Optimal Distributed Generation Placement in Power Distribution Networks

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Contents

1. Introduction

Reference

1. P.S. Georgilakis, N.D. Hatziargyriou, "Optimal distributed generation placement in power distribution networks: Models, methods, and future research," *IEEE Transactions on Power Systems*, Vol. 28, No. 3, pp. 3420 – 3428, Aug. 2013.

DG Planning Articles Reviewed in [1] *published during 1994 – 2012*

Journal	Counts
IEEE Transactions on Power Systems	22
IEEE Transactions on Power Delivery	4
IEEE Transactions on Energy Conversion	2
IEEE Transactions on Industrial Electronics	1
IEEE Transactions on Systems, Man, and Cybernetics, Part C	1
International Journal of Electrical Power and Energy Systems	16
Electric Power Systems Research	8
IET Generation, Transmission, and Distribution	8
IET Renewable Power Generation	2
European Transactions on Electrical Power	6
Electric Power Components and Systems	7
Total	**77**

2. MODELS

- Problem formulation
- Number of DG units
- Design variables
- Load profile
- Load model
- Objective
- Constraints

Optimal DG Placement (ODGP)

- Determination of the optimum locations and sizes of DG units to be installed into existing distribution networks, subject to electrical network operating constraints, DG operation constraints, and investment constraints.
- Complex mixed integer nonlinear optimization problem.

ODGP Decision

- **Decision** about DG placement is taken by their **owners and investors**, depending on site and primary fuel availability or climatic conditions.
- Although the installation and exploitation of DG units to solve network problems has been debated in distribution networks, the fact is that, in most cases, the **DSO** (distribution system operator) has **no control or influence** about DG location and size below a certain limit.

ODGP Impact

- **Inappropriate** DG placement may increase system losses and network capital and operating costs.
- On the contrary, **optimal** DG placement (ODGP) can improve network performance in terms of voltage profile, reduce flows and system losses and improve power quality and reliability of supply.
- The DG placement problem has **attracted** the interest of many research efforts in the last fifteen years, since it can provide DSOs, regulators and policy makers useful input for the derivation of incentives and regulatory measures.

Number of DG units to be installed

1. Single DG
2. Multiple DG units *

*** : leader**

Design Variables

1. Location
2. Size
3. Location and size *
4. Type, location and size
5. Number, location and size
6. Number, type, location and size

* : **leader**

Load Profile

1. One load level *
2. Multi-load level
3. Time-varying
4. Probabilistic
5. Fuzzy

* : **leader**

Load Model

1. Constant power (constant P and Q) *
2. Variable power, depending on the magnitude of bus voltage
3. Probabilistic
4. Fuzzy

*** : leader**

Types of objective function

1. Single-objective *
2. Multi-objective

*** : leader**

Types of Multi-Objective Functions

1. **Multiobjective function with weights** (also called **weighted sum method**), where the multiobjective formulation is transformed into a single objective function using the weighted sum of individual objectives:

$$F = w_1 * F_1 + w_2 * F_2 + \ldots$$

2. **Multiobjective formulation** considering more than one often **contrasting objectives** and selecting the best compromise solution in a set of feasible solutions

Single-Objective Functions

1. Minimization of the total power loss of the system
2. Minimization of energy losses
3. Minimization of system average interruption duration index (SAIDI)
4. Minimization of cost
5. Minimization of voltage deviations
6. Maximization of DG capacity
7. Maximization of profit
8. Maximization of a benefit/cost ratio
9. Maximization of system loadability limit (i.e., the maximum loading that can be supplied by the power distribution system while the voltages at all nodes are kept within the limits).

Constraints

1. Power flow equality constraints
2. Bus voltage or voltage drop limits
3. Line or transformer overloading or capacity limits
4. Total harmonic voltage distortion limit
5. Short-circuit level limit
6. Reliability constraints, e.g., max SAIDI
7. Power generation limits
8. Budget limit
9. DG with constant power factor
10. DG penetration limit
11. Maximum number of DGs
12. Limited buses for DG installation
13. Discrete size of DG units

3. Solution Methods

Solution Methods

1. Analytical methods
2. Numerical methods
   - Gradient search
   - Linear programming
   - Sequential quadratic programming
   - Nonlinear programming
   - Dynamic programming
   - Ordinal optimization
   - Exhaustive search
3. Heuristic methods
   - Genetic algorithm
   - Tabu search
   - Particle swarm optimization
   - Ant colony optimization
   - Artificial bee colony
   - Differential evolution
   - Harmony search

Evaluation

- **Analytical methods** are easy to implement and fast to execute. However, their results are only indicative, since they make simplified assumptions including the consideration of only one power system loading snapshot.
- Among the available **numerical methods** for ODGP, the most efficient are the **nonlinear programming**, the **sequential quadratic programming** and the ordinal optimization methods. The main advantage of the exhaustive search method is that it guarantees the finding of the global optimum; however, it is not suitable for large-scale systems, which is also a disadvantage for dynamic programming method.
- **Heuristic methods** are usually robust and provide near-optimal solutions for large, complex ODGP problems. Generally, they require high computational effort. However, this limitation is not necessarily critical in DG placement applications.

4. Industrial Practice *

Source: **CIGRE Working Group C6.19 “Planning and Optimization Methods for Active Distribution Networks”, Convener Prof. F. Pilo (Italy)**

Industrial Practice

1. Distribution companies still adopt traditional DG planning tools ("fit and forget" approach).
2. Advanced models and methods already exist. However, the majority of distribution utilities still use heuristic processes and empirical rules through expert judgment and practical analysis for DG planning.

5. Future Research

Future Research

1. **Coordinated planning**, e.g.:
   - Reconfiguration, capacitors placement, and DG placement for loss reduction.
   - Addition/expansion of substations/lines, and DG planning
2. **Dynamic ODGP**. Planning for multiple years.
3. Consideration of **Uncertainties**, e.g., wind and solar power generation, fuel price, load growth, etc.
4. Use of **Active Network Management**, e.g.:
   - DG can be used, not only to control the voltage, but also to prevent overloads.
   - Reduce the total costs of integrating high penetrations of DG units.
5. Improvements in **Optimization Methods**.
6. **Utility applications**, collaboration with Universities.

6. Conclusions

Conclusions

1. The most common ODGP model has the following characteristics:
    - Installation of multiple DG units
    - The design variables are the location and size
    - The objective is the minimization of the total power loss of the system
2. Distribution companies still adopt traditional DG planning tools
3. Future research areas include coordinated planning, dynamic ODGP, consideration of uncertainties, and active network management