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Optimal integration and planning of renewable distributed generation in the power distribution networks: A review of analytical techniques

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HIGHLIGHTS

- The recent planning methods for distributed generation are critically reviewed.
- A comprehensive review and comparison of analytical techniques is provided.
- The obtained insights can guide future deployment of distributed generation.

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ABSTRACT

The rapid development of distributed generation in different forms and capacities is transforming the conventional planning of distribution networks. Despite the benefits offered by renewable distributed generation technologies, several economic and technical challenges can result from the inappropriate integration of distributed generation in existing distribution networks. Therefore, the optimal planning of distributed generation is of paramount importance to ensure that the performance of distribution network can meet the expected power quality, voltage stability, power loss reduction, reliability and profitability. In this paper, we firstly discuss several conventional and metaheuristic methodologies to address the optimal distributed generation planning problem. Metaheuristic algorithms are often used as they offer more flexibility, particularly for multi-objective planning problems without the pursuit of globally optimized solution. Analytical techniques are considered suitable for modeling power system mechanisms and validating numerical methods. Then, this paper conducts a comprehensive review and critical discussion of state-of-the-art analytical techniques for optimal planning of renewable distributed generation. The analytical techniques are discussed in detail in six categories, i.e. exact loss formula, loss sensitivity factor, branch current loss formula, branch power flow loss formula, equivalent current injection and phasor feeder current injection. In addition, a comparative analysis of analytical techniques is presented to show their suitability for distributed generation planning in terms of various optimization criteria. Finally, we present conclusive remarks along with a set of recommendations and future challenges for optimal planning of distributed generation in modern power distribution networks.

1. Introduction

The rapid development of distributed generation technologies in various forms and capacities is significantly reshaping the conventional planning of power distribution networks [1]. The International Energy Agency [2] defines distributed generation (DG) as an electricity source that is connected directly to the distribution network to supply a local consumer and support the distribution network. DG technologies are usually based on renewable energy sources (e.g. wind turbines, solar photovoltaics (PV), micro-hydro generators and biomass generators) and fossil fuel energy sources (e.g. small gas turbines, internal combustion engines and micro turbines). Over the period from 2000 to 2012, the installed DG capacity per year grew from 47 GW to 142 GW worldwide, and the investments in DG technologies per year rose from $30 billion to $150 billion [3]. It has been projected that yearly installed DG capacity and investments will grow to 200 GW and $206 billion by 2020, respectively [3], as shown in Fig. 1.

Electricity is traditionally supplied by a centralized power generation system that usually consists of a few large-scale generation units, and an extensive interconnected network that transmits and distributes electricity to a range of domestic, commercial and industrial consumers, as shown in Fig. 2. In a centralized power generation system, the

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Nomenclature

f_i	i^{th} objective function
$g(x)$	equality constraints, e.g. power flow equations
$h(x)$	inequality constraints, e.g. upper and lower limits on bus voltages, and line power flows
I_i,I_{ai},I_{ri}	total current, active current and reactive current at i^{th} bus, respectively
$[I]$	vector of the equivalent current injection for each bus except the reference bus
n	number of objectives
nb,N	total number of branches and buses in the distribution network, respectively
OPF_{DGk}	optimal power factor of individual DG unit at k^{th} bus
P_{bi},Q_{bi}	active and reactive power flow through i^{th} branch, respectively
P_{Di}	active power demand at i^{th} bus
P_{DGi},Q_{DGi}	optimal active and reactive power capacity of DG at i^{th} bus, respectively
P_i,Q_i	active and reactive power injection at i^{th} bus, respectively
P_L	total active power losses in the distribution network
R_i	resistance of i^{th} branch
r_{ij}	resistance of branch i–j
$[R]^T$	vector of branch resistance
V_i,δ_i	magnitude and angle of voltage at i^{th} bus, respectively
x,Ω	set and domain of decision variables, respectively

Abbreviation

DG	distributed generation
PV	photovoltaic
MILP	mixed-integer linear programming
MINLP	mixed-integer non-linear programming
OPF	optimal power flow
GA	genetic algorithm
PSO	particle swarm optimization
TS	tabu search
SA	simulate annealing
ACO	ant colony optimization
BIBC	bus injection-to-branch current

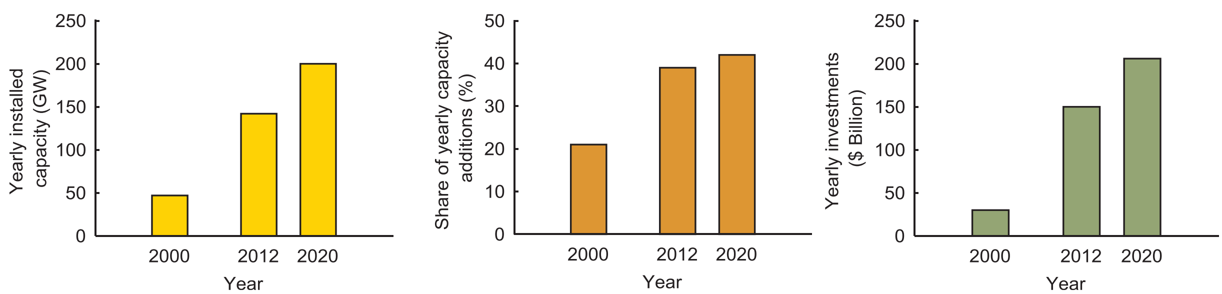

Fig. 1. Yearly installed capacity, share of capacity additions and investments in DG technologies worldwide.

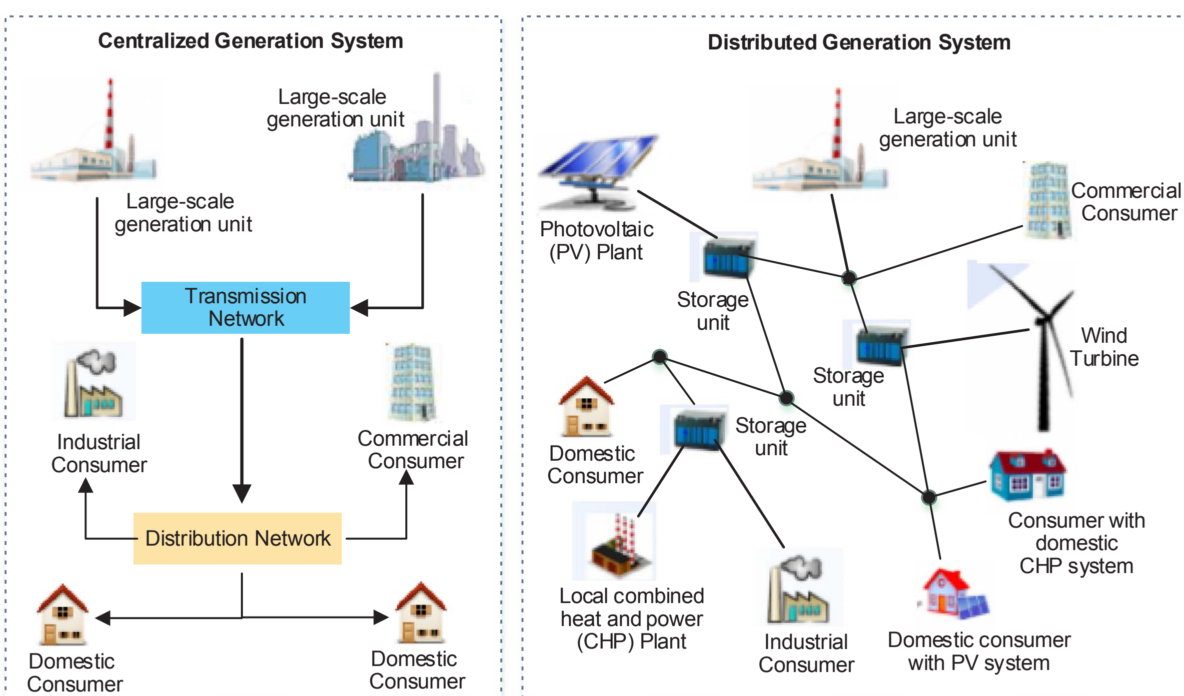

Fig. 2. Centralized and distributed power generation system.