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Optimal sizing and location of renewable energy based DG units in distribution systems considering load growth

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ABSTRACT

In recent years, scientists have extensively focused on renewable energy resources such as wind power and solar units to reduce the consumption of fossil fuels as the main source of environmental pollutions. One of the main challenges for the production of wind and solar energies is that they often involve uncertainties due to the stochastic natures of wind speeds and solar radiation. Therefore, the existing uncertainties in the resources of wind and solar units must be considered in the planning procedure of distribution systems for having a reliable performance. To consider uncertainties in the output power of renewable energy resources, a new formulation is proposed to determine the optimal location and sizing of solar and wind units in the distribution system. To achieve this, Particle Swarm Optimization (PSO) algorithm as a robust technique is employed to find the best location and sizing of wind, solar and fuel cell units in the distribution system. The main objective of the present work is to minimize the Total Harmonic Distortion (THD), the total power losses, the total cost of DG units (including investments, replacement, operation and maintenance costs) and greenhouse gas emissions. Different types of loads such as linear and non-linear loads as well as load growth are also considered in the distribution system. To demonstrate the effectiveness of the proposed algorithm, 31-bus test system is considered as the case study. Our findings show that the use of renewable energy resources significantly reduces the greenhouse gas emissions in the mentioned system. Furthermore, the simulation results reveal that DG units must be added at some years to keep the voltage within its allowable limits.

1. Introduction

In recent years, the consumptions of electrical energy have extensively increased and this motivated the distribution system companies to supply the required power by proper design and utilization of networks. Hence, implementing the DG units in the distribution systems is one of the main solutions to provide loads of the consumers. Among various DG technologies, using of renewable energy resources such as solar, wind, and biomass has been widely considered because of their environmental benefits [1]. In fact, renewable energy resources generally require less maintenance expense than other DG technologies. The costs of their operations are also low since their fuel is derived from natural and available resources. Furthermore, the greenhouse gas emissions such as carbon dioxide or other chemical pollutants can be remarkably reduced by using renewable energy resources and consequently their detrimental effects on the environment would be minimized.

The installation of the DG units has a great role in the distribution system performance. The placement and sizing of the DG units are very crucial and challenging in the distribution system since the optimal and strategic placement of DG units reduces the system power losses and improves system voltage profile, reliability, voltage regulation, power quality issues, etc. [2,3]. The installation of DG units can have either positive or negative impacts [4]. Therefore, the installation of DG units in the proper size and location in the distribution systems is the most important problem.

Recently, many different algorithms have been widely implemented and proposed to solve the DG unit optimization problems in different systems. The main differences in these solutions are based on the formulation of problem, methodology, constraints and also assumptions being made. Some studies are based on the optimization of DG units in the hybrid systems and they only find the optimal sizing of DG units. In [5] PSO algorithm is implemented for the optimization of grid connected micro-grid consisting of photovoltaic, fuel cell and ultra capacitor considering frequency control. This algorithm is also used in [6] to optimize the reliable hybrid renewable energy system. In [7], the optimal sizing of hybrid grid-connected PV–Wind power systems is determined in order to minimize the life cycle cost of the proposed system.

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Ref. [8] proposed a methodology for the optimization of a stand-alone hybrid PV-Wind-Hydrogen system supplying a desalination unit. In this research, the main purpose was to minimize the initial investment cost of the system. Determining the optimal size of the PV-diesel generator and the energy storage system in a stand-alone ship power system is done in [9]. Minimizing the investment and fuel cost and also the CO_2 emissions are the primary objectives of this paper. A method based on Hybrid Big Bang–Big Crunch (HBB–BC) algorithm is proposed in [10] for the optimization of a stand-alone PV, wind and battery bank hybrid power system. The objective of the paper is minimizing the total present cost of the hybrid system. In [11], Mine Blast Algorithm (MBA) is used to find the optimal sizing of a hybrid PV/WT/FC system for a remote area in Egypt to decline the annual cost of the hybrid system with load coverage. The main focus of the accessed papers is only based on finding the optimum sizing of the different DG technologies in hybrid systems.

Extensive optimization analyses were performed in the distribution systems by considering technical and economical constraints. In order to reduce power losses, Ref. [12] proposed a multi-objective shuffled bat algorithm for optimal placement and sizing of the DG units in radial distribution systems. In this work, minimizing the voltage deviation is also considered in its objective function. Ref. [13] used index vector method to find the optimum DG locations. In the mentioned paper, flower pollination algorithm is proposed to determine the optimal size of DG units. A novel method for optimization of DG units is presented in [14]. Minimizing the total power losses of the radial distribution system was the main objective of this paper. The loss sensitivity factor was used to find the optimal location of DG units. Also, intelligent water drop algorithm is used for the optimal sizing of the DG units. Bacterial foraging optimization algorithm is proposed in [15] for optimal location and sizing of DG unit in the radial distribution system. Reducing the total power losses and improving the voltage profile were the primary objectives of this study.

A hybrid method based on improved particle swarm optimization algorithm and Monte Carlo simulation is proposed in [16] for optimal DG placement and sizing in distribution networks in order to minimize the costs of total power losses and improve the voltage profile and reliability of the distribution networks. Ref. [17] used PSO algorithm to obtain the optimal location of DG units in the radial distribution systems and reduce the power losses. A Modified Teaching–Learning Based Optimization (MTLBO) algorithm is proposed in [18] for the optimization of DG units in distribution systems. Ref. [19] applied metaheuristic algorithms including PSO, GA and Imperialist Competitive Algorithm (ICA) to determine the optimal location and size of DG units in a distribution system.

Ref. [20] proposed a problem formulation of renewable energy DG unit location and size planning that considers various constraints, relevant uncertainties, and load variations aiming at maximizing benefits of the distribution company. The main objective of [21] was to optimize the size of DG units in a hybrid power system with wind and energy storage units considering uncertainties. Ref. [22] introduced a new application of multi objective particle swarm optimization with the aim of determining optimal location and size of DG units and shunt capacitor banks simultaneously with considering load uncertainty in distribution systems.

Some studies also used mathematic programming such as Mixed Integer Linear Programming (MILP) and Mixed Integer Quadratic Programming (MIQP) to allocate DG units. Ref. [23] presented an optimization model formulated as a MILP, which determines the optimal technology portfolio, the optimal technology placement, and the associated optimal dispatch, in a micro-grid with multiple energy types. In [24], a MILP approach is also implemented to solve the problem of optimal type, size and allocation of DG units in radial distribution systems. A method based on MIQP with quadratic constraints is proposed in [25] to determine the optimal number, locations and sizes of multiple types of DG units simultaneously for power loss minimization.

Besides the abovementioned objectives, some studies have also considered power quality issues such as voltage sag, total harmonic distortion in their objective functions. In [26], PSO algorithm is used to find the optimal placement and sizing of DG units in distribution systems considering harmonic and protection coordination limits. Maximizing DG penetration level was the main objective of the mentioned paper. In this work, the main constraints were bus voltage limits, total and individual harmonic distortion limits, etc. Ref. [27] applied genetic algorithm for the optimization of DG units in distribution systems. The main constraints of this paper were voltage limits, feeder capacity, THD limits and maximum penetration limit of DG units. In [28], Improved Gravitational Search Algorithm (IGSA) is proposed to find the optimal sizing and location of DG units in a distribution system. In this work, the authors tried to minimize the total power losses, average total voltage harmonic distortion, and voltage deviation in the distribution system. In [29,30], the voltage sag is considered as another power quality index. They used genetic algorithm to find the optimal allocation of DG units.

In most of previous works, the authors did not consider the uncertainty of the output power of DG units and required loads in distribution systems. In addition, the load growth for different types of loads was not considered in their optimization procedure. Furthermore, loads did not vary with time and were assumed to be constant in previous studies. To incorporate the uncertainty and load growth, a new methodology is presented for optimal sizing and placement of renewable energy resources in the distribution system. Therefore, the innovations of our paper based on literature reviews can be listed as follows: (i) incorporating different types of loads such as linear and non-linear loads in distribution system (ii) considering the time-varying loads in the distribution system (iii) considering load growth for the available loads in the mentioned system (iv) considering the uncertainty of wind and solar power and load demand in the simulation procedure.

In this paper, the optimization of distribution system based on wind, solar and fuel cell is carried out via PSO algorithm. The backward/forward sweep technique and harmonic power flow algorithm are implemented for power flow simulation. The optimization objectives are considered as follows: (i) the reduction of the system power losses, (ii) the reduction of total costs of capital, operation, maintenance and replacement of DG units, (iii) the reduction of total harmonic distortion, (iv) the improvement of voltage profile, and (v) the decrease of greenhouse gas emissions in the radial distribution system.

The rest of this paper is outlined as follows: the components used in the distribution system are stated in Section 2. Section 3 presents uncertainty calculation. The problem formulation is described in Section 4. The PSO-based approach for solving the optimization problem with harmonic consideration is given in Section 5. The simulation procedure and results are given in Section 6, and finally, the conclusion is presented in Section 7.

2. Components used in distribution system

2.1. Renewable energy resources

Since the early 1970s, the exploitation of renewable energy resources such as wind and solar power has become increasingly attractive and cost effective due to oil crisis [31]. Several environmental and economical benefits made them very popular as alternative resources for energy production in distribution networks. In fact, the main advantages of these resources are that they have minimum environmental impacts and also low greenhouse gas emissions. To take full advantages of these resources in the present study, renewable energy resources including wind and solar power are used to install in the distribution system. These units are briefly expressed in below.