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A generic framework for distributed multi-generation and multi-storage energy systems

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ABSTRACT

We have introduced a generic decision support tool for concurrent optimal selection, sizing, and operation scheduling of grid-connected or off-grid multi-generation/multi-storage distributed generation and storage (DGS) systems with respect to the dynamics of historical/projected periodical weather data, electricity price, DGS system cost, DGS aging, and the major critical design and operational parameters. This decision support program enables the consumer (ranging from a small house to large-scale industrial plants) to implement the most efficient electricity management strategy while achieving the goal of minimizing the electricity bill.

1. Introduction

Before the Industrial Revolution, food, water, and energy supply chains were decentralized and scattered. In other words, the producers were consumers of their products (farms and agriculture), and the redundancies were supplied to neighbourhood community markets. The Industrial Revolution transformed the lifestyle by centralizing production systems in order to benefit from the economy of scale. This resulted in the development of complex supply chain systems to link the now distant producers to their customers. Similar issues occurred for energy networks as the small scale suburban power generators moved out of cities in order to improve safety and reduce the levelized cost of energy (LCOE). In recent years, however, it seems that distributed [renewable] energy resources (DERs) are "moving the energy network forward to the past!" by recommending network decentralization.

DERs have a few critical advantages, including abundance and relatively scattered geographic distribution. As such, exploring the utilization of local (renewable) energy sources has been a matter of economic benefit and security for energy-importing societies. Furthermore, the possibility of generating energy on the demand side has many advantages in terms of energy efficiency, as it can reduce the power loss due to network transmission, the network footprint, reserve generation capacity, etc. All these features have stimulated the idea of moving from traditional, often low-efficiency, and centralized macrogrids to a decentralized form with numerous small but smart grids fueled using local resources (Fig. 1). The concept of a microgrid seems to have been introduced by the electrical equipment company ABB *Ltd*. in an energy forum in the 2000 [1]. Lasseter [2] argued that, although the application of individual distributed generations (DG) is advantageous from many aspects, it generates many new problems. Therefore, Lasseter and Paigi [3] reasoned that "a better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a microgrid". According to ABB, for microgrids "the investment, maintenance, and operating costs are low and the renewable energy sources have a large share in the mix with correspondingly positive effects on the environment" [1]. Especially, decentralizing the grid seems to be environmentally and economically a viable option at resourced but remote locations, as generally the cost of building a network in a rural area with low population density is much higher than that for high-density urban area. For instance, the South Australia Power Networks company has spent 70% of its investment towards meeting just 30% of its customers' demand at rural locations. For such a scenario the company has projected that with

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Abbreviations

CAPEX	capital expenditure
CC	charge controller
DER	distributed [renewable] energy resources
DG	distributed generation
DGS	distributed generation and storage (Here DGS means: “distributed generation, or storage, or both”)
DOD	depth of discharge
DSM	demand side management
EES	Electrical energy storage
FOM	fixed operation and maintenance cost
GHG	greenhouse gas
GHI	global horizontal irradiation
MILP	mixed integer linear program
MINLP	mixed integer nonlinear program
NPV	net present value
OPEX	operational expenditure
PR	performance ratio
PV	photovoltaic
SOC	state of charge
ToU	time-of-use
LLP	loss of load probability
UN	United Nations

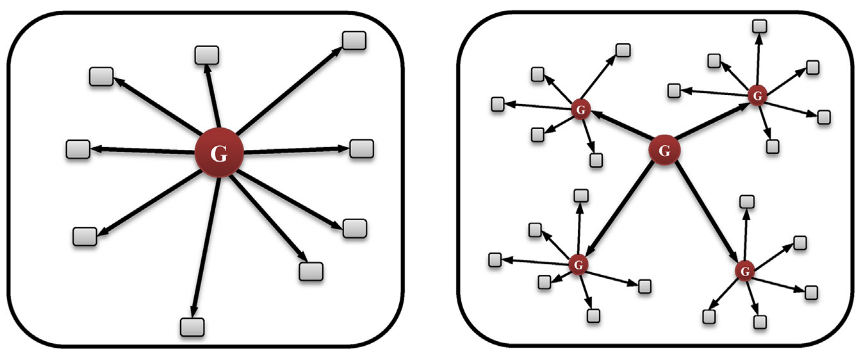

Fig. 1. Centralization versus decentralization (G: Generator).

renewable technologies (wind and solar) along with storage, the rural communities could build microgrids and quit the connection to a macrogrid [4]. Therefore, grid decentralization with the development of microgrids appears a “practically” viable option for locations with suitable resources.

There has been an increasing rate of research into microgrids with mixes of various power generating technologies, both renewable and nonrenewable. A search with keywords of “micro grid” or “microgrid” or “micro-grid” and “electricity” brings 881 documents in Scopus citations, the oldest of which was published in 2000 [1] (see Fig. 2). Over 10 “review” papers on microgrids have appeared in the past few years [5–17], reflecting the high level of academic attention.

Huang et al. [5] reviewed microgrid architectures with distributed energy resources and storage. They analyzed emergency control of microgrids with respect to energy sources and inverters. They concluded that the microgrid technology was not mature at the time and there were various steps to be taken until putting the

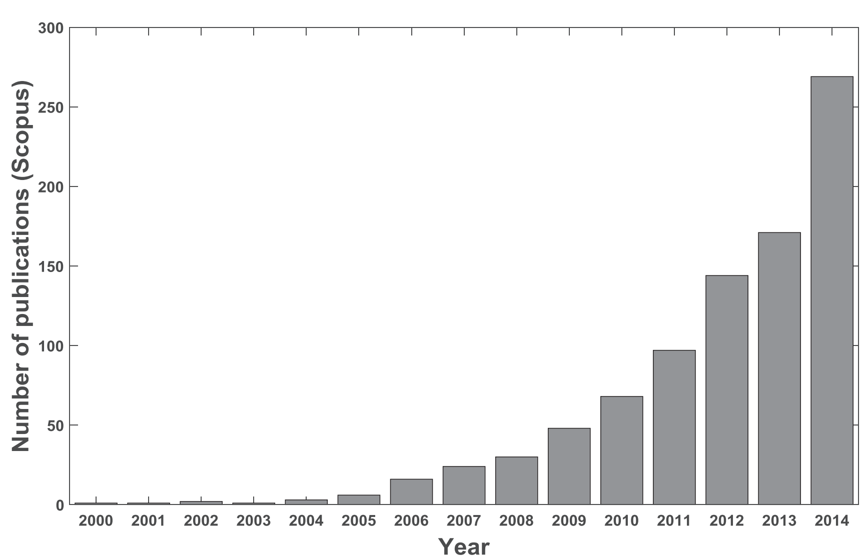

Fig. 2. Trend of publications relevant to microgrids.