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A Review on Different Technique for Optimal Placement of DG in Distribution System

Md.Firoz Ansari[1], Dr. Poonam Syal[2], Dr.Lini Mathew[3]

[1] *M.E.Student, Department of Electrical Engineering, NITTTR, Chandigarh, Punjab University, India*
[2]*Associate Professor, Department of Electrical Engineering, NITTTR, Chandigarh, Punjab University, India*
[3]*Associate Professor, Department of Electrical Engineering, NITTTR, Chandigarh, Punjab University, India*

Abstract – *Distributed Generations (DGs) play an important role in distribution networks. DG units are small scale generating units, connected directly to medium voltage networks near the load centers. Distributed Generation resources have a lot of concentration in present time due to its optimistic impact on power system. Studies show that improper placement and improper sizes of DG units may lead to losses increase, with bed effect on voltage profile and harmonics. The optimal placement of DG is necessary for maximizing the DG potential benefits in power system such as maintaining and improving reliability and stability. There are several research studies to solve DG placement problem by various objectives and their imposed constrains. However, the methodical principle for this object is still an obscure problem. This paper presents general backgrounds and an overview of research and development in the field of different solution techniques for optimal placement of DG. This paper provides helpful guidelines and resources for the future studies in this area.*

Keywords- *Distributed Generation (DG), Distributed Energy Resources (DER), Distribution Systems Optimization, Analytical Approach, Numerical Approach, Heuristic Approach, Optimal location.*

I. INTRODUCTION

The Distributed Generation (DG) is also known by other names like decentralized generation, embedded generation, and dispersed generation. Distributed Generation is simply defined as only source of electrical energy of limited size that is connected directly to the distribution system of a power network. DG units are small scale generating units, connected directly to medium voltage distribution system near the load centers. DG can be powered by number of sources both renewable and non-renewable such as PV solar, wind, mini hydro, geothermal, full-cell, gas turbines etc. [1]. Distributed power generation resources in distribution system have been used to reduce the power losses in the plant, distribution and transmission network and to improve power quality as well as network reliability. The improper allocation of distributed generation units is increasing the losses as well as causing the problem in system performance [2]. The DG placement problem has therefore attracted the interest of many researchers in the last fifteen years [13-31]. This paper reviewed methods of optimal placement of DG and models of DG.

II. DG MODELING

A. Problem Statement
The optimal placement of DG problem deals with determination of the proper placement and size of DG units to be installed into existing distribution system, subject to electrical network operating constrains, DG operating constrains. The optimal placement of DG is a complex mixed integer nonlinear optimization problem.

B. Objective
The first step for optimal placement of DG problem is selection of objective function. The objective function can be single and can be multiple objectives. The main single objective functions are (1) minimization of power losses; (2) minimization of energy losses; (3) minimization of DG cost; (4) voltage profile improvement; (5) maximization of DG capacity; (6) minimization of SAIDI(system average interruptions duration index) etc. Among all these objective minimization of power losses is most common objective used in single as well as multi-objective problems. The multi-objective problems can be solved in different ways:

- The multi-objective function is changed into single objective function by weighted sum of individual objectives.
- The multi-objective problem considering more than one often contrasting objectives and selecting the best compromise solution in a set of feasible solutions.
- Goal multi-objective function, where the multi-objective problem is transformed into a single objective function using the goal programming technique.

C. DG Variables

The following design variables are computed for DG: (1) location; (2) size; (3) location and size; (4) location, size and type; (5) number, location and size; and (6) number, location, size and type.

D. Load Variables

The load profile for optimal placement of DG problem is usually taken as constant load model as in conventional power flow but it can be modeled as: (1) single and multi-load levels; (2) probabilistic loads; (3) time-varying; and (4) fuzzy. The load can be either concentrated on the network buses or distributed along the lines. In case of concentrated load, the following modeling alternatives exist: (1) constant power; (2) variable power that depends on the magnitude of bus voltage; (3) probabilistic; and (4) fuzzy.

E. Types of DG

The power output of Distributed Generator is dependent on the DG technology; So DGs are classified into four types on the basis of power output [3].

- Type-I DG, The DG generates only active power.
- Type-II DG, The DG generates only reactive power.
- Type-III DG, The DG capable of generating both active as well as reactive power.
- Type- IV DG, The DG capable of generating active power but it consumes reactive power.

F. Number of DGs.

In distribution system DG placement can be: (1) single DG placement; or (2) multiple DG placements. But the number of DGs increases the cost also increases.

G. Constraints

The objective is subjected to the following constraints: (1) size and angle of the slack bus voltage; (2) voltage limitation at load bus; (3) power flow equality; (4) branch capacity limits; (5) total harmonic distortion limits; (6) maximum penetration of DG units in the system; (7) short-circuit level limits; (8) power generation limits; (9) reliability constrains; (10) maximum number of DGs; (11) DG with constant power factor; (12) Limited buses for DG installation.

H. Taxonomy

In Table 1, Table II and Table III are reviewed optimal placement of DG types, load models, objective function for analytical approaches, numerical approaches and heuristic approaches.

III. METHODS FOR OPTIMAL PLACEMENT OF DG.

A. nalytical Approach

An analytical technique based on the loss formula is proposed to find size and site of DG so as to minimize power losses [4]. An analytical expression for optimal placement of DG presented in [5] for all types of DG. An analytical method using a loss sensitivity factor that is based on the equivalent current injection is developed in [6] to find the optimal location and size of DG. [7] Developed three analytical approaches using three different power losses expressions to identify the optimal power factor and size of DG units at various locations for optimizing power losses and a methodology to identify the best location. [8] Presented the optimal power flow based technique that provides a means of determining the maximum capacity of generation that may be accommodated in a network.

Table I. Reviewed for Analytical Approach

Reference	DG Type	Number of DG	DG Variables	Load Model	Objective	Objective Function
[4]	Type-I	Single	Size and Location	Constant	Single	Loss minimization
[5]	Type-III	Single	Size, Location and Power Factor	Constant	Single	Loss minimization
[6]	Type-I	Single	Size and Location	Constant	Single	Loss minimization
[7]	Renewable Based DG	Multiple	Size And Location	Constant	Single	Loss minimization
[8]	Type-III,IV	Multiple	Size	Constant	Single	Loss minimization

B. Numerical Approach

1. Linear Programming (LP)

Linear programming is used to find optimal placement of DG in distribution network for maximization of generation [9].

2. Nonlinear programming (NLP)

The mixed integer non-linear programming (MINLP) is developed to find optimal number of DGs to place in distribution system to minimize the cost while the optimal location is decided by loss sensitivity factors in nodal price based zones [10]. MINLP is employed for optimal allocation of different types of DG units considering electricity market price fluctuation [11]. The optimal placement of DG is formulated as a multi-period ac Optimal Power Flow (OPF) that is solved using NLP [12-14]. MINLP is used for optimal placement of DG considering the uncertainties in generation by renewable energy sources as well as uncertainties in load [15-16]. Optimal placement of DG problem is solved by MINLP to improve voltage stability [17].

3. Sequential Quadratic Programming (SQP)

SQP is developed to solve optimal placement of DG without fault level constraints [18].

4. Gradient Search

Gradient search is developed for optimal sizing of DGs in meshed networks [19].

5. Ordinal Optimization (OO)

An ordinal optimization is implemented for specifying the sizes and sites of multiple DGs. An exhaustive search is developed for solving the optimal placement of DG in distribution networks with variable power load [20-22].

C. Heuristic Approach

Heuristic approaches are best suitable for optimal placement of DG problems solution. These provide robust technique and optimum solution. Some of the algorithms that adopt heuristics concepts are given below.

1. Genetic Algorithm (GA)

The GA is a search algorithm based on the application of natural selection and natural genetics to obtain the best optimal solutions for optimization problems [23-26]. The GA is initialized with a population of individuals (solution-optimal location) and a binary representation of the decision variables to perform the search by using genetic operators i.e. crossover, mutation and selection. The quality of an individual is assessed by its fitness, which is based on fitness function. In case of DG placement, this fitness is assessed based on optimizing real power losses, to reduce operational and investment costs, and also providing optimal location and size [27-32]. The population is randomly generated at the start of each search step. The fitness evaluation is used to select the best solution (individuals) from the

Table II. Reviewed for Numerical Approach

Reference	DG Type	Number of DG	DG Variables	Load Model	Objective	Objective Function	Method
[9]	Type-I	Multiple	Size and Location	Constant	Single	Generation maximization	Linear Programming
[10]	Type-I	Multiple	Location and Number of DG	Constant	Single	Cost minimization	MINLP
[11]	Type-I	Single	Size and Location	Constant	Single	Power loss minimization	MINLP
[12]	Wind based DG	Multiple	Type, Size and Location	Probabilistic	Single	Energy loss minimization	OPF
[13]	Renewable based DG	Single	Size and Location	Constant	Multiple	Voltage profile, Power Loss and reliability	OPF
[14]	Renewable based DG	Multiple	Size and Location	Constant	Multiple	Loss minimization	OPF

(Continue Table II)

[15]	-------	Multiple	Size and Location	Constant	Single	Power loss minimization	MINLP
[16]	Type-III	Multiple	Size and Location	Constant	Single	Loss minimization	MINLP
[17]	Renewable based DG	-------	Size and Location	Constant	----------	Voltage Stability margin improvement	MINLP
[18]	Type-III	Multiple	Size, Type Location and Number of DG	Constant	Single	Power loss minimization	SQP
[19]	Type-I	Multiple	Size	Constant	Single	Power loss minimization	Linear Programming
[20]	Type-I	Single	Size and Location	Voltage Dependent	Single	Loss minimization	Exhaustive Load Flow
[21]	--------	Multiple	Size, Location and Number of DG	Constant	Single	Power loss minimization	Ordinal Optimization
[22]	Type-III	Multiple	Size, Location and Number of DG	Constant	Single	Node voltage normalization	Exhaustive Search

Table III. Reviewed for Heuristic Approach

Reference	**DG Type**	**Number of DG**	**DG Variables**	**Load Model**	**Objective**	**Objective Function**	**Method**
[23]	Type-I	Single	Size and Location	Constant	Single	Loss Minimization	GA
[24]	Type-I	Multiple	Size and Location	Constant	Single	Benefit/Cost Maximization	GA
[25]	Type-I	Single	Size and Location	Constant	Multiple	Voltage profile improvement, Power flow reduction	GA
[26]	---------	--------	-----------	---------	----------	Search optimal value	GA
[27]	Type-I	Multiple	Size and Location	Constant	Multiple	Voltage Stability and Loss Minimization	Dynamic Programming
[28]	Type-I	Single	Size and Location	Constant	Multiple	Benefit Maximization	Hybrid GA and OPF
[29]	Type-I	Single	Size and Location	Voltage dependent	Multiple	Voltage profile and Power loss index	GA
[30]	Type-I	Multiple	Size and Location	Constant (Distributed)	Single	Loss Minimization	GA
[31]	Type-I	Multiple	Size and Location	Multi-level	Single	Benefit maximization	GA
[32]	Type-I	Multiple	Size and Location	Constant	Multiple	Real and reactive power minimization	Fuzzy embedded GA
[33]	Type-I	Single	Location	Constant	Multiple	Cost reduction	GA
[34]	--------	Multiple	Size and Location	Voltage dependent	Multiple	Real and reactive power loss	PSO
[35]	--------	Multiple	Size and Location	Constant	Single	Energy loss minimization	PSO
[36]	Type-III	Single	Type, Size and Location	Constant	Multiple	Maximize DG penetration level	PSO
[37]	Type-I	Multiple	Size and Location	Constant	Single	Cost minimization	TS

(Continue Table III)

Reference	DG Type	Number of DG	DG Variables	Load Model	Objective	Objective Function	Method
[38]	------	Multiple	Size and Location	Distributed	Multiple	Power loss minimization	TS
[39]	Type-I, III	Multiple	Size and location	Constant	Single	Loss minimization	ABC
[40]	-------	Single	Location	Constant	Multiple	Reliability enhancement	ABO
[41]	Type-I	Multiple	Size and Location	Multi-level	Single	Loss minimization	SHA
[42]	Type-I	Multiple	Size and Location	Constant	Single	Power loss minimization	DE
[43]	Type-III	Single	Size and Location	Constant	Multiple	Cost and loss minimization	Heuristic
[44]	Type-III	Single	Size and Location	Constant	Single	Power loss minimization	Curve-fitted heuristic
[45]	Type-I,III	Multiple	Size and Location	Constant	Single	Power loss minimization	Curve-fitted heuristic
[46]	Type-I	Multiple	Size and Location	Constant	Single	Power loss minimization	Modified teaching learning algorithm

present generation to upgrade into the next generation. The GA functions are applied for the next generation for having new and better individuals. This process is continued until the best solution in the population is found [33].

2. Particle Swarm Optimization (PSO)

PSO is used to find optimal placement of DG model in distribution system network with non-unity power factor considering variable power load models [34]. The PSO is developed for optimal placement of various DG types that inject real power and inject or absorb reactive power [35]. Discrete PSO computes the optimal DG placement. PSO is used for optimal selection of types, sizes and locations of both synchronous-based and inverter-based DG units to achieve maximum DG penetration considering standard harmonic limits and protection coordination constrains [36].

3. Tabu Search (TS)

TS method is used for optimal placement of DG and reactive sources at by optimizing cost of power loss, cost of fuel served for energy losses and cost of reactive sources for multi-level load [37]. The optimal placement of DG problem is optimized by the TS technique for the case of uniformly distributed loads [38].

4. Artificial Bee Colony (ABC)

The ABC algorithm is used to find the optimal location and size of DG for minimization of losses [39].

5. Ant Bee Optimization (ABO)

An ant bee optimization algorithm is proposed to solve optimal placement of DG problem for enhancement of reliability of system [40].

6. Harmony Search Algorithm (HSA)

HAS and sensitivity factor are proposed to find optimal site and size of DG respectively [41].

7. Differential Evaluation (DE)

The optimal DG sizes are calculated through DE and the optimal DG locations are computed based on bus voltage sensitivities [42].

8. Other Heuristic Algorithms

A conventional iterative technique is implemented to optimally allocate the DG by minimizing losses and cost [43]. A sensitivity test is performed to find candidate bus for optimal placement of DG while best size of DG is found by curve-fitted heuristic [44]. An analytical technique is used to obtain candidate buses for placement of DG and optimal size is obtained by curve-fitted heuristic technique [45]. A simplified teacher- learning algorithm is implemented to find optimal size of DG at optimal location by minimizing losses [46].

IV. CONCLUSION

The paper has presented a critical review of various existing models and optimization techniques applied to the optimal placement of DG units. Many objectives are reported in literature for optimal placement of DG problem but most widely used are minimization of loss, enhancement of voltage stability, maximization of benefit and maximization of DG capacity. The solution methodology which is used for optimal placement of DG problems are classified as analytical, numerical and heuristic approaches. The most commonly used techniques for the optimal placement of DG solution are GA and various heuristics algorithms.

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