Renewable and Sustainable Energy Reviews 48 (2015) 413–424

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Computational optimization techniques applied to microgrids planning: A review

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ARTICLE INFO

Article history:
Received 30 July 2014
Received in revised form
14 March 2015
Accepted 3 April 2015

Keywords:
Microgrid
Optimization
Planning
Sizing
Siting
Scheduling
Methodology

ABSTRACT

Microgrids are expected to become part of the next electric power system evolution, not only in rural and remote areas but also in urban communities. Since microgrids are expected to coexist with traditional power grids (such as district heating does with traditional heating systems), their planning process must be addressed to economic feasibility, as a long-term stability guarantee. Planning a microgrid is a complex process due to existing alternatives, goals, constraints and uncertainties. Usually planning goals conflict each other and, as a consequence, different optimization problems appear along the planning process. In this context, technical literature about optimization techniques applied to microgrid planning have been reviewed and the guidelines for innovative planning methodologies focused on economic feasibility can be defined. Finally, some trending techniques and new microgrid planning approaches are pointed out.

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Abbreviations: IEA, International Energy Agency; ICTs, Information and Communications Technologies; CHP, Combined Heat and Power; DER, Distributed Energy Resources; RES, Renewable Energy Sources; CERTS, Consortium of Electric Reliability Technology Solutions; WOS, Web of Science; LP, Linear Programming; ILP, Integer Linear Programming; IP, Integer Programming; SA, Simulated Annealing; TS, Tabu Search; GRASP, Greedy Randomized Adaptive Search Procedures; VNS, Variable Neighbourhood Search; ILS, Iterated Local Search; KKT, Karush-Kuhn-Tucker; ES, Evolutionary Strategy; IMP, Integer Minimization Problem; GA, Genetic Algorithm; PSO, Particles Swarm Optimization; AIS, Artificial Immune System; MIP, Mixed Integer Programming; MINLP, Mixed Integer Non Linear Problem; ESS, Energy Storage System; MILP, Mixed Integer Linear Programming; ANN, Artificial Neural Networks; MV, Medium Voltage; Vaccine-AIS, Vaccine-enchanced Artificial Immune System; MDPSO, Modified Discrete Particle Swarm Optimization; VERA, Versatile Energy Resource Allocation; SQP, Sequential Quadratic Programming technique; DP, Dynamic Programming; MPDP, Multi-Path Dynamic Programming; TOU, Time Of Use; DC, Direct Current; MADS, Mesh Adaptive Direct Search; MGSA, Modified Gravitational Search Algorithm; EMS, Energy Management System; AMFA, Adaptive Modified Firefly Algorithm; GSA, Gravitational Search Algorithm; SCSS, Self-adaptive Charged System Search; BFA, Bacterial Foraging Algorithm; CHASE, Competitive Heuristic Algorithm for Scheduling Energy-generation; MAS, Multi-Agent System; GIS, Geographical Information System; VPP, Virtual Power Plants; DH, District Heating

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http://dx.doi.org/10.1016/j.rser.2015.04.025
1364-0321/© 2015 Published by Elsevier Ltd.

1. Introduction

Modern societies are highly dependent on electric energy supply. Following IEA energy statistics, this dependence has been increasing during the last 40 years. Nevertheless, electric power systems have not been significantly upgraded for decades. Since new enabling technologies for energy systems are being developed (such as ICT, microCHP, energy storage and renewable energy sources, smart meters, etc.), new concepts are appearing in modern power systems. One of the most popular is the microgrid concept, being a novel power grid structure based on DER, RES, power electronics and ICTs.

One of the earliest definitions of microgrids was made by CERTS. They define microgrids as *clusters of generators, including heat recovery, storage, and loads, which are operated as single controllable entities*. In addition a comparison between microgrid concepts is done by Ping et al. in [1]

Some microgrid classifications have been presented in technical papers since this concept appeared in 1998, according to Web of Science (WOS) references. Lilienthal points out in [2] different criteria for microgrid classification such as: other grids connection, types of energy generation, voltage level of distribution system, peak load, generation capacity, energy production, number of customers served, load management and metering. He also makes a proposal for microgrid classification regarding size and grid connection, defining four main microgrids types such as: large grid-connected microgrids, small grid-connected microgrids, large remote microgrids and small remote microgrids.

Due to the modular nature of microgrids, they can operate both independently or in conjunction with the main electrical grid. Microgrids not only have less financial commitments and require fewer technical skills to operate, but also rely more on automation [3,4]. *These advantages make microgrids a suitable solution to gradually modernize existing power grids*. Other advantages for microgrid establishment are the integration of renewable resources from local areas and the independence of the consumer from large corporations that manage actual power grids.

Despite all these advantages, planning a cost-effective microgrid is considered as a complex process due to all alternatives to consider at any decision level. Every decision taken in a planning process will influence the capacities of the system in a competitive energy market. Every planning process is built around specific goals and constraints. Not only goals and constraints (such as technical, environmental, geographical, social and regulatory constraints) define by themselves the whole framework of the planning process, but also uncertainties are a key factor in every planning process. They are a powerful source of risks that system planners need to avoid, or at least to control. French in [5] identifies several sources of uncertainties in all the main steps of a decision making process: *uncertainties in modeling, uncertainty expressed during the exploration of the model and uncertainties in the interpretation of results*. But other authors in [6], motivated by practical needs for modeling the decision making problem, have classified every uncertainties under two main categories:

- External uncertainty: related to the lack of knowledge (about the consequences of an action, outside of the control of the decision-maker), and to the nature of the environment.
- Internal uncertainties: presented in the process of identification, structuring and analysis of the decision-maker (depending on the decision maker).

Beyond these uncertainties, constraints and planning objectives, every commercial microgrid must be addressed towards two main goals: cost efficiency and customer satisfaction. In a microgrid, consumer satisfaction means reliability and quality keeping, causing as low environmental impact as possible. Hence, some of these objectives can be opposed to the others regarding costs of the system. It is generally accepted that it is necessary to invest in renewable power sources and in energy efficiency-based technologies in order to minimize the environmental impact of a microgrid. These investments may upgrade the system, but also influences economic feasibility. For instance, economic feasibility for renewable power sources will depend on different issues such as local electricity costs, space requirements, allocation, initial investment, operational and management costs, grid-connection charges, taxes and grants. Strong investments are also needed in order to raise the reliability or the quality of supply, but every project has its own economical constraints, especially at the design stage. *That is the reason why the microgrid planning process is usually based on an optimal or trade-off solution searching process*.

A microgrid (considered as a community energy system) usually encompasses a mix of traditional an renewable power sources-based technologies. Different authors have previously reviewed planning tools for microgrid-related technologies [7,8]. For example, in [7] Mendes et al. introduce the most common available tools for community energy systems planning. They include a survey of these tools, qualifying them as *bottom-up, simulation, equilibrium, operation optimization and investment optimization tools*. Some of these tools are suitable for microgrid planning, such as HOMER, DER-CAM, EAM, MARKAL/TIMES, RETScreen and H2RES. Also D. Conolly et al. presents in [8] a deep comparison of 37 different analysis software tools used to evaluate renewable energy sources integration projects. This paper also includes HOMER, MARKAL/TIMES, RETScreen and H2RES.

Since *a microgrid planning process can be approached as a sequence of optimization problems*, along technical literature different optimization problems have been considered at different planning levels. In this context, different researches have decided to reviewed optimization applied to microgrid-related technologies such as renewable power sources [9–11]. Baños et al. review in [10] optimization methods applied to wind power, solar energy, hydropower, bioenergy, geothermal energy and hybrid systems. Different approaches to optimal design of renewable energy based on hybrid systems are also reviewed in [9] by Erdinc et al. Iqbal et al. present in [11] a generic list of inputs, outputs, objectives and constraints resource allocation problem of renewable energy sources. They also introduce a list of optimization tools, a conflicting objective matrix, and an optimization techniques review.

Hence, several optimization planning techniques have been applied not only to renewable energy sources, but also to energy community systems, e.g. district heating [12–15]. Different energy community systems may require different optimization techniques due to system constraints (mainly technical, environmental and economical) and uncertainties. The appearance of new computational optimization methods and algorithms are allowing new approaches to planning problems. *The coexistence of these widely used mathematical optimization techniques with new ones makes more attractive the idea of reviewing microgrid planning problems*.

2. Computational optimization techniques: a brief introduction

The term computational optimization refers to a group of mathematical techniques focused on the selection of an optimal solution (with regard to some criteria) from a set of available alternatives. Indeed, optimization includes finding the best available values of some objective function given a defined domain or a set of constraints, including a wide range of objective functions and types of domains. The generalization of optimization theory and techniques to other formulations comprises a large area of applied mathematics. Baños et al. introduce in [10] different disciplines included into

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