A Review of Optimal DG Placement Techniques in Distribution Networks

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Abstract- In power distribution networks, the DG placement technique is one of the best ways for improving reliability and stability. The optimal placement of DG is important for maximizing the DG potential advantages in the power distribution network. The improper placement and sizing of distributed generation units is increasing the losses as well as causing the problem in the power system performance and stability. The various technique and methods have been utilized to obtain the most suitable results for optimal DG placement. This paper is reviewed most popular techniques and methods for the optimal distributed generation placement. This paper provides helpful resources and guidelines for future studies.

Keywords- *Distributed Generation (DG), Distributed Energy Resources (DER), Optimal Placement of DG, Analytical Approach, Numerical Approach, and Heuristic Approach.*

I. INTRODUCTION

The electrical energy is an important part of human life and for economic development. The energy demand across the world is ever increasing and expected to grow in future. The engineers are continuously trying to make it simple, like easy to generate, transmit and distribute with minimum electrical power loss at less expensive cost and easy to use for the consumers.

In a specific order of minimization, DG is one of the efforts in the distribution system. Distributed generation is the dispersed generation or decentralized generation or embedded generation which acquires by conventional and non-conventional energy sources. A conventional source primly contains gas turbine, reciprocating engine, mini turbine, and fuel cell while a non-conventional source contains PV solar, wind, mini hydro, geothermal and biomass.

Due to the limitation of conventional sources and the increasing demand for high-quality electric power, the non-conventional energy resources are used in the power distribution system. The non-conventional sources are highly efficient to reduce global warming and greenhouse emission. Distributed generation resources in the power distribution system are used to reduce the power losses and operating cost in the plant, transmission and distribution network and to improve power quality as well network reliability.

This paper presents the taxonomy of optimal placement of DG techniques. The optimal placement of DG type, bus test system, and number of DG, load model, DG variable, the objective with the objective function and optimization techniques has been reviewed in table-I, table-II, and table-III.

II. OBJECTIVE

The objective function of the optimal placement of DG can be single and multiple objectives. The main objective functions for optimal placement of DG are:

- Minimization of power losses and TDH.
- Improve the voltage profile in a distribution system.
- Minimization of energy cost.
- Maximization of DG capacity.
- Minimization of system average interruption duration index (SAIDI).
- Determine the design variable (i.e. size and location) for DG placement.

The minimization of power losses is a most common objective function used in single as well as multi-objective problems.

III. DG MODELING

A. General Problem Formulation

To obtain the solution of the specific problem of DG placement with a determination of optimal location and size of DG to optimize the objective function. The type and number of DGs are also obtained in DG placement problem considering different load models.

B. Number of DGs.

- Single DG
- Multiple DG
- IEEE Bus test system

C. Design and Load Variable

The design variables are considered for installation of DG such as location, size, the number of DG and load variables are considered such as constant power, variable power depend on the magnitude of bus voltage, time-varying, probabilistic and fuzzy.

D. Types of DG

There are four types of DG on the basis of power output [1].

- Type-I, Generate only active power.
- Type-II, Generate only reactive power.
- Type-III, Generate both active as well as reactive power.
- Type-IV, Generate active power but it consumes reactive power.

IV. OPTIMIZATION TECHNIQUES/METHODS FOR DG PLACEMENT

A. Analytical Optimization Technique

The analytical optimization technique of DG placement is based on the 2/3 rule. This rule has been proposed by H.L.Wills [2] to connect a distributed generation network with 2/3 capacity of incoming generation and place at 2/3 length of the line. Acharya et.al [3] proposed an analytical technique expression to find optimum location and size of DG in the power distribution system so as to minimize power losses. The loss formula based analytical technique proposed by Wang and Nehrir [4] which is applicable to both meshed and radial distribution system. The optimal location, power factor, and size of DG found by Hung et.al [5] using multi-objective index based analytical technique for reducing power losses. Three analytical approaches developed by Hung et.al [6] using three different power loss expressions to find the power factor and optimal size of Dg units at various locations for minimizing power losses and a technique to find the suitable location. An analytical technique using a loss sensitivity factor that is based on injecting active power is developed by T.gozel et.al [7] to find the location and size of a single DG. S.H Lee et.al [8] proposed an analytical method to finding optimal locations of multiple DGs in combination with a Kalman filter algorithm to deterring their optimal size. The analytical expression for finding the optimal location and size of one and two DGs are investigated by P.M.Costa et.al [9]. An analytical technique developed by Mithulananthan et.al [10] to computes the optimal location and size of multiple DG. M.Shaaban et.al [11] developed loss formula, voltage sensitivity coefficient and sensitivity index to minimize power loss and improve voltage profile.

Table I. Reviewed for Analytical Approach

Ref.	DG Type	Bus System	Number of DG	DG Variables	Load Model	Objective	Objective Function	Optimization Technique
[2]	Type-I	33-bus	Single	Location and Size	Distributed	Single	Loss minimization	Zero point analysis and migration zero point
[3]	Type-I	30, 33, 69-bus	Single	Location and Size	Constant	Single	Loss minimization	Exact loss formula and exhaustive approach
[4]	Type-I	30-bus	Single	Location and Size	Constant	Single	Loss minimization	
[5]	Type-I, III	33-bus	Single	Location and Size	Constant	Single	Loss minimization	Exhaustive load flow
[6]	Renewable Based DG	69-bus	Multiple	Location and Size	Constant	single	Loss minimization	Alternative expression
[7]	Type-I	13-bus	Single	Location and Size	Constant	Single	Loss minimization	Classical grid search algorithm for different load model
[8]	Renewable Based DG	30-bus	Multiple	Location and Size	Constant	Single	Maximum DG capacity	Kalman filter algorithm
[9]	Type-I	34-bus	Multiple	Location and Size	Constant	Single	Loss minimization	Analytical approach in the presence of micro-generation
[10]	Type-I, II, III, IV	16 ,33 , 69-bus	Multiple	Location, Size and PF	Probabilistic	Single	Loss minimization	Improved analytical method
[11]	Non-Dispatchable renewable DG	13-bus	Multiple	Location and Size	Constant	Multiple	Active power loss reduction and Voltage profile improvement	Exact loss formula and voltage sensitivity coefficient

B. Numerical Method

In this search provide many techniques such as N.S.Rau et.al [12] presented the **Gradient Search Algorithm (GSA)** for optimal sizing of DG in meshed networks, ignoring and considering fault level constraints.

Linear programming (LP) technique is used to find the optimal placement of DG models and achieving maximum penetration of DG suggested by A.Keane et.al [13]. Harrison et.al [14] proposed an optimal power flow (OPF) based technique for minimization of cost of the load.

The **Non-linear programming (NLP)** is used to solve the DG problem. Atwa et.al [15] suggested finding the optimal number of DG to place in the distribution network to minimize the cost using mixed integer non-linear programming (MINLP). Mixed integer non-linear programming is developed by Kumar and Goa [16] to find the optimal number of DGs to be placed in the distribution network to minimize the cost. MINLP is developed by Atwa et.al [17] for optimal placement of DG considering the uncertainties in the generation by non-conventional energy sources as well as uncertainties in load. S. Pokar et.al [18] employed MINLP for optimal location of different types of DG units considering electricity price fluctuation.

The **Ordinal optimization (OO)** technique is developed by Zhu et.al [19] to decide the size and location for placement of DG in the distribution network. An exhaustive is developed by D. Singh et.al [20] for solving the placement of DG in distribution networks with variable power load.

Sequential quadratic programming (SQP) is developed by A.M.EI.Zonkely et.al [21] to solve optimal placement of DG without fault level.

C. The Meta-Heuristic Search

Heuristic approaches are the best suitable solution for optimal placement of DG problems. These techniques provide an optimum solution. Some of the heuristics concept algorithms are as follows.

Genetic algorithm (GA) is a search algorithm based on a natural selection and genetics to find the size and location of DG. A genetic algorithm based approach was suggested by Singh et.al [22] to find the size and location of DG so as to minimizing power losses considering distributed load. GA is used to solve an optimal placement of DG that consider variable power concentrated load models developed by D.Singh et.al [23], distributed loads, and constant power loads developed by R.K.Singh et.al [24]. Borges et.al [25] implemented GA for optimal DG placement by maximizing benefit relation. GA is developed in addition to deterministic approach by Haesen et.al [26] for multiple objectives DG placement. P.Harrison et.al [27] implemented a combination of GA and OPF for optimal placement of DG. A hybrid GA and fuzzy goal programming are developed by K.H.Kim et.al [28] for optimal DG placement. A combined GA and tabu search is implemented by M.Gandomkar et.al [29].

Tabu search (TS) algorithm was developed by Pham D.T et.al [30] to solve the combinational optimization problem. The optimal DG placement is solved by K.Nar et.al [31] using the TS method for the case of uniformly distributed loads.

Particle swarm optimization (PSO) is applied to find the size and optimal location of DG with nonunity power factor considering variable power load models implemented by A.M.EI.Zonkely et.al [32]. An improved PSO is developed for optimal placement of DG types that inject the active power and absorb the reactive power suggested by W.Prommee et.al [33]. A hybrid GA and PSO is presented by M.H.Moradi et.al [34]. PSO optimize the size while the location is optimized by GA. Discrete PSO is complete with OPF by Gomez-Gomezalez et.al [35]. Ishak et.al [36] used PSO to find optimal size of DG while the optimal location of DG is found by novel maximizing power stability index.

Table II. Reviewed for Numerical Approach

Ref.	DG Type	Bus System	Number of DG	DG Variables	Load Model	Objective	Objective Function	Optimization Technique
[12]	Type-I	6-bus	Multiple	Size	Constant	Single	Loss minimization	Gradient search algorithm
[13]	Type-I	5-bus	Multiple	Location and Size	Constant	Single	Maximizing DG capacity	LP
[14]	Type-III, IV	GSP (Grid supply point)	Multiple	Size	Constant	Single	Load Shed minimization	OPF
[15]	Wind-based DG	14, 30-bus	Multiple	Location and Size	Probabilistic	Single	Energy loss minimization	MINLP
[16]	Type-I	24-bus	Multiple	Location and Number of DG	Constant	Single	Cost minimization	MINLP
[17]	----------	Reliability test system	Multiple	Location, Size, and Type	Constant	Single	Annual energy Loss minimization	MINLP
[18]	Type-I	30-bus	Single	Location and Type	Constant	Single	Loss minimization	MINLP
[19]	----------	Three interconnected circuit system	Single	Location and Size	Constant	Single	Loss minimization	Exhaustive search
[20]	Type	38-bus	Single	Location and Size	Voltage dependent	Single	Loss minimization	Exhaustive load flow
[21]	----------	30-bus	Multiple	Location and Size	Voltage-dependent	Multiple	Power loss indices, voltage profile index minimization	SQP

Table III. Reviewed for Meta-Heuristic Approach

Ref.	DG Type	Bus system	Number of DG	DG Variables	Load Model	Objective	Objective Function	Method
[22]	Type-I	13-bus	Multiple	Location and Size	Constant	Single	Loss minimization	GA
[23]	Type-I	16, 37-bus	Single	Location and Size	Constant	Multiple	Voltage profile and Power loss index	GA
[24]	Type-I	33-bus	Multiple	Location and Size	Distributed	Single	Loss minimization	GA
[25]	Type-I	21, 43-bus	Multiple	Location and Size	Constant	Single	Benefit/Cost maximization	GA
[26]	Type-I	69-bus	Single	Location and Size	Variable	Single	Loss minimization	GA
[27]	Type-I	69-bus	Single	Location and Size	Constant	Multiple	Benefit maximization	Hybrid GA and OPF
[28]	----------	34-bus	Multiple	Location	Constant	Multiple	Loss minimization	GA
[29]	Type-I, IV	14, 34-bus	Multiple	Location and Size	Constant	Single	Loss minimization	GA
[30]	----------	------------	-----------	-----------	------------	----------	Search optimal value	GA, TS
[31]	Type-I, IV	37-bus	Multiple	Location and Size	Distributed	Multiple	Loss minimization	TS
[32]	---------	30-bus	Multiple	Location and Size	Voltage dependent	Multiple	Real and reactive power loss	PSO
[33]	--------	69-bus	Multiple	Location and Size	Constant	Single	Energy loss minimization	PSO
[34]	Type-I	33-bus	Multiple	Location and Size	Constant	Multiple	Power loss minimization, Voltage regulation, and stability improvement	PSO
[35]	Type-I	33-bus	Multiple	Location and Size	Constant	Single	Cost minimization	Discrete PSO and OPF
[36]	Type-I	30-bus	Multiple	Location and Size	Constant	Single	Loss minimization	PSO
[37]	Type-I, III	69-bus	Multiple	Location and Size	Constant	Single	Loss minimization	ABC
[38]	----------	13,33-bus	Single	Location and Size	Constant	Multiple	Reliability enhancement	ACO
[39]	Type-I	33, 69-bus	Multiple	Location and Size	Multi-level	Single	Loss minimization	SHA
[40]	Type-III	6, 14, 30-bus	Multiple	Location and Size	Constant	Multiple	Cost and Loss minimization	Heuristic
[41]	Type-III	33, 69-bus	Single	Location and Size	Constant	Single	Loss minimization	Curve-fitted heuristic
[42]	Type-I, III	12, 33-bus	Multiple	Location	Constant	Single	Loss minimization	Curve-fitted heuristic
[43]	Type-I	16, 33-bus	Multiple	Location	Constant	Single	Loss minimization	Sensitivity index based heuristic algorithm

Artificial Bee Colony (ABC) algorithm is implemented by Abu-Mouti at.al [37] to find optimal location and size for placement of DG and reduce the power losses.

Ant colony optimization is proposed by L.Wang et.al [38] to find the location and size of DG.

Harmony search algorithm (HSA) and sensitivity factor are proposed by R.S.Rao et.al [39] to find the location for placement of DG.

Other heuristic algorithms such as a conventional iterative technique are implemented by Ghosh et.al [40] to find optimal location and size for placement of DG. F.S.Abu-Mouti et.al [41] performed a test to find the candidate bus for optimal placement of DG while the size of DG is found by the curve-fitted heuristic. Naik et.al [42] developed an analytical technique to obtain candidate bus for placement of DG. Rosseti et.al [43] implemented a sensitivity index based heuristic algorithm for optimal placement of DG along with reconfiguration of the network for reduction of losses.

V. CONCLUSION

This paper has presented a brief review of various optimization techniques and models for placement of DG.

It is concluded that the most objective is to minimization of power losses, improvement of system voltage, maximization of benefit and maximization of DG capacity. The techniques for optimal placement of DG can be classified as analytical, numerical and heuristic approaches. The most popular and efficient techniques are used for optimal placement of DG are Genetic Algorithm (GA) and various meta-heuristic algorithms.

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