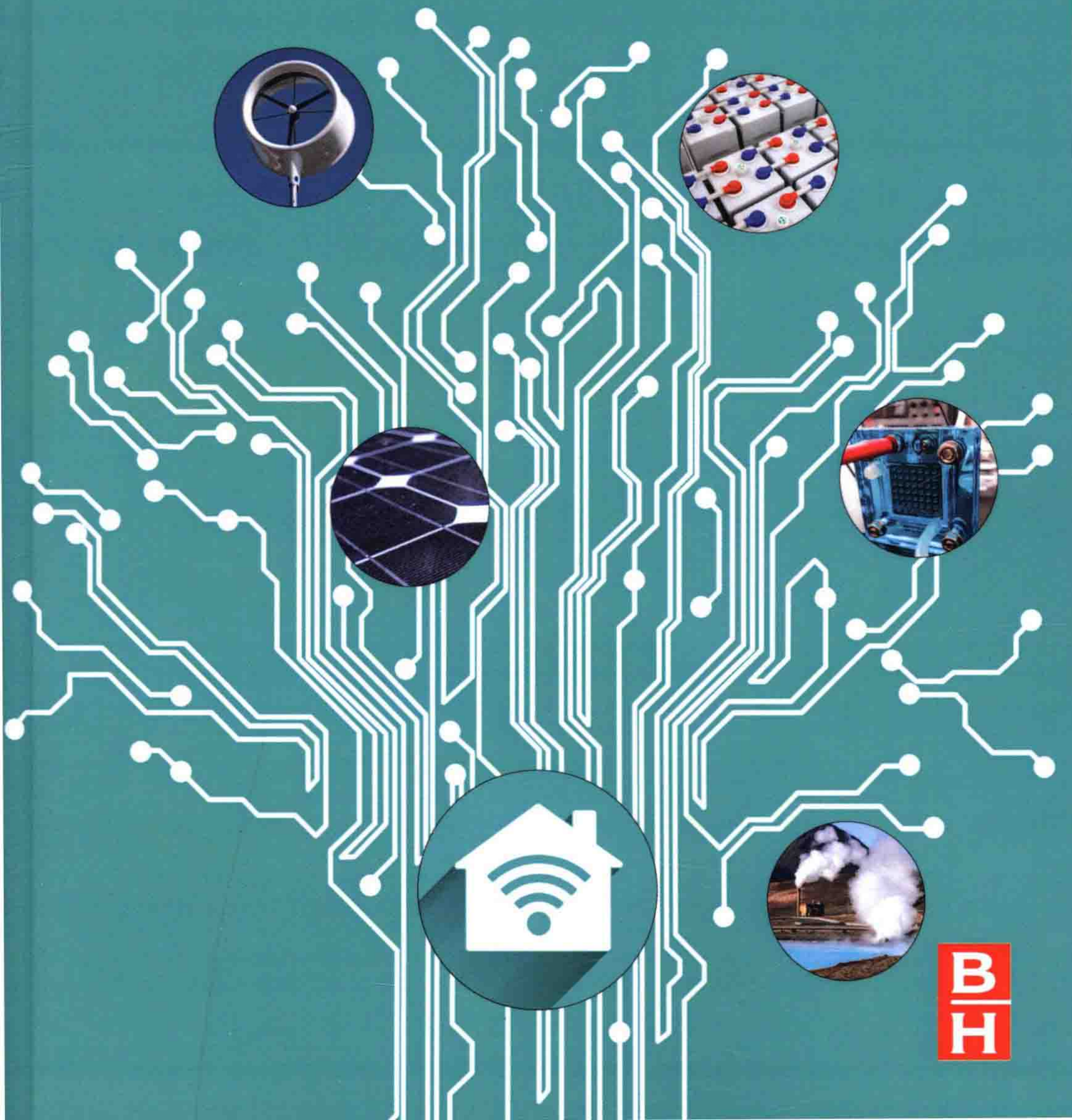
G. B. Gharehpetian
S. Mohammad Mousavi Agah

Distributed Generation Systems

Design, Operation and Grid Integration



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Distributed Generation Systems

Design, Operation and Grid Integration

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A tangible and applicable concept of distributed generation units in the real world

Distributed Generation Systems closes the information gap between recent research on distributed generation and industrial plants, and provides solutions to their practical problems and limitations.

It provides a clear picture of operation principles of distributed generation units, not only focusing on the power system perspective but targeting a specific need of the research community. With worked examples and figures on principal types of Distributed Generation (DG), placing an emphasis on real-world examples, simulations, and illustrations, this book is a useful reference for practitioners.

This book uses exact practical exercises relating to the concepts used in operation and integration of DG units in distribution networks, and helps engineers accurately design systems and reduce the maintenance cost.

Key Features

- Provides examples and datasheets of principal systems and commercial data in MATLAB
- Presents guidance for accurate system designs and maintenance costs
- Identifies troubleshooting references for engineers

Related Titles

Sioshansi / Distributed Generation and Its Implications for the Utility Industry / 9780128002407

Breeze / Power Generation Technologies, Second Edition / 9780080983301

Sioshansi / Smart Grid - Integrating Renewable, Distributed & Efficient Energy / 9780123864529

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CHAPTER 1

Distributed Energy Resources

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1.1 INTRODUCTION

In 1882 in New York City Thomas Edison established the first power plant and distribution network called a power company to provide lighting for the residential sector. Several similar power companies were established in later years. At that time, power generation was decentralized or distributed. In other words, the electrical energy was produced and consumed in the same place. Hence, it was not necessary to establish transmission lines for transmitting the produced electrical energy from the power plant to the consumption place.

In the early 20th century, all power companies were integrated for reasons such as the need to reduce production costs and increase reliability for all subscribers as consumers of electrical energy with the development of the power industry.

At the beginning of 1990, integrated power companies were faced with huge growth in electrical energy consumption due to global population growth and prosperity. This provided challenges for the centralized supply of electrical energy because of electrical energy consumption growth combined with the increasing inability of supplying electrical energy by transmission lines. In addition, following technological developments in the electricity industry, electrical energy production from renewable sources were gradually becoming economically feasible as indicated by increased investment in solar and wind power plants established in the late 1990s.

Environmental considerations became a major concern for humanity because more than 70% of all electrical energy produced came from fossil fuels.

Alarming changes in global climate because of environmental pollution and the consumption of nonrenewable resources of fossil fuels caused designers of electrical energy plants to take into account both environmental considerations and safe and highly reliable electricity generation as a universal human obligation.

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In a centralized system of energy production, all the abovementioned problems and challenges exist due to the productive resources with fossil fuels and the need for energy transfer from production centers to consumption places through a broad network of interconnected transmission systems at different voltage levels.

From the electrical perspective, there are electrical energy losses from production centers to consumption places. About 5% of the energy produced in power plants with an efficiency of 30%–40% is wasted. In addition, in the transmission system between 4% and 5% of electrical energy is wasted and at the end of the distribution network about 10%–15% is wasted. The production of electrical energy consumption was raised near the consumption place, however, by considering all abovementioned challenges with a lot of casualties caused by the transfer of the energy from production to consumption.

The transmission lines development projects will be postponed by the release of the network capacity with supplying the electrical energy to the consumption place (transferring of enormous investments from development projects to projects with higher priority). For instance, for a transmission line with a capacity of 110 MW with an annual growth of 5 MW, there is a need for another transmission line with the same capacity. If the annual growth of the loads is supplied in the consumption place, then an investment required for the establishment of a new transmission line will be delayed due to the lack of transmitting 5 MW of electrical energy. In the 1990s this issue led to international acceptance of decentralized or distributed power generation as an ecofriendly method and placed it on the agenda. But it should also be noted that the development of distributed power generation will not be a complete negation of centralized power generation. But the proper placement of these two power generation systems together, due to the annual growth of load, will cause the investment in transmission lines projects to be delayed. However, these investments can be greatly reduced by controlling the load growth through demand-side management and demand response method. With the development of distributed generation (DG) in the 1990s and the willingness of consumers to embrace the gradual establishment of these kinds of resources, forecasts in relation to the installed capacity of these resources show increased growth in the future. However, the Electrical Power Research Institute (EPRI), predicted that 25% of the total productive resources in the United States would be supported with distributed resources, but for some reason this has not happened. According to Gas Energy Research (GER), installed capacity of DG resources in the world should have reached 27,000 MW by 2015, which is a substantial amount.

Table 1.1 Increased installation of distributed generation in the United States [1]

Year	2005	2006	2007	2008	2009	2010	2011	2012
DG (MW)	900	1300	2000	3000	4000	5100	5600	6600
Year	2013	2014	2015	2016	2017	2018	2019	2020
DG (MW)	7800	9000	10,300	12,100	13,800	15,300	16,800	19,100

The abovementioned key notes represents a worldwide movement to increase DG systems. Table 1.1 presents the prediction of increased installation of DG in the United States between 2006 and 2020. As seen in this table, the latest estimation of the installation of DG in the United States is 19,100 MW (in 2020), which is more accurate than other estimations.

1.2 DEFINITIONS OF DG

A clear definition is necessary for the DG concept because there is diversity and different combinations of phrases in English in relation to DG.

In general, there are two terms in the scientific literature: *distributed generation* and *decentralized production*. The evolution of the use of these words indicates that DG has gradually eliminated the term decentralized production in almost all relevant scientific literature.

In addition to these terms, *embedded generation* is common in some texts. Also, the term *distributed resource* is sometimes used for the concept of DG.

From the perspective of the electricity market to the DG, the term *distributed utility* is an alternative to all sets of DG, which are used as a distributed company. Finally, we note that the outdated term *power distribution* no longer is used in the scientific literature.

As for a definition of DG, with reference to sources in this field, we are faced with two general definitions. According to the first definition given above, DG refers to the energy source that production capacity is limited. Although this definition is correct in some cases, fails in comprehensiveness. But the second definition of DG sources, with the direct ability of the connections to the distribution network and to the consumer, offers a comprehensive definition. Based on the concepts discussed above, the second definition will be used in this book. So in general, these sources are directly connected to the distribution network or the consumer who must be supplied.

Before expressing the characteristics of these resources, it is necessary to highlight a common mistake in connection with the definition of these resources. It is usual that every source of renewable energy for energy production is known as DG or any DG is necessarily called as a renewable source.

In other words, a DG addition to the use of fossil fuel resources (as the primary nonrenewable energy source) has the ability to use renewable energy sources.

This mistake occurs in the type of technology used in the production of these resources. On the other hand, it is believed that productive resources should necessarily use the latest technology. DG, in addition to using old technologies such as internal combustion engines, and diesel and gas turbines, also uses new technologies including fuel cells and power electronic converters.

1.3 FEATURES OF DG

In this section, the characteristics of DG resources, on the basis of the two criteria of voltage level and production capacity, as discussed in the previous section, are explained.

For the first criterion, the voltage level of the connection as a criterion is very important because the DG can be connected to the distribution network and also directly feed the consumer.

Therefore, the voltage levels of 11, 20, and 33 kV as a medium voltage level to connect the DG sources to the distribution networks and the voltage level of 400 V as a low voltage level for direct connection of these sources to the consumer are considered.

For the second criterion, as production capacity, research centers and researchers have proposed different definitions and ranges. For example, the EPRI has defined a production capacity of 1 kW to 50 MW for the application of a DG as a production source. According to Gas Research Institute (GRI), the production capacity range is from 25 kW to 25 MW. Preston & Wrestler company and Cardel company define the production capacity range of 1 kW to 100 MW and 50 kW to 1 MW, respectively. According to the Institute of Electrical and Electronics Engineers French Community (CIGRE), production capacity of DG should be in the range of 50 kW to 100 MW.

However, apart from the criteria presented above, on the basis of production capacity, DGs are divided into four categories: micro (1 W to 50 kW), small (5 kW to 5 MW), medium (5–50 MW), and large (more than 50 MW).

It is important to always consider that with further increase in the range of production capacity, the injection current of DG to the distribution network does not exceed the limit of the tolerable network's current capacity.

1.4 OPERATION OF DG

The operation of DGs is one of the most important subjects in this field. Detailed knowledge of operational abilities of these resources in a manner