \cdot \frac{I_{MPPT}}{V_{oc} \cdot I_{sc}} \dots\dots\dots (4)$$

$$T_{cy} = T_A + s \left(\frac{N_{OT} - 20}{0.8} \right) \dots\dots\dots (5)$$

Where,

FF - fill factor

I_{MPPT} - maximum power point of the current (A)

I_{isc} - short circuit current (A)

K_i - indicator or derivative of current temperature

K_v - indicator or derivative of voltage temperature

N_n - the total number of PV modules

N_{OT} - rated operating temperature of module (in C)

V_{voc} - open circuit voltage (V)

T_{cy} & T_{iA} - PV module te and the ambient temperature (in C) temperature

V_{vMPPT} - highest power point of the voltage (V)

DGEN composed of different types. They are classified according to the type of fuel burnt, renewable power sources, non-renewable power sources, production capacity, electricity production, etc. On the basis of energy supply capacity, DGENs are considered as two main types.

Type1: Asynchronous DGEN of PV (capable of supplying only real power).

Type2: capable of providing both true & apparent power.

B. Problem Formulation

Goal functions are essential to minimize the depletion of true power losses, boost voltage stability indexes and optimize energy loss costs. Therefore, weight method is adopted for the transformation of multi-objective functions to a single target function is implemented in the presented work.

The OF of the proposed work is represented mathematically by using following equations.

$$\min F = W1.F1 + W2.F2 + W3.F3 \dots\dots\dots (6)$$

Here, F1 – Active power loss,

F2 – Voltage stability indices and F3 – Total cost which includes DG cost and power loss cost.

Here, W1, W2 and W3 are weightage factors and it follows as $W1+W2+W3 = 1$

Power Losses: Active power loss in the line depends on the amount of current flowing through the line and the resistance of the line. The total active power loss at all node's origins the mixing current in the substation network and DGENs are computed. The updated goal function is described as follows:

$$F1 = \frac{P_{Loss DG}}{P_{Loss}} \dots\dots\dots (7)$$

P_{loss} – Loss of active power in MW in absence DGEN.

$P_{loss DG}$ - Active power loss in MW in presence of DGEN placed

Voltage stability Indices (VSI): Generally the distribution network is designed in radial structure and the flow of power is only in one direction from generation to load side. Usually the buses located far away from the feeder in the secondary distribution having more voltage drop and also the magnitude of the voltage is less and these buses are more sensitive to voltage collapse. It is therefore important to identify the buses in the substation that are far from the feeder and VSI is used to overcome the same [4].

$$VSI(r) = \frac{|V_s| - 4[P_r(r)R_r + Q_r(r)X_r]}{|V_s|^2 - 4[P_r(r)R_r - Q_r(r)X_r]^2} \dots\dots\dots (8)$$

VSI(r) is the Receiving end index of particular node.

Vs, Pr, Qr, Rr and Xr are the voltage at sending end node, along with true, reactive power, resistance and reactance of receiving side.

$$F2 = \frac{1}{\min(VSI(r))} \quad (9)$$

Here r = Total number of buses excluding bus 1(slack bus)

Cost function: The cost is based on the power loss in MW and also the power generated by DGen, whereas the DGen cost is considered as \$46/MWh and the power loss cost is considered as \$44.5/MWh.

$$Total\ Cost = \frac{(CPDG \sum_{i=1}^n P_{dg,i} + CPD.P_{Loss\ DG})}{CPD.P_{Loss}} \quad (10)$$

$$F3 = \frac{1}{Total\ Cost} \quad (11)$$

In the function of optimization

Here $P_{DGen,i}$ – is the PV connected at i^{th} bus

This target is limited by power flow limit and voltage limit ($0.95 < V < 1.05$).

IV. WHALE OPTIMIZATION ALGORITHM

Whale optimization technique is the very powerful Meta heuristic optimization technique which can be used to solve optimization problems which consists of multi-objective functions. Among the species of whales, humpback whale is very popular because of its special hunting technique. The technique used for hunting the food is named as bubble-net method of feeding [6]. Hump back whales are always hunt a group of very small fishes or krills. During the time of hunting it was noticed that this hunting process is achieved by creating a simultaneous bubbles over the circle or it produces the bubbles in the number 9 shaped path is shown in fig 4.1 below.

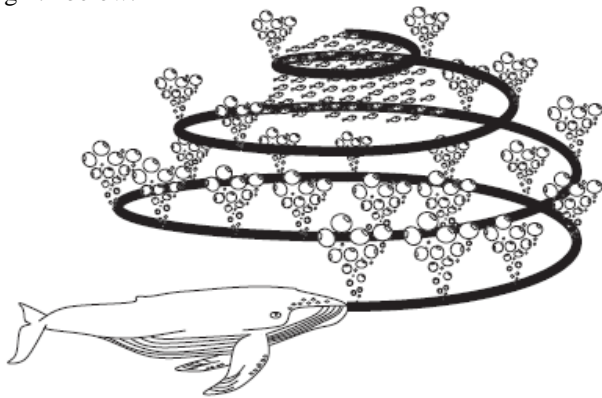


Fig.2.: Bubble net type of hunting behaviour of whales
Mathematical modelling of the WHOA is obtained by performing the operations such as spiral bubble net feeding maneuver, search for the prey and encircling prey is explained in WHOA.

A. Algorithm for whale Optimization method

Step 1: Initially set the population size of whale as X_{ij} . Where ($i = 1, 2, \dots, n$) and $j =$ number of search variables (DGEN Size and location).

Step 2: Estimate the fitness of each search variable or agent. X^* =the best search variable

Step 3: Test every search agent for full number of successful iterations target. Change a, A, C, l, and p. (where, A & C – matrix coefficients, a- decreased linearly

from 2 to 0, l is the arbitrary number between [-1, 1], p is arbitrary number between [0,1]).

Step 4: if $|A| < 1$ and $p < 0.5$, Then change the current search agent's position by

$$D = |C.X(t) - X(t)| \quad (12)$$

$$X(t+1) = X(t) - A.D \quad (13)$$

Where t is number of iteration.

else if $|A| >= 1$, Check search agent randomly (X_{rand}) is chosen. Update presently available search agent's location with following approximation.

$$X(t+1) = X_{rand} - A.D \quad (14)$$

Step 5: if $p >= 0.5$, Update the status of current agent's location with the equation (15) as given below.

$$X(t+1) = D'.e^{bl}.\cos(2.\pi l) + X^*(t) \quad (15)$$

Step 6: Test whether any search agent exceeds the search space and adjust it. Calculate the fitness of each search agent. Adjust X^* if there is a better solution, increase the number of iterations as $t = t+1$ and go to Step 3.

Step 7: X^* results are displayed.

V. PARTICLE SWARM OPTIMIZATION(PSO) ALGORITHM

The PSO is a most simple and powerful heuristic-based optimization technique used to solve non-linear and complex optimization problems introduced by Kennedy and Eberhart in the year 1995. PSOA is basically inspired from the natural and social behavior of animal cultures. In this technique a group of living creatures to find the food in best possible way.

The application of PSOA and also CSOA towards optimum allocation of DGEN by reducing the multi-objective function is same as discussed in Section III. The particle here means the control variable of the problem. The three variables and three sizes of the control variables DGEN. A particle carries six variables as a vector. The methodology of the method is well articulated and results are presented. PSOA produces better results than previous systems.

A. Particle Swarm Optimization Algorithm-Procedure

Step 1: Population size is initialized as N for the control variable X.

Step 2: X's initial population is provided within the limits of power as well as the particle's initial velocity (V_j) is considered as zero.

Step 3: For each population, determine the fitness (Fuel Cost (F)), find new velocities and update the same. Then increment the iteration count.

Step 4: Fitness values are assigned to the personal best (Pbest) of their own X value for each population. The X value that is responsible for the lower cost value is then taken as the best global (Gbest) benefit. Then the velocity function is determined using the equation below.

$$V_j(i) = V_j(i-1) + c_1r_1[P_{bestj} - X_j(i-1)] + c_2r_2[G_{best} - X_j(i-1)]$$

where, $j = 1, 2, \dots, N$

here,

$c1, c2$ are cognitive and social learning rates taken 2

$r1, r2$ are uniform distributed randoms in range 0 and 1

Step 5: The X value is then modified with the below equation.

$$X_j(i) = X_j(i - 1) + V_j(i)$$

Step 6: At the end of all the iterations move to step 3 and proceed until it ends.. Here the total iteration count is equals to stop criteria and finally G_{best} value is the result.

VI. CUCKOO SEARCH OPTIMIZATION ALGORITHM (CSOA)

CSOA is an effective optimization method established in the year 2010 by Yang and Deb. To represent the CSOA algorithm in the simple way the following three idealized rules are considered.

Rule 1: In first step each cuckoo will laid one egg at a time and keep this egg in any randomly selected nest.

Rule 2: Here the high quality of eggs available in the best nests will be used for the forthcoming generation (solution).

Rule 3: In rule 3 by fixing the host nests followed by the eggs laid by each cuckoo can be find out with a probability of $P \in [0, 1]$.

The fitness function is directly proportional to the objective function in case of maximization problem. So the cuckoos will search the best nest to laid their eggs so that increasing the maximum survival rate. Therefore the best search can be represented by using the mathematical equation and the steps are described as follows.

A. Cuckoo Search Optimization Algorithm

Step 1: Initialize the parameters and run the LFA.

Step2: Set the maximum and minimum limits of the constraints.

Step 3: Choose the random population say X variable for host nests say n.

Step 4: By using the levy flight equation, determine the fitness function and if the solution is good replace with the previous solution.

Step 5: All the remaining nests are destroyed after keeping the best nests which gives accurate values of the solution.

Table III: Results obtained for WHOA method-type 1

Type	case	Optimal place			Optimal size in MW			Loss in MW	VPI	Obj	Cost in \$/MWh
		DG1	DG2	DG3	DG1	DG2	DG3				
1	Case 1	61	-	-	2.2	-	-	0.0868	0.886	0.492	105.0626
	Case 2	12	61	-	1.2	2	-	0.0785	0.957	0.444	58.69325
	Case 3	12	61	68	5	1.9	1	0.0784	0.942	0.433	320.8888

Step 6: Give the rating to the available solutions and from that find the best possible fitness function value X.

Step 7: Continue the process and go to next iteration count and repeat the process with step 2.

Step 8: continue the process till the end of the last iteration.

VII. RESULTS AND DISCUSSION

In this section the results of the new optimization technique named as Whale optimization algorithm is used for the optimal placement and sizing of DGEN sources connected in the RD network for the multi objective problem formulation with the moto of reducing the power loss, improving the voltage profile along with the cost minimization of DGEN.

To validate the results and say it gives better and good results the proposed algorithm is compared and analyse the results with more efficient and most commonly used algorithms like Particle swarm and Cuckoo search algorithms.

The comparative analysis of the above said optimization techniques is developed and compared for performance comparison. IEEE 69 bus standard test system is used to validate the objectives as we discussed in section III. The figure 1 below describes the IEEE 69 bus standard RDS consists of totally 68 branches with the net load demand of 3.8022 MW and 2.6946 MVAR.

In the Proposed work DGEN sources belongs to type 1 and type 2 category is considered under six different cases.

Table-II: Classification of various categories of DG

Cases	Type of DGEN source	NO. of DG sources	Nature of Supply
Case 1	Type 1	One DG	Supply only Real Power
Case 2		Two DG	
Case 3		Three DG	
Case 4	Type 2	One DG	Supply Both True and Apparent Power
Case 5		Two DG	
Case 6		Three DG	

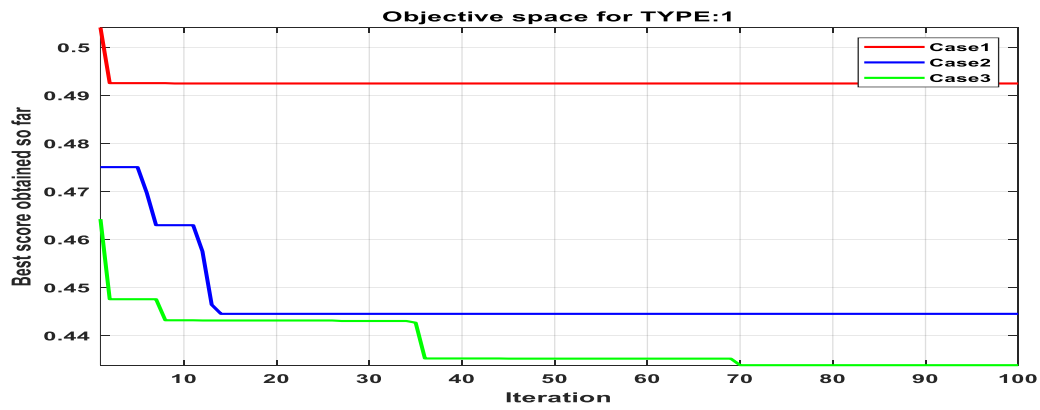


Fig.3: Convergence graph for type 1 DGEN
Table IV: Results obtained for WHOA method-type 2

Type	case	Optimal place			Optimal size in MW			Loss in MW	VPI	Obj	Cost in \$/MWh
		DG1	DG2	DG3	DG1	DG2	DG3				
2	Case 4	61	-	-	2.1	-	-	0.0255	0.9	0.408	97.73475
	Case 5	13	61	-	0.8	1.9	-	0.0104	0.9772	0.353	124.6628
	Case 6	2	17	61	4.9	0.6	1.8	0.0082	0.9773	0.329	336.1649

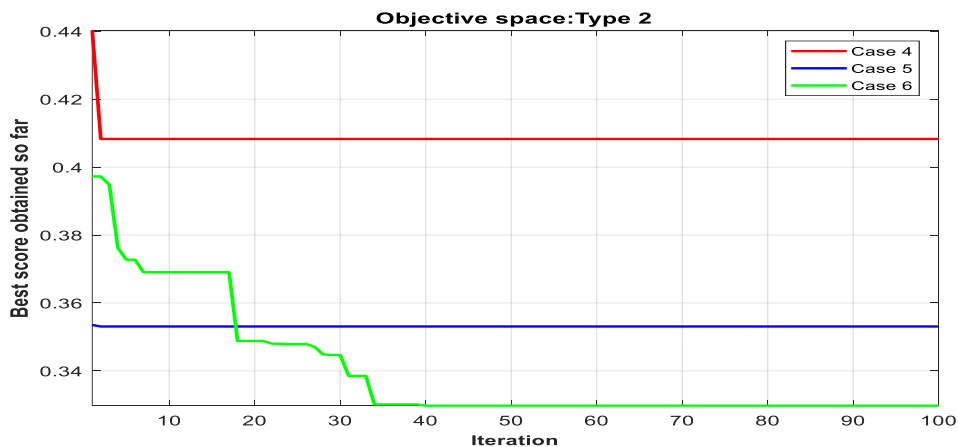


Fig.4: Convergence graph for type 2 DGEN
Table V: Results obtained for PSO method-type 1

Type	case	Optimal place			Optimal size in MW			Loss in MW	VPI	Obj	Cost in\$/MWh
		DG1	DG2	DG3	DG1	DG2	DG3				
1	Case 1	61	-	-	2.2	-	-	0.086	0.885	0.492	105.027
	Case 2	62	51	-	1.76	1.64	-	0.0823	0.911	0.464	84.62235
	Case 3	61	67	50	1.89	1.7	2.48	0.0945	0.958	0.453	169.34525

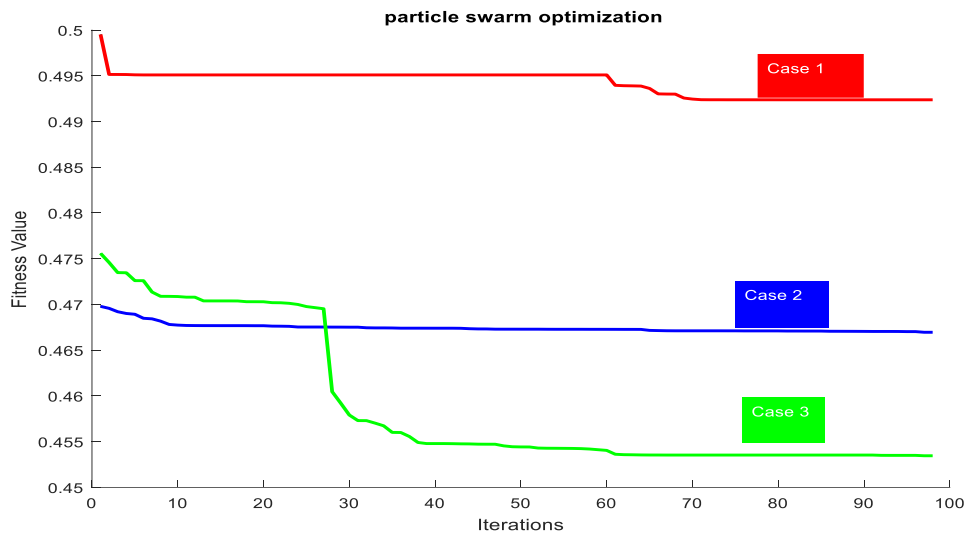


Fig.5: Convergence graph for type 1 DGEN

Table VI: Results obtained for PSO method-type 2

Type	case	Optimal place			Optimal size in MW			Loss in MW	VPI	Obj	Cost in\$/MWh
		DG1	DG2	DG3	DG1	DG2	DG3				
2	Case 4	61	-	-	2.14	-	-	0.0265	0.9	0.408	99.61925
	Case 5	47	61	-	2.51	2.05	-	0.0249	0.9	0.3857	210.86805
	Case 6	61	19	40	1.94	0.43	3.45	0.0283	0.974	0.36	268.97935

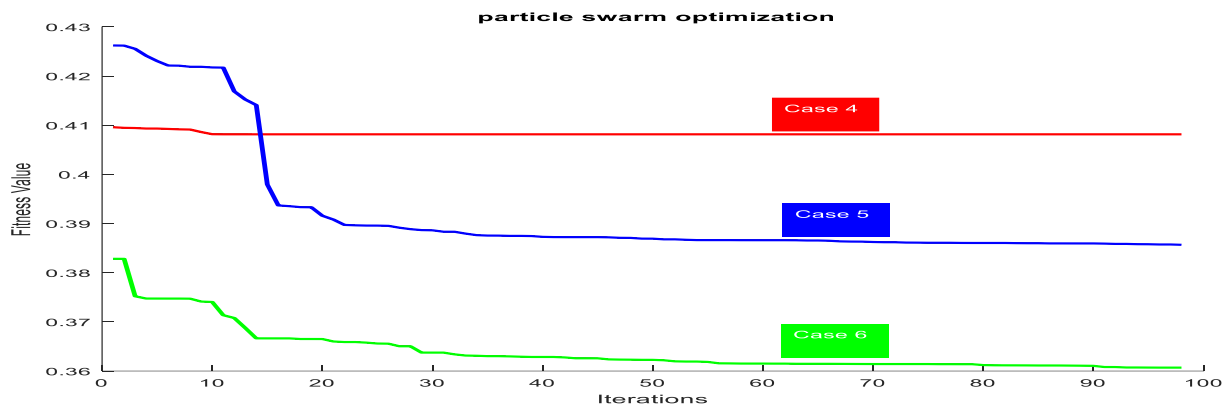


Fig.6: Convergence graph for type 2 DGEN

Table VII: Results obtained for CSOA method-type 1

Type	case	Optimal place			Optimal size in MW			Loss in MW	VPI	Obj	Cost in\$/MWh
		DG1	DG2	DG3	DG1	DG2	DG3				
1	Case 1	61	-	-	2.16	-	-	0.086	0.885	0.492	103.187
	Case 2	12	61	-	1.65	2.1	-	0.0912	0.977	0.4515	79.9584
	Case 3	16	61	4	0.86	2.3	3.45	0.087	0.977	0.435	149.2315

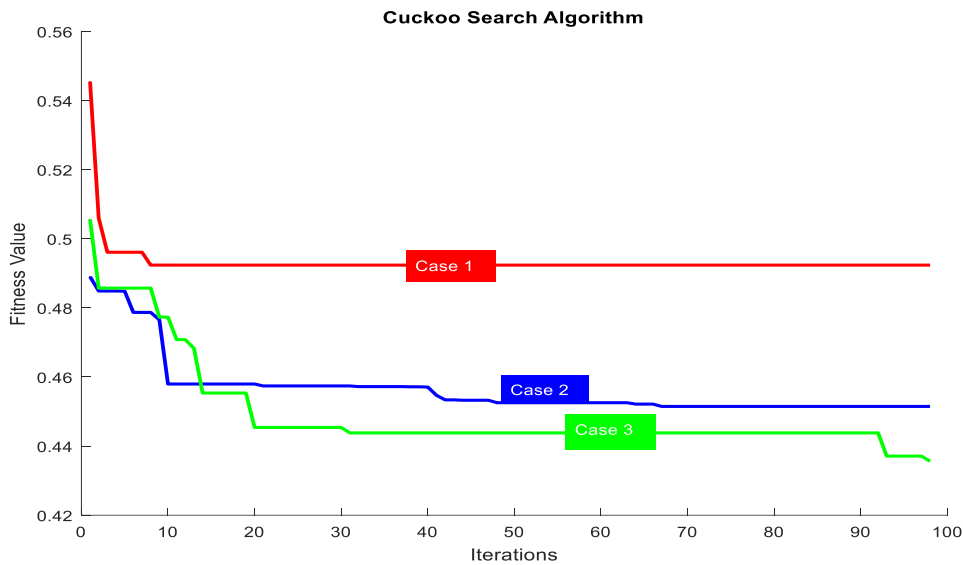


Fig.7: Convergence graph for type 1 DGEN

Table VIII : Results obtained for CSOA method-type 2

Type	case	Optimal place			Optimal size in MW			Loss in MW	VPI	Obj	Cost in\$/MWh
		DG1	DG2	DG3	DG1	DG2	DG3				
2	Case 4	61	-	-	2.1	-	-	0.0266	0.9	0.408	97.7837
	Case 5	61	12	-	1.85	1.0513	-	0.0111	0.9772	0.352	133.9568205
	Case 6	69	3	61	1.267	4.9661	1.9041	0.025	0.978	0.35	375.4051074

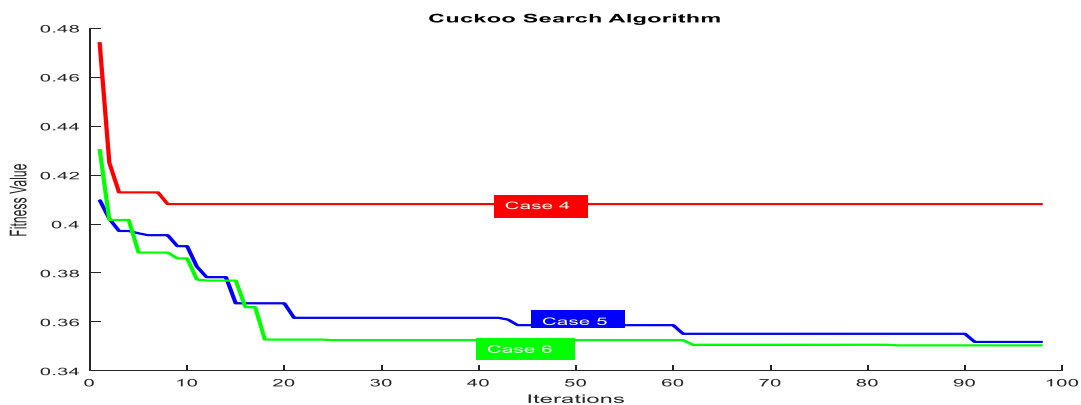


Fig.8: Convergence graph for type 2 DGEN

In all six cases, Table III to VIII shows the position and scale of DG as well as Fig.3 to fig.8 displays the convergence graph for all 3 cases of Type I and Type II DGEN algorithms. The DGENs are considered here with generators based on PV. DGEN's cost is estimated to be 46\$/MWh and energy loss costs are considered to be \$44.5/MWh [7].

Out of all the 6 cases considered economics wise best is case-4 of type 2 category. In terms of VSI indices it is case 2

and in terms of energy loss or the loss of power is in case 6. So you can choose to run it in real time framework with cost, loss and VSI parameter.

From the study it is clear that cost analysis is very important parameter for the placement and sizing of DGEN problem and price or economics based research is not done so far in any literature. From Table III to VIII shows the PSO and CSA algorithm results. Among all the three types comparatively whale optimization shows better results.

The comparative analysis of all the three algorithms in terms of cost, power loss and percentage of improvement is shown in the figure 9 to fig.11 shown below.

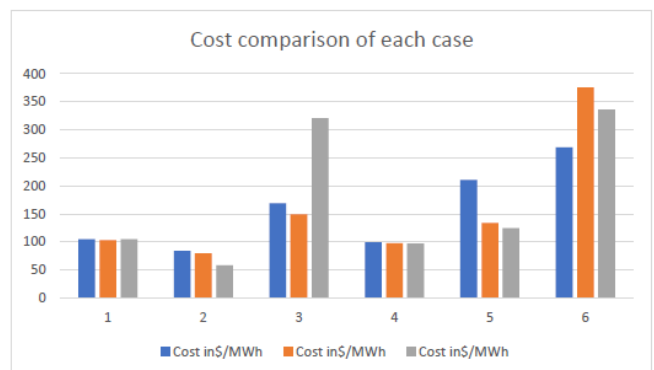


Fig.9: Cost wise comparison of all three algorithms.

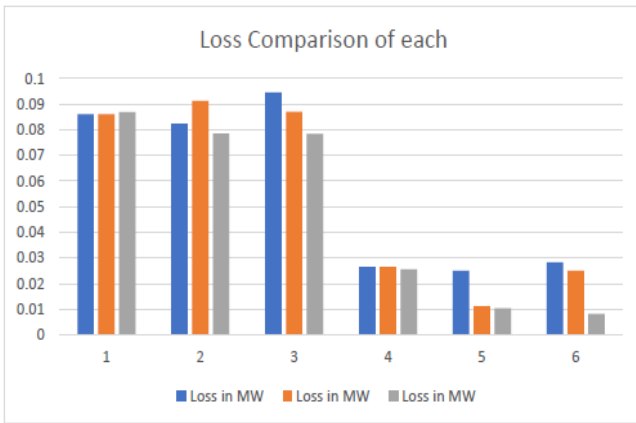


Fig.10: Power Loss comparison of all three algorithms.

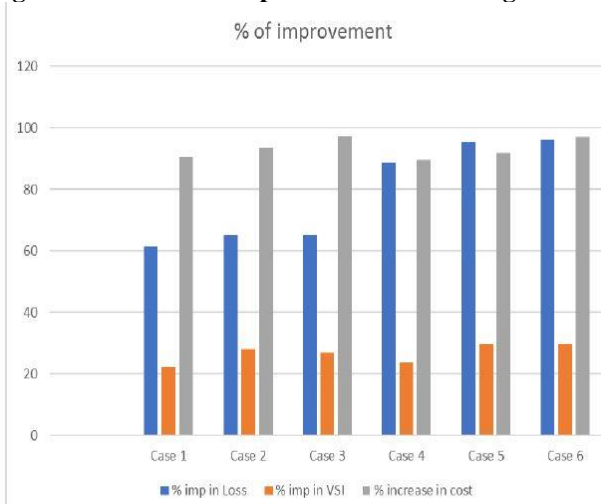


Fig.11: Percentage Improvement comparison with all three algorithms.

VIII. CONCLUSION

This paper presents the multi objective approach for ODGP placement along with the DG cost and tariff cost. The same can be done and analyzed the results by using IEEE 69 bus system. In this paper three popular meta-heuristic algorithms named as PSO, CSOA and WHOA is used for the DG placement problem with an intension of minimization of losses, maximization of VSI along with cost analysis. The results of PSO algorithms is compared with CSOA and later the combined results of CSOA and PSO are compared with a Whale optimization technique. From the results it is cleared that the WHAO performs better as compared to PSO algorithm and CSOA algorithm with convergence iteration count and also in the placement of DGEN location and size in all the cases with both the types of DGENs. This proves that the optimal location and sizing of DGENs are done properly compared to PSO and CSOA. The WHOA is optimum than the PSO and CSOA. This proves the convergence is better in WHOA algorithm

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