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Operation and planning of distribution networks with integration of renewable distributed generators considering uncertainties: A review

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ABSTRACT

Distributed generators (DGs) are a reliable solution to supply economic and reliable electricity to customers. It is the last stage in delivery of electric power which can be defined as an electric power source connected directly to the distribution network or on the customer site. It is necessary to allocate DGs optimally (size, placement and the type) to obtain commercial, technical, environmental and regulatory advantages of power systems. In this context, a comprehensive literature review of uncertainty modeling methods used for modeling uncertain parameters related to renewable DGs as well as methodologies used for the planning and operation of DGs integration into distribution network.

The authors strongly recommend this review to researchers, scientists and engineers who are working in this field of research work.

1. Introduction

Provision of electric energy for consumers is mostly based on having centralized generation which involves use of conventional generators. Then, the generated electricity is transmitted via a transmission line to substations where the voltage is step down before the electricity is distributed for energy consumption. However, the centralized generation is characterized by the following challenges including transmission and distribution losses, high cost of fossil fuels, and greenhouse effect (greenhouse effect is a process whereby some of the sunlight energy to the earth is been trap by the atmosphere). Therefore, the distributed generators (DGs) have been adopted to overcome these challenges. Dispersed generation, district generation, decentralized generation, embedded generation, local generation, and on site generation, are all terms that refer to DG.

In order to help understand the DG concept, there are different definitions of DG in the existing literature [1–8], which are defined from the perspective of location and/or capacity.

With respect to location, DG can be defined as electric power generation source connected directly to distribution network or on the customer side (very close to the demand) [1,2]. Also, it means small generating units installed in strategic places of the power network close to load centres [3–5]. In perspective of capacity, DG is a large number of small size power (500 kW and 1 MW) generating unit which are distributed within the distribution network [6]. While, others defined DG as the strategic placement of small power generating units (rating from 5 kW to 25 MW) at or near customer loads [2]. In perspective of location and capacity, DG is a small unit of power (usually with rating from less than 1 kW to many tens of MW) that is not a part of a large central power network and is located close to the load [7]. Small generation units of 30 MW or less located at or near consumer centres are also referred to with the same term [8].

In general, DG is defined as an electric power source connected directly to the distribution network or on the customer site of the network [1]. From the perspective of size, Ackerman et al. [1] have classified DG into four sizes as follows: micro distributed generation (1–5 kW), small distributed generation (5–5 MW), medium distributed generation (5–50 MW) and large distributed generation (50–300 MW).

Currently, DGs installation in power systems are rapidly increasing due to its ability to maximize the usage of renewable energy such as wind, solar, hydro, geothermal, biomass and ocean energy etc. [1,9–15]. According to Borges et al., DGs can be used in an isolated way to supply the consumer's local demand or in an integrated way to supply power to the remaining of the system [3]. Optimum priority during planning should be given to location, size, and types of DG in order to

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maximize the benefits of DGs [11]. Optimal allocation of DGs reduces system losses and leads to improvement in the voltage profile, enhances system reliability, load ability, voltage stability, voltage security, and power quality.

DG is considered as an alternative solution to supply power for new costumers especially in the competitive electricity market [5] for the following reasons: a) Quick response time and minimal risk to investment since it is built in modules; b) Small-size modules that can track load variation more closely; c) The government approval for utilities and land availability can be discarded due to small physical size that can be installed at load centres; d) The successive improvement of DG technologies.

In the following literature, most of the studies have been carried out to investigate optimal methodologies in order to minimize the power losses and cost of DGs. For example, the authors in [16–19] have focused on reviewing the optimization methods used in DGs planning considering objectives, decision variables, and DG type applied constraints. While, in [20,21] the authors have reviewed uncertainty modeling approaches for DGs planning to show both the weakness and robustness of these methods.

It is clearly shown from the above description that all the published review work was restricted to consider the DGs planning. According to the author's knowledge, there is no study that covers the uncertainty and optimization methods concurrently, which is most important for any researcher in DGs planning. With the above backdrop, the novelty of this work relates to review the optimization method used in DGs placement problem in addition to uncertainties methods.

This paper is organized in the following manner. Section 2 represents the details of DG include the technologies and types, applications and benefits. Section 3 illustrates the challenges to increased penetration of DG. Section 4 discusses DG planning models including objectives, constraints, uncertainties modeling methods, reliability indices under uncertainties, market and economic operation aspects of renewable DGs under uncertainty and mathematical algorithms. Finally, a conclusion is presented in Section 5.

2. Distributed generation (DG)

2.1. Technologies and types

DGs technology can be classified into three types including renewable technology (green or sustainable), non-renewable technology (traditional) and storage technology [22–26]. Renewable technology comprises wind, solar (photovoltaic (PV) and thermal), bio-mass, geothermal, tidal and hydro-power (small and micro). Non-renewable technology comprises micro-turbine, gas turbine, reciprocating engines and combustion turbine. Storage technology comprises batteries, supercapacitor, flywheels, compressed air energy storage (CAES) and pumped storage. Each technology has its own benefits and properties [12–27]. Furthermore, the deployment of these technologies has started to take place in the electricity market, thereby providing an alternative means of meeting the customer load demand. Fig. 1 depicts the classification of DGs technologies.

2.2. Applications

The types of DGs technologies that can be used in various applications according to the load requirements, includes [28,29]:

- As stand-by sources for supplying the desired power for sensitive loads (e.g. hospitals) during grid outages.
- Standalone sources in isolated areas – rural and remote areas.
- As supply for peak loads at peak periods in order to reduce the power cost.
- To combine heat and power (CHP), also known as Cogeneration, by injecting power into the network.

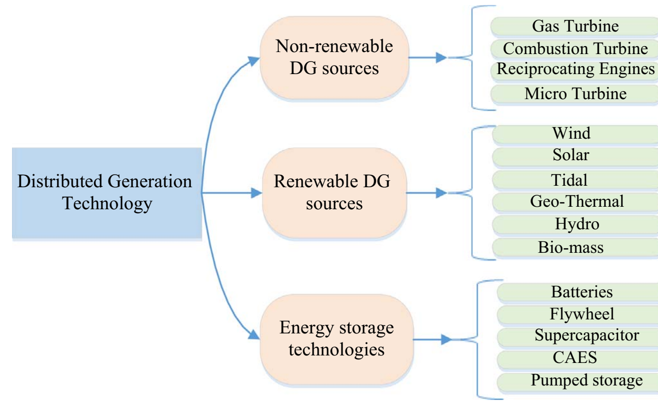

Fig. 1. : Distributed Generation Technologies.

- To supply part of load and support the grid by improving voltage profile, power quality and reducing the power losses.
- Grid connection to sell electric power.

2.3. Benefits

Several benefits can be attained by connecting DGs to distribution systems. These benefits are categorized into technical, economic and environmental benefit. Table 1, gives a description of these benefits according to their category [22,28–33].

3. Challenges

Today's DGs installations are facing multiple challenges that can be classified into four types; commercial, technical, environmental and regulatory. Overcoming of these challenges will lead to maximize the utilization of DGs [14,17]. These challenges are better explained in Fig. 2.

3.1. Commercial challenges

The number of DGs can be increased by implementing active management approaches in distribution networks. New commercial

Table 1
DG benefits.

Technical point of view	Economical point of view	Environmental point of view
• Integration of DG at strategic locations leads to reduced system losses. • Integration of DG provides enhanced voltage support thereby improving voltage profile. • Improved power quality. • Enhancement in system reliability and security. • Power supply autonomy of rural or isolated areas. • Increase overall electric power energy efficiency.	• Deferred investments for upgrade of facilities. • Lowering operation and maintenance cost. System productivity is enhanced due to diversification of resources. • It results to an indirect monetary benefit by reduce healthcare costs due to improved environment. • Reduced fuel costs due to increased overall efficiency. • Reduced reserve requirements and associated costs. • Lower operating costs due to peak shaving. • Reduction of investment risks.	• Reduced output emissions of pollutants. • Reduce global warming • Encourages use of renewable energy