Multi-Objective Optimization of DG Sizing and Placement using BBO Technique

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***Abstract*— Recent trends in power system have made it an open access environment to the customers. Distributed generations (DGs) have been preferred due to various merits such as a Green House Gas (GHG) emission reduction in generation, improvement in voltage profile as well as voltage stability at heavy load levels in distribution feeders, enhancement of reliability and power quality. Also the power market immunity has been enhanced using DG technologies. In spite of the enormous advantages of DG technologies, the DG management and power dispatch is a bigger challenge for distribution system operators. This project presents a novel application of Biogeography Based Optimization (BBO) with the aim of determining the optimal DGs' placement & sizing. In the proposed multi-objective optimization, along with the operational constraints, such as improving voltage profile and stability, power-loss reduction, etc., we also take into account the economic aspects i.e., the electrical power distribution company's and DG owner's economic benefits. The proposed approach has been studied and tested on the IEEE 33-bus radial distribution test system and the consequences have been discussed.**

Index Terms*— *Distributed Generation (DG), DG placement and Sizing, Biogeography Based Optimization (BBO), Pareto Optimality, Distribution Company (DisCo), DG owner.

NOMENCLATURE

C_{sub}	Cost of the purchased active power from the substation by DisCo.
C_{DG}	Cost of the purchased active power from the DG Owner for DisCo.
C_{inv}	Investment Cost of DG.
C_{main}	Maintenance Cost of DG.
C_{oper}	Operational Cost of DG.
IN_{DG}	DG Owner's Income.
CP_{DG}	Contract Price of DisCo with the DG.
$C_{MWh,P}$	Cost of active power in MWh bought from substation.
INF_R	Inflation Rate.
INT_R	Interest Rate.
L_b	Length of the branch.
V_n	Node Voltage.
T_h	Total number of hours in a year.
T_d	Total number of hours in a day.
CF	Capacity Factor of the DG.
$P_{DG,i}$, $Q_{DG,i}$	Active Power &Reactive Power supplied by the DG.
P_n, Q_n	Active power &Reactive power line flow.
TVPI	Total Voltage Profile Index.
TVSI	Total Voltage Stability Index.
TPLI	Total Power Loss Index.
V_{rated}	Rated bus voltage.
λ_k, μ_k	Immigration&Emigration rates.
E, I	Maximum Emigration rate & Maximum Immigration rate of the habitat.
S	No of Species.

I. INTRODUCTION

For many years, electricity production and distribution has been carried out by centralized, regulated electric power authority that is responsible for both the operation of power generation facilities along with the transmission and distribution lines. Later the power system was opened to the other utilities apart from the main authority. This led to a competitive environment for electric power generation and the transmission system was made an open access. Utility deregulation is one of the reasons for the advancements in the Distributed Generation (DG) technology.

DG plays a vital role in the enhancement of the performance of the distribution system. Distribution system generally indicates a radial power supply system and this challenges the integration of DGs with the power system. DG forms an important part in the distribution system planning because of its compact size and minimal investment cost along with environmental benefits. In addition, DG also causes considerable cost reduction being placed near the load and reduced power distribution losses. DG attracts people's interest in case of low investment cost and uninterrupted power supply in the current scenario of unpredictable load growth.

Some of the positive impacts of integrating DG to the distribution system has been listed below

- Reduction in power distribution losses along the feeders.
- Improvement in the power utility reliability.
- Enhancement of Voltage profile and Power quality.
- Prevention of overloading of transmission and distribution system equipment and their effective utilization.
- Environment friendly.
- Comparatively lower investment, operational and maintenance cost due to simpler construction and easier operation.

II. MOTIVATION FOR DG GROWTH

The growth of DGs was motivated by various factors and they have been classified into two main categories, environmental and commercial. These factors are discussed briefly below.

A. Environmental factor

1. Reduction in Green House Gas (GHG) emissions

Since the GHG emissions are a big concern nowadays, the need for renewable energy and Combined Heat & Power units (CHP) led to one of the major factors of DG technology. DGs can make use of renewable energy to produce electrical energy and thus DG integration to the grid can promote the concept of clean & green energy. But integration of these renewable energy DGs to the power system is not an easy job.

2. Reduction in the necessity for new transmission circuits and large generating plants

Another factor which has more public attraction for DG from the environmental perspective is the controversy towards the construction of generating stations and new transmission lines. Public awareness towards global warming and other environmental ill effects makes people go against the new transmission and generation facilities. This is where the DGs help in eliminating the need for new transmission lines as they being placed locally, near the loads. Also the distribution losses are reduced when they are properly sized and placed on the distribution network. Hence there is no necessity for a new generating unit and the power balance between the production and load can be achieved to an acceptable level.

B. Commercial factor

1. Unpredictability in power markets favours low capacity DGs

In a restructed power system, the concept of competition and choice in electricity endangers all the players from the generating end through transmission and distribution businesses to retailers. The capital investment required to establish new power generation stations are very high. The fluctuating and competitive market environment leads to new generation setups with a low capacity rating where the risk in financial aspects is comparatively small.

2. DGs are cost effective, efficient and reliable

Since the DGs are placed locally near the loads, the quality and reliability of the power dispatched can be maintained. Voltage profile improvement and the duration of power interruption to the customers can be taken care automatically when the DGs are allowed and able to be alive on the network during outages i.e., islanding mode.

III. LITERATURE REVIEW

Multiple advantages of renewable energy leads greater increase of their penetration level into the power systems. Most noticeable merits among these are reduced fuel usage, power dispatch to remote places, the need for clean energy sources, the economic benefits for investors in the modern power market and the operational benefits for utilities.

Proper sizing and placement of DGs in the power distribution system play a significant role in minimizing power distribution losses. For the calculation of optimal size and an effective placement of DG, an analytical expression has been developed with the concern to minimize the total power loss in the primary distribution systems [1-3]. Loss allocation for customers and distributed generators in radial distribution networks have to be considered. Hence, an approach has been devised to evaluate the technical benefits of DG and then applied to assess the voltage improvement, line-loss reduction and reduction of environmental impact [4-6].

Additionally, the DG owner's and the Distribution Company's (DisCo) economic aspects should be considered for the deregulated markets. The approach involves the interests of two different agents: the DG owner who would like to claim his profit from the power sales to be maximum, and the DisCo, which seeks for the reduction in payments in meeting out the demand. A key to figure out the location and contract pricing of distributed generation units for their dispatchable power in distribution systems has been discussed [7-8].

Cost–benefit analysis (CBA) is an organized methodology for evaluating the strengths and weaknesses of any functional requirements in the aspect of economy [9]. Main purpose of CBA are to justify the soundness of the investment or decision.

The necessity for the enhancement of computation speed & accuracy led to the invention of Evolutionary Algorithms (EA). EAs are inspired by biological maturation, such as reproduction, evolution and selection. Candidate solutions considered in the optimization problem are important and the fitness function decides the accuracy of the solutions. Also, the computational complexity is due to fitness function assessment. Fitness approximation has to be done to deal with this difficulty [10-13].

In the proposed approach, Biogeography Based Optimization (BBO) has been utilized. BBO is an EA, which stochastically optimizes a function and iteratively improves the accuracy of the candidate solutions with regard to the fitness function. Complex real-valued functions can be optimized through this method [11].

Since the problem is a multi-objective optimization type, Pareto Optimality principle has been implemented. Pareto optimality is utilized to allocate the resources where there is a difficulty in selecting the optimal solution in a multi-objective problem[12, 13].

IV. PROBLEM FORMULATION

The problem wheels around DG placement & sizing in electrical distribution system with the objective of maximizing the profit of DG owner & minimizing the purchasing cost of DisCo. Several constraints have been considered while solving the multi-objective optimization problem, which will be discussed below.Following are the assumptions made for solving the problem:

- There are no limitations over the terrestrial or fundamental resources to integrate various DG technologies with the distribution system.
- It is considered as a negative PQ load for the connection from a DG unit through a bus in power-flow analysis.
- The proposed approach of DG allocation considers the Disco's and the DG owner's perspectives in the power market.

A. Objective Function and Constraints

1. Objective Function

As mentioned earlier, this optimization problem of allocation of DG is solved considering the profit for the DG owner and the reduction of power purchasing cost of DisCo with several constraints and limitations, along with certain operational indices.

The objective function is given below

$$\begin{cases} F1 = \max(IN_{DG} - C_{INV} - C_{MAIN} - C_{OPERATE}) \\ F2 = \min(C_{SUB} + C_{DG}) \end{cases} \tag{4.1}$$

1.1 Components of the Maximizing Function of DG Owner's Profit

This section gives the details of the various costs involved in the DG owner profit maximization function.

- *DG Investment Cost:* This indicates the initial investment involved in the installation of the DG.

$$C_{inv} = \sum_{i=1}^{N_{DG}} P_{DG,i} * Investment\ Cost \tag{4.2}$$

- *DG Maintenance Cost:* This cost includes the repair, restore and maintenance work involved in the long run.

$$C_{main} = \sum_{j=1}^{N_N} \sum_{i=1}^{N_{DG}} P_{DG,i} * maintenance\ cost * T_h * CF_i * \left(\frac{1+\text{INF\_R}}{1+\text{INT\_R}}\right)^j \tag{4.3}$$

- *DG Operational Cost:* This includes the cost of generation, fuel and others. The equation is a cumulative of all such costs.

$$C_{oper} = \sum_{j=1}^{N_N} \sum_{i=1}^{N_{DG}} P_{DG,i} * operational\ cost * T_h * CF_i * \left(\frac{1+\text{INF\_R}}{1+\text{INT\_R}}\right)^j \tag{4.4}$$

- *DG Owner's Income:* This indicates the selling price of the generated power from the DG to the DisCo.

$$IN_{DG} = \sum_{j=1}^{N_N} \sum_{i=1}^{N_{DG}} P_{DG,i} * CP_{DG} * T_h * CF_i * \left(\frac{1+\text{INF\_R}}{1+\text{INT\_R}}\right)^j \tag{4.5}$$

1.2 Components of the Minimizing Function of DisCo's Cost

This section describes the cost spent by the DisCo on purchase of power from the substation and DG owner.

- *Cost of DG power purchased:* This cost is the one which is evaluated earlier as the DG owner's income.
- *Cost of Substation power purchased:* This indicates the cost of power purchased by the DisCo from the substation.

$$P_{sub,t,j} = \sum_{n=1}^{N_{Bus}} P_{l,n,t,j} - P_{Loss,t,j} - \sum_{i=1}^{N_{DG}} P_{DG,i} \quad (4.6)$$

Since the power purchase made every hour t of the day, the cost of power purchased from substation is given the equation below.

$$C_{sub} = \sum_{j=1}^{N_N} \sum_{t=1}^{24} P_{sub,t,j} * T_d * C_{MWh,P} * \left(\frac{1+\text{INF\_R}}{1+\text{INT\_R}}\right)^j \quad (4.7)$$

2. Constraints and Indices

While considering the economic aspects, we also must study the operational constraints of the power system taken into account. Below listed are the operational constraints and indices which are helpful in maintaining the system stability and power quality.

2.1 Constraints

Basic constraints are laid upon the following factors:

- Capital cost of DG owner
- Capacity of DG
- Contract Price
- Active and Reactive Power flow
- Bus Voltages and Branch Currents

2.2 Indices

These indices help to evaluate whether the system is operating in a desired stable state.

- Total Voltage Profile Index
- Total Voltage Stability Index
- Total Power Loss Index

V. MULTI-OBJECTIVE OPTIMIZATION

Complex problems are solved with lesser computational efforts, time and high accuracy using various optimization techniques, which have gained greater importance nowadays. Various evolutionary algorithms that imitate nature's behavior such as genetic algorithm, particle swarm optimization, etc., are widely used in varied fields. BBO is one of the EA found by Dan Simon in 2008. This optimization technique is analogous to the biogeography theory. The immigration rate λ and the emigration rate μ are functions of the number of species in the habitat.

A. Algorithm

Step 1

Run the distribution power flow for a base case and determine the active and reactive power losses.

Step 2

Identify the candidate solutions of DGs' size and location with minimum power losses using BBO.

Step 3

From the candidates, check for optimal set from multi-objective optimization using Pareto optimality principle, where DG owner's profit is maximized and DisCo's cost is minimized using equation (4.1).

Step 4

Run the power flow by assigning the appropriate size and location for DGs and calculate the active and reactive power losses.

Step 5

Repeat the steps 3 and 4 for all possible candidate solutions. Also calculate the operational indices TVPI, TVSI, TPLI for the particular candidate and check if the candidate is satisfy the limits. If not, ignore the candidate and go to step 2.

Step 6

Calculate and display the result for the best possible candidate solution.

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B. Flowchart

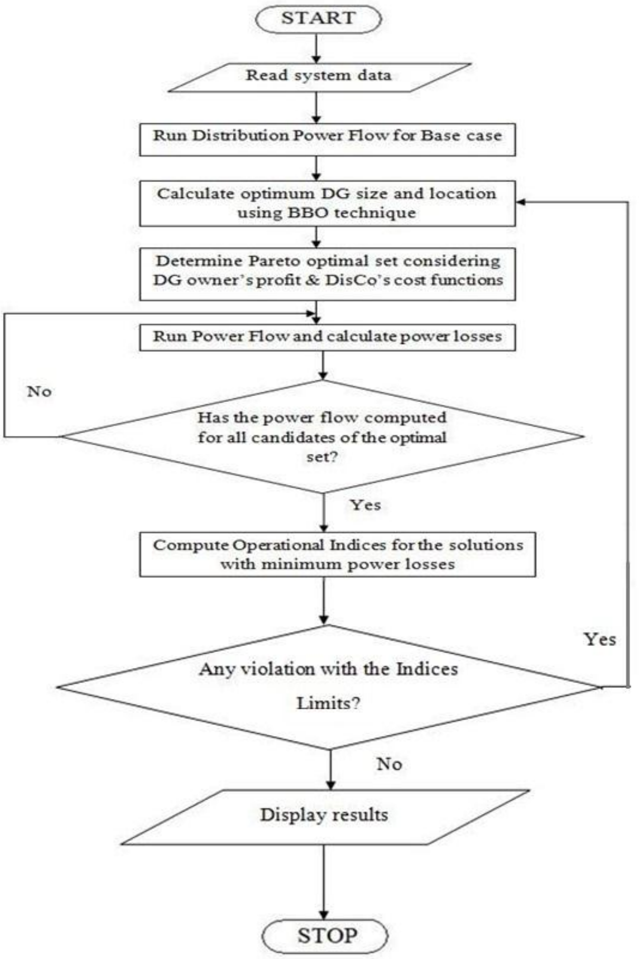

Fig 1: Flowchart of the proposed approach

VI. RESULTS AND DISCUSSIONS

In order to evaluate the effectiveness of the proposed approach, it has to be tested on a standard test system. Here, the algorithm is tested on IEEE 33-bus radial distribution system (Fig 2) and the results are discussed below. Table has the values used for the initialization of the parameters. The following cases not only show the potency of the proposed method, but also give a comparative analysis which proves the DGs in the distribution network has various merits as mentioned earlier.

TABLE I
INITIAL PARAMETERS

Parameters	Values
λ_b (f/km.year)	0.12
CF	1
N_N	20
N_{BUS}	33
N_b	32
INT_R(%)	12.5
INT_F(%)	9
T_h	8760
T_d	365
Max(CP_{DG})($/MWh)	50
Min(CP_{DG})($/MWh)	45
P_{max} (MW)	1
P_{min} (MW)	0

- *Case I:* This is the base case where the DGs were not placed and evaluating the power distribution losses & the cost of power bought by DisCo from the substation.
- *Case II:* Firstly, the sizing and placement for one DG has been simulated and the relevant losses and costs are calculated. Then the DG count has been increased to three and the results were compared.

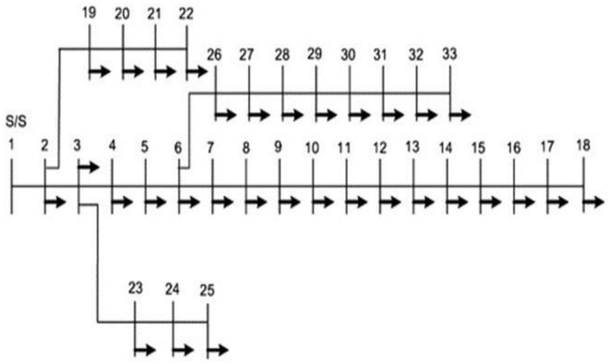

Fig 2: IEEE 33-bus radial distribution test system

TABLE II
VARIOUS DG COSTS

Parameters	Values
DG investment cost ($/MW)	318000
DG maintenance cost ($/MWh)	7
DG operation cost ($/MWh)	29

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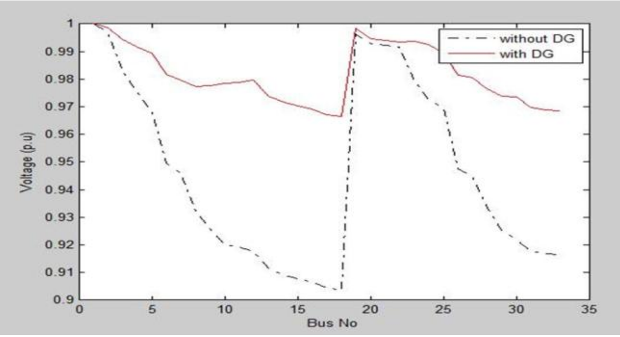

Fig 3: Voltage profile without & with DG

VII. CONCLUSION

In this paper, a technique which involves Biogeography Based Optimization for optimum DG sizing and placement in the power distribution system has been given. Objectives such as voltage profile and voltage stability improvement and reduction of transmission losses have been taken into account, but the important objective is maximizing the profit of DG owner and minimizing cost of DisCo. This algorithm is convenient in such a way that it holds good for any system with suitable modifications. On testing with IEEE 33-bus distribution system, it has been detected that, there is a considerable voltage profile improvement in the system and there is a notable system power loss reduction. Also the computational time is lesser and accuracy is better when compared with other evolutionary algorithms.

Objective Function ($*10^7$)	Load Variation (%)	P Loss (KW)	Q Loss (KVAR)	DG Size (KW)	DG Bus Location	No of DGs	Cost Functions (for 20 Years)								Operational Indices		
							DG Owner's Cost					DisCo's Cost					
							Investment Cost ($)	Maintenance Cost ($)	Operational Cost ($)	DG Owner's Income ($)	DG Profit ($)	DG Power Purchased ($)	Substation Power Purchased ($)	CP($)	TVPI	TVSI	TPLI
NA	0	210.9876	143.1284	NA	NA	0	NA	NA	NA	NA	NA	NA	25091003.45	NA	1	1	1
2.414	0	130.1877	87.1721	992.4036	12	1	315584.35	3678624.41	887943.82	5713402.69	831250.10	5713402.69	18232155.31	45.04	0.64	1.02	0.62
2.285	5% low	115.3313	77.3128	998.9118	12		317884.34	3705434.28	894415.17	5752747.91	835014.12	5752747.91	16903736.47	45.02	0.63	1.02	0.61
2.554	5% high	145.9045	97.6546	997.9181	12		317337.97	3699065.48	892877.87	5742188.60	832907.29	5742188.60	19486084.90	45.02	0.65	1.02	0.62
2.325	0	73.5537	50.9443	961.1381, 996.5926, 999.9180	12, 24, 30	3	940532.28	10963360.37	2646328.36	17021465.25	2471244.24	17021465.25	5310317.76	45.02	0.33	1.06	0.35
2.20	5% low	66.9047	46.3451	985.0428, 989.0567, 997.6430	12, 24, 30		945014.12	11015603.13	2658938.69	17117354.84	2497798.91	17117354.84	3990621.22	45.06	0.29	1.06	0.35
2.44	5% high	81.5513	56.4136	975.8296, 992.5320, 996.6065	12, 24, 30		942859.87	10990492.09	2652877.40	17059340.55	2473111.19	17059340.55	6503378.05	45.01	0.36	1.06	0.35

Table Iii
Comprehensive Results Obtained From The Proposed Methodology

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