Electrical Power and Energy Systems 45 (2013) 413–419

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

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

# Multi-objective optimization for upgrading primary feeders with distributed generators from normally closed loop to mesh arrangement

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ARTICLE INFO

*Article history:*
Received 12 June 2012
Received in revised form 4 September 2012
Accepted 26 September 2012
Available online 6 November 2012

*Keywords:*
Distributed generation
Primary feeder
Genetic algorithm
Multi-objective optimization
Normally closed loop
Mesh arrangement

ABSTRACT

This paper presents a multi-objective evaluation approach for finding the optimal schemes for upgrading primary feeders with distributed generation resources (DGs) from normally closed loop to a mesh arrangement. To build a DG-friendly distribution system for the development of DGs, a genetic algorithm (GA) based approach has been proposed to solve this multi-objective optimization problem. The major objectives include improving the average voltage deviations, minimizing the total line losses and maximizing the possible installed capacity of DGs. Based on the given total installation capacity and location for DGs, two distinct planning strategies are discussed. The results show that the proper schemes for utilizing additional feeders are important to improve the voltage profile along feeders, to reduce the system power losses and maximize the possible installed capacity of DGs. The outcomes are of value to the upgrades and expansions of primary distribution systems and the implementation of sustainable development of renewable energy.



## 1. Introduction

As of now, a bulk of the world's electric energy is produced by fossil fuel in particular coal-fired power plants. The undesirable consequences of the burning of fossil fuels, such as high carbon dioxide emissions, have been getting a lot of attention. And the carbon dioxide emissions are generally considered to be the major contributing factor of global warming. Renewable energy which is produced without the undesirable consequences of the burning of fossil fuels has been considered as one of the key solutions to energy challenges and global warming. As a result, more renewable energy is required and a large number of distributed generators have been installed and operated in parallel with distribution systems [1]. In recent years, the penetration of distributed generation in Europe is increasing tremendously, especially on the wind energy resources. In India, demand for electric power is increasing gradually and the peak load demand management is becoming crucial. The power generation from renewable sources was proposed to fill the gap between peak load demand and availability of power at the regional level [2]. In [3], a real time supervisor was proposed to enhance congestion management. The proposed supervisor performs automatic and dynamic re-dispatchings using both variable speed wind generators and conventional generators. The proposed approach leads to reduced re-dispatching costs and increase network reliability.

Traditional electric power distribution systems are designed without considering the impact of distributed resource (DR) interconnection. It often results in operating situations that do not occur in a conventional system. Several system issues which may be encountered as DR penetrates into distribution systems were discussed in [4]. The voltage issues covered are the DR impact on system voltage, interaction of DR and capacitor operations, and interaction of DR and voltage regulator and LTC operations. It is undoubted that a large number of small generators will be connected to the distribution networks. Efficient integration of this distributed generation requires network innovations. Some innovative concepts such as microgrids and virtual utilities were presented in [5]. In [6], an optimal control method of distribution voltage with coordination of distributed installations, such as on-load tap changer (OLTC), step voltage regulator (SVR), shunt capacitor (SC), shunt reactor (SR), and static var compensator (SVC) was proposed to minimize voltage variation from the standard value and reduce distribution loss under limited number of operations of control devices. To control the voltage deviation of distribution system caused by DGs, an optimal voltage control methodology by using the tap changing transformer and the inverter based DGs has been proposed in [7]. In [8], the present status of battery energy storage technology and methods of assessing their economic viability and impact on power system operation were discussed. Further, the role

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http://dx.doi.org/10.1016/j.ijepes.2012.09.017

of battery storage systems of electric hybrid vehicles in power system storage technologies was examined as well.

Besides, many researches were concentrated on the evaluation of allocation of DGs in a distribution system. A methodology was proposed to study the effect of load models on the assessment of energy losses based on time series simulations to take into account both the variations of renewable generation and load demand. Simulation results indicate that the load model to be adopted can significantly affect the results of DG planning [9]. For solving the distribution system planning problems by implementing DG, some optimal models and algorithms were presented in [10–15]. A GA-based methodology considering system losses, reliability, and voltage profile for finding the optimal allocation and sizing of DGs was proposed in [16]. In [17–22], some optimal algorithms were used to determine the optimal allocation of DGs to reduce system loss. In [23], an analytical method based on the loss sensitivity factor was utilized to determine the optimal size and location of DGs so as to minimize system loss. The continuous power flow calculation and sensitivity analysis were employed to assess the placements of DGs in distribution networks to improve the voltage profile and reduce power loss [24]. In [25], the application of particle swarm optimization (PSO) technique was applied to search for the optimal size and location for placement of DGs in power networks.

This paper differs greatly from the above researches that focused on the discussion of the planning, design, and operation of DGs under the conventional architecture of distribution system. The main object of this paper is to build a DG-friendly environment for installation of DGs. In this paper, the genetic algorithm with multiple-objective indicators are applied to find out the optimal scheme for improvement of primary feeders with normally closed loop arrangement to mesh arrangement for suitable installation of DGs. This paper is organized as follows. Section 2 introduces mathematical models of DGs and interconnection rules for DGs; Section 3 presents the problem formulation for finding the optimal schemes of upgrading primary feeders from normally closed loop to a mesh arrangement for suitable installation of DGs; In Section 4, test cases and results are presented to demonstrate the proposed method. In Section 5, a conclusion will be drawn.

## 2. Mathematical models of DGs and interconnection rules for DGs

### 2.1. Mathematical models of DGs

Three mathematical models are commonly used to represent the performance of DGs in the power system analysis. That is, the constant-power-factor model, the constant-voltage model, and the induction-machine model [26]. To minimize the adverse impact while DGs operated in parallel with the distribution system, many power companies have announced that the installed DGs should have the ability to control their output power and reactive component. Therefore, the constant-power-factor model of DGs is chosen to simulate the operating characteristic of DGs and applied for the evaluations of upgrading schemes of primary feeders in this paper.

### 2.2. Interconnection rules for DGs

According to the interconnection rule for DG of Taiwan Power Company (Taipower) and National Electric Code of Taiwan, the rules related to DG interconnection outlined as follows are applied in this research.

- The voltage variation at the point of common coupling (PCC) should not be more than 2.5% due to the parallel operation of DGs with the distribution grid.
- The voltage profile along a distribution feeder should be kept within 5% of nominal voltage.
- The wind power generators connected to high-voltage networks (>600 V) should be equipped with the function of low voltage ride through (LVRT).

## 3. Problem formulation

In this paper, the typical feeder model and an optimal algorithm are adopted to find the finest planning and design, and operation modes for DGs interconnection. The steady-state voltage variations due to the interconnection of DGs is taken into account. To build a proper meshed distribution system for the interconnection of DGs, an optimal solution algorithm is required. In this paper, all computer programs were developed using the MATLAB R2006a software package and were run on a Windows XP-based PC with AMD Athlon 64 processor 3200+.

By using the GA and a simplified power flow program, a multi-objective optimization for finding the optimum schemes of meshed distribution feeders is proposed. Three objective functions used in this paper are (1) average voltage deviation, (2) total line loss and (3) total possible installed capacity of DGs. The allowable steady-state voltage deviation and maximum continuous operation current limitations were also used to ensure safe operation. The details of the proposed method are shown as follows.

### 3.1. Objective functions

#### 3.1.1. Average voltage deviation ($AV_d$)

When DGs are connected to the grid, the voltages at the points near the DGs-connection points will deviate. Both over- and under-voltage are disturbances. In recent years, converter-driven circuits have been widely used to drive modern equipment. However, the equipment has become more sensitive to voltage disturbances. The voltage disturbances attack not only the performance but also the lifetimes of equipment.

Therefore, the steady-state voltage deviations caused by DGs interconnection should be reduced as much as possible and the deviations must meet local rules. Reducing the voltage deviations is an important objective to be achieved by distribution engineers. The average voltage deviation can be evaluated as follows.

$$AV_d = \frac{\sum_{i=1}^{n} \frac{V_{2i} - V_{1i}}{V_{1i}}}{n} \times 100\% \tag{1}$$

where $i$ is the number of load tapped-off points (load points for short) on the feeder of interest; $n$ the total number of load points on the feeder of interest; $V_{1i}$ the bus voltage at load point $i$ without DGs; $V_{2i}$ the bus voltage at load point $i$ with DGs.

#### 3.1.2. Percent total line loss ($P_{TLL}$)

Upgrading primary feeders from normally closed loop to a mesh arrangement gains an advantage of decreasing total line losses. Distribution systems are located in the most downstream portions of a power system. If the power losses of distribution feeders are reduced, the power losses of transmission lines can be decreased, and the capacities of generation and transmission can be released. The total line loss and its percentage can be evaluated as follows.

$$TL_l = \sum_{j=1}^{k} P_j \tag{2}$$

$$P_{TLL} = \frac{TL_{l1} - TL_{l2}}{TL_{l1}} \times 100\% \tag{3}$$

where $j$ is the number of feeder segments in the feeder of interest; $k$ the total number of feeder segments in the feeder of interest; $P$ the