Maximization of Net Profit by optimal placement and Sizing of DG in Distribution System

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Abstract - *The economy of the Distribution system (DS) greatly depends upon the amount of electricity purchase from transmission grid and the line loss of the distribution system. The inclusion of Distributed Generation (DG) in the passive distribution system acts as an active power supply to the local load thereby reduces the line loss and also reduces the amount of electricity purchase from the transmission grid. Reduced purchase of electricity from the grid helps to increase net savings of the DS and also increases the load utilization level of the power system network. Considering the above theme, in this paper maximization of economic benefit in terms of improving the net savings or net profit of the vertically integrated distribution system has been proposed. The maximum economic benefit optimization is carried through the stochastic optimization tools such as Genetic Algorithm (GA) and Particle Swarm optimization (PSO). The effectiveness of the proposed optimization has been tested with the standard 9 Bus distribution system. To attain the realistic results time varying load scenario has been incorporated and the results are recorded.*

***Key Words*: Economic Benefit, Vertically Integrated Distributed system, PSO, GA.**

1. INTRODUCTION

In recent years due to the advancement of technology, the utilization of electricity has been increased a lot and leads to the shortage of transmission capacity to meet the load variation in the distribution system. The shortage issue is effectively carried by the inclusion of DG in the distribution system [1]. DG helps to convert a passive DS to the active DS. The active DS helps to reduces the transmission loss and also provide reliable electricity to the consumer. Implementation of DG is highly affected by the DG's size and placement. Improper placement and sizing of DG will adversely affect the system's static security constraints such as voltage profile, line flow in the transmission line. Hence it is necessary to optimize the placement and sizing of DG [2]. The optimization problem can be interpreted as a mixed integer non-linear optimization problem. Optimization procedures such as analytical, deterministic and stochastic methods are used to find the optimal position and sizing of DGs for maximizing the system voltages or minimizing power loss. Initially in late 1990's and early 2000, many literatures [3-4] have used analytical based optimization approach for finding the best position and sizing of DGs to solve different DG-unit problems.In early 2000, Evolutionary/meta-heuristic computing techniques like Genetic Algorithm (GA) [5-6] and Particle Swarm Optimization (PSO) [7] have emerged as a very powerful general purpose solution tools for solving the complex Power system problems. Basically these Meta-heuristics search techniques are capable of finding the optimum solution of a problem irrespective of the number of control variables and also effective in handling the mixture of continuous and discrete variables. Due to the development in the practice of stochastic algorithms, Differential Evolution [7], Ant Colony optimization (ACO) [8], Fuzzy systems [9], Plant growth simulation [10], Immune algorithm based optimization (IA) [11] and Bee Colony optimization algorithm (BCO) [12] as a tools for solving optimal DG allocation problem. Recent year's revolutionary hybrid process of combining the advantages of two meta-heuristic algorithms in determining the optimal solution has been practised more in many applications. In literature [13], the above revolutionary way of combining GA and PSO has been used in determining the optimal placement of DG.

In recent years, few papers [14-16] have proposed to consider the economic objective of maximizing the profit of the distribution system along with technical objective of minimizing the line power loss and maximizing the voltage profile. The above economic based objective paper increases the net savings or net profit of the distribution companies in the deregulated electricity system by optimally placing and allocating the size of the DG. Based on the above methodology of maximizing the net profit or net savings of the distribution companies, in this paper maximization of the economic benefit for the vertically integrated distribution system has been proposed by reducing the purchase of electricity from the transmission grid (TG). The reduction of electricity is compensated by the inclusion of DG. Though the inclusion of DG helps in reducing the technical issues such as line losses and voltage profile reduction, the economic factor of DG such as operational and maintenance cost has been the difficulty to achieve the maximizing economic benefit results. Hence it is necessary to optimize the DG placement and sizing by considering the electricity purchase cost from the transmission grid and also considering the DG maintenance and operation cost. GA and PSO algorithms have been used as an optimization tools for solving the optimization problem. To check the consistency of optimization problem, 9 bus radial distribution test system has been used for implementation. The performances of both GA and PSO are highlighted by comparing the results.

2. MATHEMATICAL FORMULATION

The inclusion of DG directly supplies electric power to the local load thereby reducing the purchase of electricity from the transmission grid and also reduces the total loss in the distribution system. The reduced purchase of electricity from the transmission grid improvises the net savings of the distribution system but the size of DG has a great deal with the investment and operation cost of DG and also with the raw materials for the operation of DG. Hence it is important to model the electricity purchase cost from the transmission grid, DG's Investment and operation cost to achieve the objective of maximizing the economic benefit of the distribution system [14]. Also the load pattern plays a vital role in designing the DG participation in the distribution system. The above mentioned costs model and the load level pattern are described in the below sections as follows.

2.1 Multi-load Level

Load is the most uncertain unit in the power system; it will be varied continuously with respect to the demand. Based on the statistical data, the load pattern will clearly depicts the load demand per hour/day/year in the Distribution system. Hence it is important to analyze the load pattern to get the accurate load data for designing the DG participation. In this paper, the load pattern of a day has been segregated into three load levels such as light load, medium load and Peak load. The load demand of each load level will be a certain percentage of active and reactive power from the nominal load. Based on a day load pattern interval, the annual load pattern has been designed. This annual load level interval helps to design the DG participation share for each load level in the distribution system and also the optimal DG sizing for each load level can be achieved accurately.

2.2 Electricity Purchase Cost

In a distribution system, the total load demand and the power losses are supplied from the transmission grid. This is given as below

$$PT_{DS} = TD + RPL \quad \ldots\ldots(1)$$

Where

PT_{DS} = Total Real Power supplied to DS fron TG in kW
TD = Total Real Power Demand of DS in kW
RPL = Total Real Power loss of DS in kW
If a portion of Total real power demand is supplied by DG then the equation (1) becomes

$$PT_{DS} = TD - (TD * DGR) + RPL \quad \ldots\ldots(2)$$

DGR is the Percentage of real power supplied by the DG to the Total real power Demand. Since the load demand is varied with respect to the load levels, the total DG participation ratio also varies with respect to the load level. Hence the purchase of electricity from the transmission grid is also varied depend on the load level.

Considering the load level, the purchase cost of electricity from the Transmission grid before and after DG placement is given by the equations (3) and (4) as follows

$$EPC_{BeforeDG_i} = \left((TD_i + RPL_i) * T_i * K_{ECi}\right) \quad i\ \varepsilon\ [1,t] \quad \ldots\ldots \quad (3)$$

$$EPC_{AfterDG_i} = \left((TD_i - TDG_i + RPL_i) * T_i * K_{ECi}\right)\ i\ \varepsilon\ [1,t] \ldots (4)$$

$$TDG_i = (TD_i * DGR_i)$$

Where

$EPC_{Before\ DG_i}$ = Electricity Purchase Cost of i^{th} load level from TG Before DG inclusion in $
$EPC_{After\ DG_i}$ = Electricity Purchase Cost of i^{th} load level from TG after DG inclusion in $
K_{ECi} = TG Elecricity Purchase cost factor in $/kWh
TDG_i = Total DG Supply in i^{th} load level in kW
t = Total Number of load level
T_i = Total No of operation Hours in a year in the i^{th} load level

2.3 DG investment Cost

Another important cost to consider is the investment cost of DG. DG investment cost heavily depends on the site and the installation charges [14]. The site is selected based on the size of DG. Hence the DG investment cost is evaluated by using the Investment cost factor with respect to the size of the DG as given in the below equation

$$DGC_{inv} = \sum_{n=1}^{NDG} MDG_n * Invf \quad \ldots.(5)$$

Where

DGC_{inv} = DG investment cost in $
MDG = Maximum DG Installion size in KW
Invf = Investment Cost factor in $/KW
NDG = Total Number of DG

2.4 Operation and Maintenance Cost of the DG

The operation cost of DG mainly depends on the input fuel source hence the operation cost is equivalent to the fuel cost. The DG operation cost also varies with respect to the load level as the number of operation hours varies. Compare to the DG operation cost, the DG maintenance cost is meager. Hence the total DG operation and maintenance cost [14] is estimated with the factor value based on the size of DG. The equation (6) has been modeled to estimate the DG operation and maintenance cost

$$DGC_{O\&M_i} = \sum_{n=1}^{NDG}(DG_{in} * T_{in} * K_{OMDG}) \quad .... (6)$$

$DGC_{O\&M_i}$ = Total DG operation and Maintenace Cost in the i^{th} load level in $

T_{in} = Total No of operation Hours in a year for the n^{th} DG in the i^{th} load level

K_{OMDG} = DG operation and Maintenance Cost factor in $/KWh

DG_{in} = n^{th} DG size in i^{th} load level in KW

NDG = Total Number of DG

2.5 Distribution system's net saving Evaluation

As stated in the introduction of this section, the main aim of this paper is to improve the economic benefit of the DS by increasing the Net savings of the DS. This net savings largely depends upon the participation of DG in reducing electricity purchase cost from the transmission grid and also the various DG costs as discussed in the sections 2.2, 2.3 and 2.4. Based on the above cost formulas, the Net savings is modeled for the plan period and it is given in the equation (7).

Net savings or Net Profit

$$= \left(\left(\sum_{k=1}^{Ny} \left(\sum_{i=1}^{t} \left(\left(EPC_{Before\ DG_i} - EPC_{After\ DG_i} \right) - \left(DGC_{O\&M_i} \right) \right) \right) * (PWF_k) \right) - (DGC_{inv}) \right) \quad .... (7)$$

Where

Ny = DG planning period in years

PWF_k = Present Worth factor

The Present worth factor [14] depicts the annual cost with considering the Inflation rate and Interest Rate in planning Period. Since the Electricity purchase cost and DG's input fuel source varies with respect to the time it is necessary to include the Present worth factor to balance the cost in the planning periods

$$PWF_k = \left(\frac{1+InfR}{1+IntR}\right)^t \quad ....(8)$$

Where

InfR is the Inflation Rate in %

IntR is the Interest Rate in %

2.6 Objective Function

The objective function (F1) of this paper is to maximize the net savings of the distribution system by reducing the purchase cost of Electricity from the transmission Grid by incorporating the optimal DG size at the optimal Bus placement. This objective function is given in the equation (9) as follows

$$F1 = Max\ (Net\ savings\ )or\ \ Max(Net\ Profit) \quad ....(9)$$

The above objective is achieved by satisfying following operational constraints

Constraint I: Bus Voltages

The systems Bus voltage must be maintained around its nominal value within a permissible voltage band, specified as [V_{min} V_{max}] .This can be mathematically described as:

$$V_{i\,min} \le V_i \le V_{imax} \quad ....(10)$$

Where,

V_{imin} is the minimum permissible voltage at i^{th}bus

V_{imax} is the maximum permissible voltage at i^{th}bus

Constraint II: The DG capacities

The capacity of each DG should also be varied around its maximum size as estimated for the planning period. Hence each DG must also be maintained within a permissible band, specified as [P_{DGmin} $P_{DG\,max}$] , where P_{DGmin} is the minimum permissible Real Power value of each DG capacity and P_{DGmax} is the maximum permissible Real Power value of each DG capacity. This should be a mandatory requirement since if a DG capacity is less than the specified minimum value, then the type and cost of the corresponding DG should also be varied. Similarly the Power factor (Pf) of each DG should to be maintained within a permissible band, specified as [Pf_{min} Pf_{max}] where Pf_{min} is the minimum permissible Power factor value of each DG capacity and Pf_{max} is the maximum permissible Power factor value of each DG capacity. This can be mathematically described as:

$$P_{DGmin} \le P_{DG} \le P_{DG\,max} \quad ..... (11)$$

$$Pf_{min} \le Pf \le Pf_{max} \quad ..... (12)$$

Reactive power formulation of the Distribution Generation from the Real Power is given as below

$$Q_{DG} = (P_{DG}).\tan(\,Cos^{-1}(Pf)\,) \quad ..... (13)$$

Where Q_{DG} is the reactive Power from DG in Kvar

Constraint III: Power balancing Constraints

The bus Voltage and the distribution system line flows are obtained using the newton raphson load flow solution. The Power balance constraints are one of the most important criteria to be met during load flow calculation. The Power Balance constraints of each bus to be met is given as follows

$$P_{Gi} - P_{Di} - V_i \sum_{i=1}^{N} V_j Y_{ij} \, Cos(\theta_{ij} - \delta_i + \delta_j) = 0 \quad .....(14)$$
$$Q_{Gi} - Q_{Di} - V_i \sum_{i=1}^{N} V_j Y_{ij} \, Sin(\theta_{ij} - \delta_i + \delta_j) = 0 \quad .....(15)$$

Where

P_{Gi} is the Real Power supply by DG in p. u
Q_{Gi} is the Reactive Power supply by DG in p.
P_{Di} is the Real Power Load Demand in p. u
Q_{Di} is the Reactive Power Load Demand in p. u
V_i is the Voltage Magnitude at the i^{th} bus in p. u
V_j is the Voltage Magnitude at the j^{th} bus in p. u
δ_i is the Voltage angle at the i^{th} bus in p. u
δ_j is the Voltage angle at the j^{th} bus in p. u
N is the total Number of Bus in the Distribution system
Y_{ij} is the Magnitude of the Admittance Matrix between the i^{th} and j^{th} bus in p. u
θ_{ij} is the Angle of the Admittance Matrix between the i^{th} and j^{th} bus in p. u

3. GA AND PSO FOR MAXIMUM NET SAVINGS

GA and PSO based stochastic algorithms are used to solve the optimization problem of maximizing the net profit of the DS with the optimal allocation of predetermined number of DG's in the specified timing and also not violating the system operation limits as given in the section 2.6. In this paper, both the GA and PSO algorithmic structure follows the same methodology used in the literature [13].

4. RESULTS AND DISCUSSION

In this paper, the proposed optimization problem of achieving maximum economic benefits mentioned in the section 2.6 has been accomplished with MATLAB Programming application. The optimization has been carried out for DG's planning period of 3 years and the number of DG chosen for optimization is three. Assumed all the three generators should be in operation for all the three load levels and also a minimum of 100 KW is supplied from each generator. As mentioned in the section 2.1, three load level patterns such as light, medium and peak have been used in this optimization. The operation time duration of DG and DG's load demand sharing percentage of each load level is mentioned in the table 1. To check the effectiveness of the optimization problem, 9 Bus radial distribution test system has been used for implementation. While implementing the optimization problem for achieving best results, the system should not violate the systems security limits. The systems static constraint limits are given in the table 2. The Technical information regarding the multi load level and commercial information [14] regarding the purchase of electricity from the transmission grid are given in the table 1. Similarly, DGs commercial information [14] and maximum Installed size information are given in the table 3 and table 4 respectively. As mentioned in the section 3, two standard optimization Algorithms GA and PSO are also used for solving the optimization problem. The Parameters of optimization algorithms are given in the table.5. The results and detailed study for test system are as follows

4. 1 9 Bus Radial Distribution Test system:

The test system for case study is 9 bus [10] radial distribution system. Total nominal load of the system is (12368 + j 4186) kVA. The rated line voltage of the System is 23 kV. Base case real power loss and reactive power loss for the nominal load is 783.4347 kW and 1036.4117 kVAR respectively. Minimum bus voltage of the nominal load is 0.8375 p.u at bus no.9. The load demands of light, Medium and Peak load level of this system is given by 6184 kW, 12368 kW and 19788.8 kW respectively. As per DGs load demand share contract in the table.1, the total DG real power supply for each load level demand is given by 3092 kW, 4947.2 kW, 5937kW respectively. Optimal size, location and power factor of the DG for each load level in achieving the maximum net profit or net savings using GA and PSO algorithms are obtained and recorded in the table.6. From the table.6, it is inferred that 16% of the cost has been saved from the total electricity purchase cost by placing and sizing the DG with the optimum results recorded in the table 6. It is inferred from the table 6 that 91-92 % of the real power loss has been reduced from the base case real power loss in light load level for the two algorithms. Similarly for the two algorithms, around 90% and 86% of the power loss has been reduced from the base case real power loss in medium and peak load level respectively. The percentage reduction of real power loss from the nominal load for the algorithms has been recorded in the sixth column of the table.6. A minimum voltage of 0.97 p.u , 0.95 p.u and 0.93 pu have been maintained in light, medium and peak load level during optimization. From the above, it is evident that the voltage of all the bus have been maintained within their limits and also ensures the high security of the system.

5. ALGORITHM'S PERFORMANCE MEASURES

The Statistical measures such as worst, best, mean, standard deviation and the objective of maximum net profit in percentage of the two algorithms for the given test system is recorded in the table 7 by conducting 20 different trials. From this, it is inferred that the percentage of maximum net profit for the test system is same to the both algorithms but the number of iterations for achieving maximum net profit using PSO is better than compared to GA. It is obvious from the two algorithms convergence graph in fig.1. It is also evident from the table 7 that the low standard deviations around the high mean value of PSO shows the better quality and robustness of the PSO compared to that of GA. The statistical analysis clearly depicts that PSO provides greater amount of balance between exploitation and exploration process. PSO optimization percentage of reduction in real power loss shows better reduction rate compared with that of base case real power loss in all the three load levels.

Table 1: Technical and Commercial Information

Multilevel load	Annual Time Duration T in Hrs	% of Nominal Load	DGR	K_{ECi} in $/KWh
Light	2190	50%	50%	0.053
Medium	4745	100%	40%	0.073
Peak	1825	160%	30%	0.105

Table 2: System's Static Constraint limits

Parameter	Value
Pf_{min}	0.7
Pf_{max}	Unity
V_{min} in p.u	0.9
V_{max} in p.u	1

Table 3: Commercial Information of DG

Parameter	Value
K_{OMDG} [14] in $/Kwh	0.036
Invf in $/Kw [14]	400
Number of DG NDG	3
Interest Rate [IntR]	9%
Inflation Rate [InfR]	12%
N_y	3 Years

Table 4: DG's Installation Capacity of the Test system

Radial Bus Distribution Test System	Maximum DG Installation size MDG in kW DG1	DG2	DG3
9 Bus	2000	3000	2000

Table 5: GA and PSO Algorithmic Parameters

Parameters	GA [13]
Population size	30
Selection Method	Roulette Selection
Cross Over	Simple Cross over
Mutation	Simple Mutation
Mutation Probability	0.05
Cross Over Probability	Randomly selected between 0.5 to 0.8 For Each Trial
Survival Selection	0.8
Probability Termination	1000
	PSO[13]
Initial Inertia W	0.98
Constants C1,C2	2,2
Random numbers r1,r2	Between 0 to 1
Pop size	30
Termination	1000

Table 6: Simulation Results of GA and PSO for 9 Bus test system

Parameters	Techniques					
	GA			PSO		
	Loc	Size	Pf	Loc	Size	Pf
Light Load						
Total Load is 6184 kW						
Total Real Power Loss before DG is 169.8987 kW						
Optimal location, size in kW & pf of DG	6	1332	0.9	6	1615	0.918
	9	1006	0.99	8	650	0.990
	8	755	0.885	9	827	0.993
Minimum voltage bus	4			4		
Minimum voltage (p.u)	0.9927			0.9911		
Total real power loss after DG in kW	16.12			12.25		
Medium Load						
Total Load is 12368 kW						
Total Real Power Loss before DG is 783.4347 kW						
Optimal location, size in kW & pf of DG	6	1784	0.846	6	1978	0.812
	9	1808	0.985	8	1329	0.993
	8	1355	0.977	9	1641	0.992
Minimum voltage bus	5			7		
Minimum voltage (p.u)	0.9753			0.975		
Total real power loss after DG in kW	80.199			78.212		
Peak Load						
Total Load is 19788.8kW						
Total Real Power Loss before DG is 2590.2818 Kw						
Optimal location, Size of DG in kW and pf of DG	6	1422	0.712	6	1517	0.7
	9	2796	0.989	8	2420	0.973
	8	1720	0.944	9	2000	0.987
Minimum voltage bus	7			9		
Minimum voltage (p.u)	0.9388			0.9326		
Total real power loss after DG in kW	369.15			372.91		
Total Electricity Purchase Cost Before DG in $	30355517.55					
Total Electricity Purchase Cost after DG With DG O&M	25493057.53					

cost and Investment Cost in $	
Total Net Savings or Total Profit in $	4862460.022

Table 7: Comparison of Algorithm's Performance Measure

Test System		**9 Bus**	
Algorithm		**GA**	**PSO**
Worst		4860880.44	4862124.74
Best		4861220.34	4862460.02
Mean		4861044.88	4862314.03
Standard Deviation		99.42	93.60
Net Profit in %		16.01	16.01
% of Real Power Loss reduction	**Light**	90.51	92.79
	Medium	89.76	90.01
	Peak	85.74	85.60
No of Iterations for convergence		550	380

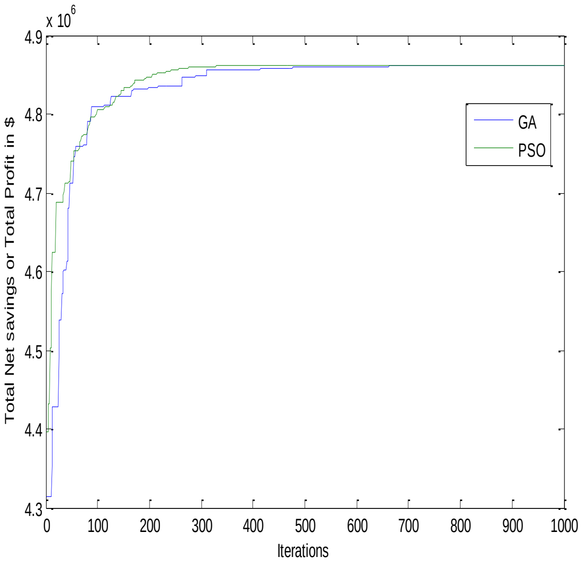

Fig.1: Convergence graph of GA and PSO.

6. CONCLUSION

The proposed optimization problem of DG placement and sizing helps the Distribution System to increase their total net savings of the system and also by maintaining the system's bus voltage in high profile, the security level of the system has been improved. The real power loss of the system after DG inclusion has been drastically reduced compared to that base case (nominal) load demand. The PSO ensures good optimization results by showing its better performance measures compared to that of the GA. Performance of PSO clearly depicts that the algorithm has a greater balance between diversification and intensification during the search for best optimized results convergence graph of both GA and PSO is given in fig.1.

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