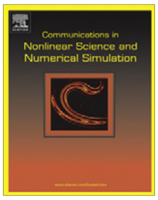
Commun Nonlinear Sci Numer Simulat 16 (2011) 851–862

Contents lists available at ScienceDirect

Commun Nonlinear Sci Numer Simulat

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



A novel method for optimal capacitor placement and sizing in distribution systems with nonlinear loads and DG using GA

Seyed Abbas Taher *, Mohammad Hasani, Ali Karimian

Department of Electrical Engineering, University of Kashan, Kashan 87317-51167, Iran

ARTICLE INFO

Article history:
Received 12 September 2009
Received in revised form 8 May 2010
Accepted 11 May 2010
Available online 25 May 2010

Keywords:
Capacitor placement
Genetic algorithms
Harmonic distortion
Nonlinear load
Harmonic power flow
Optimization

ABSTRACT

A genetic algorithm (GA) is proposed for simultaneous power quality improvement, optimal placement and sizing of fixed capacitor banks in radial distribution networks with nonlinear loads and distributed generation (DG) imposing voltage–current harmonics. In distribution systems, nonlinear loads and DGs are often considered as harmonic sources. For optimizing capacitor placement and sizing in the distribution system, objective function includes the cost of power losses, energy losses and capacitor banks. At the same time, constraints include voltage limits, number/size of installed capacitors (at each bus) and the power quality limits of standard IEEE-519. In this study, new fitness function is used to solve the constrained optimization problem with discrete variables. Simulation results for two IEEE distorted networks (18-bus and 33-bus test systems) are presented and solutions of the proposed method are compared with those of previous methods described in the literature. The main contribution of this paper is computing the (near) global solution with a lower probability of getting stuck at a local optimum and weak dependency on initial conditions, while avoiding numerical problems in large systems. Results show that proposed method could be effectively used for optimal capacitor placement and sizing in distorted distribution systems.

1. Introduction

Power distribution from electric power plants to ultimate consumers is accomplished via transmission, subtransmission, and distribution lines. Voltage profile improvement and system losses reduction by capacitor installation depend greatly on how capacitors are placed and operated in the system [1–3]. The general capacitor placement problem consists of determining the optimal location and size of the capacitors to be installed and efficient control schemes in the buses of distribution systems [4–10]. Power injections and power demands that appear at various places in the distribution systems are assumed to be distributing equally between the phases. In reality, distribution systems are well known to be unbalanced due to many single and double phase lines as well as unequal phase parameters and different phase loading. Capacitors need to be installed for improving voltage profiles and reducing system losses for the distribution feeders that serve a variety of load conditions. Much mathematical research on the capacitor placement has been carried out in distribution systems. Grainger and Lee [1] proposed nonlinear programming such as gradient search method for optimal capacitor placement. Using mixed integer programming, Baran and Wu [2] distinguished capacitor placement problem separately into a master problem and a slave problem. The master problem is used to determine the location of the capacitors while the slave problem is used to determine the type and size of the capacitors. Chen et al. [3] considered the mutual coupling effect of conductors to install capacitors in unbalanced distribution systems. Chiang et al. [4,5] formulated capacitor placement problem as a discrete

---

* Corresponding author. Tel.: +98 9131614352; fax: +98 3615559930.
E-mail address: sataher@kashanu.ac.ir (S.A. Taher).

1007-5704/$ - see front matter
doi:10.1016/j.cnsns.2010.05.011

combinational optimization problem and used simulated annealing (SA) to search the global optimum solution. In order to reduce the search space, Huang et al. [6] proposed tabu search (TS)-based solution algorithm and sensitivity analysis method to select the candidate installation locations of the capacitors. Huang et al. [7,8] applied immune algorithms (IAs) to capacitor placement problem by representing objective function and constraints as antigens. Chang and Silva et al. [9,10] proposed heuristic constructive and ant colony search algorithms for optimal capacitor placement. Many researchers proposed genetic algorithm (GA) application to search global optimal solution of capacitor placement problem [11–18]. Sundhararajan and Pahwa [11] used sensitivity analysis to search the location of the capacitors and GA to determine size of the capacitors, which somewhat depends on experiences in the selection of the probability parameters. Miu et al. [12] suggested the two-stage algorithms that combine the good qualities of GA and a fast sensitivity-based heuristic. In order to reduce computation time [15], applied multi population formulations consisting some subpopulations which corresponded to each load level, in which the strings in each individual load level were formed by candidate locations and sizes of capacitors. Their architectures found the solution faster and more precise than the formulation of single-population. The fuzzy set theory was also tested in handling capacitor placement by Su and Tsai [19]. In this approach, membership functions of power loss and voltage limits were expressed in fuzzy set notations. The fuzzy-reasoning technique was then performed to compute the results. Lately, an application of GA was also considered by Sundharajan and Pahwa [20]. Based on the mechanism of natural selection, this method anticipated that the capacitor placement schedule would evolve toward the optimal solutions.

In this paper, a new method has been suggested to determine the optimal capacitor placement and sizing, taking into account fixed capacitors as well as potential harmonic interactions (losses, resonance and distortion factors) in the presence of nonlinear loads and DG using GA. This proposed method has been tested on distorted 18-bus and 33-bus IEEE systems. The objectives on this method were to maximize net saving and minimize power loss in the distorted distribution network having taken the cost of capacitors into account. The effectiveness of proposed method were compared with those introduced in [21,22], which suggested improved economical benefits.

2. Problem description

2.1. Power flow computations

For modeling a distribution system with nonlinear loads at fundamental and harmonic frequencies, the formulation and notations of [23,24] are used. Linear loads are modeled as shunt admittances at harmonic frequencies [25]. DG is a nonlinear power source, which is a harmonic source. DG is modeled as a six-pulse converter. Nonlinear loads with given V–I characteristics (either in the frequency or time domain) represent the coupling between harmonic voltages and currents. These loads are modeled as shunt harmonic current sources and are updated at each iteration step of the harmonic power flow. The harmonic power flow solution is achieved by forcing the total mismatch active and reactive powers as well as mismatch active and reactive fundamental and harmonic currents to zero, using the Newton–Raphson method.

2.2. Problem formulation

In this paper, the following assumptions are made: (a) capacitors with fixed values (c_f), (b) presence of linear and nonlinear loads, and (c) presence of DG in a balanced three phase system.

2.2.1. Constraints

Voltage constraints will be taken into account by specifying lower (e.g., $V_{min} = 0.9$ pu) and upper (e.g., $V_{max} = 1.1$ pu) bounds of effective voltage (e.g., V_{rms}) as below:

$$V_{min} \leqslant V_{i_{rms}} \leqslant V_{max} \tag{1}$$

where rms magnitude voltage is:

$$V_{i_{rms}} = \sqrt{\sum_{k=1} (V_i^{(k)})^2}$$

so that i and k, are the bus number and harmonic order, respectively.

The distortion of voltage is considered to be bounded by maximum total harmonic distortion of voltages (THD_v):

$$THD_v \leqslant THD_V^{max} \tag{2}$$

where

$$THD_V = \left(\frac{\sqrt{\sum_{k \neq 1} (V_i^{(k)})^2}}{V_i^{(1)}} \right) \times 100$$

and $THD_V^{max} (= 5\%)$ is the standard value of THD. Bounds in Eqs. (1) and (2) are according to IEEE-519 standard [26].