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A new method for optimal location and sizing of capacitors in distorted distribution networks using PSO algorithm

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ABSTRACT

This paper presents an optimization algorithm for simultaneous improvement of power quality (PQ), optimal placement and sizing of fixed capacitor banks in radial distribution networks in the presence of voltage and current harmonics. The algorithm is based on particle swarm optimization (PSO). The objective function includes the cost of power losses, energy losses and those of the capacitor banks. Constraints include voltage limits, number/size of installed capacitors at each bus, and PQ limits of standard IEEE-519. Using a newly proposed fitness function, a suitable combination of the objective function and relevant constraints is defined as a criterion to select a set of the most suitable buses for capacitor placement. This method is also capable of improving particles in several steps for both converging more readily to the near global solution as well as improving satisfaction of the power quality constraints. Simulation results for the 18-bus and 33-bus IEEE distorted networks using the proposed method are presented and compared with those of previous works. In the 18-bus IEEE distorted network, this indicated an improvement of 3.29% saving compared with other methods. Using the proposed optimization method and simulation performed on the 33-bus IEEE distorted network an annual cost reduction of 31.16% was obtained.

1. Introduction

Capacitor placement in distribution networks for reactive power compensation, voltage regulation, power factor correction, and power/energy loss reduction has been extensively researched and documented in the literature [1–5]. Some workers, have assumed linear system loads and used power flow for system solution [2–5]. However, limited attention is given to this problem in the presence of non-linear loads.

Non-linear loads and devices generate and inject considerable harmonic currents into power system. If (shunt) capacitor banks are not properly selected and placed in the power system, they could amplify and propagate these harmonics and deteriorate power quality to unacceptable levels, resulting in creation of harmonic parallel resonances. Therefore, analyses, simulation, and optimal selection of capacitor banks under harmonic conditions are required in distribution networks.

In some recent works, the presence of distorted substation voltage has been considered for solving the capacitor placement problem. The presented mathematical optimal methods for shunt capacitor placement include exhaustive search [6], local variations [7], mixed integer-non-linear programming [8,9], heuristic methods [10], maximum sensitivities selection [11–13], fuzzy set theory [14,15], and genetic algorithms (GAs) [16]. Some of these publications [6–11,14] ignore the couplings between harmonic voltages and currents. Refs. [12,13,15,16] use a harmonic power flow that considers harmonic couplings caused by the non-linear loads.

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Nomenclature

n	total number of buses
i	bus number
h	harmonic order
F_{loss}	energy loss cost
F_{cost}	cost of fixed capacitors
F_{capacity}	cost corresponding to power losses (e.g., used capacity of the system)
P_{loss}	total system losses
$V^{(h)}$	bus voltage vector at harmonic h
L	highest order of considered harmonics
C	size of connected capacitors
T	duration of load (h/year)
SC	set of possible shunt capacitor buses
u_{fi}	number of fixed capacitor banks at bus *i*
K_{cfp}	cost per unit of fixed capacitance
K_E	cost per megawatt-hour (e.g., K_E = 50 US $/MWh)
K_A	saving per megawatt for reduction in losses (e.g., K_A = 120,000 US $/MW)
$V_i^{(h)}$	magnitude of *h*th harmonic voltage at bus *i*,
$\theta_i^{(h)}$	phase of *h*th harmonic voltage at bus *i*,
$Y_{ij}^{(h)}$	magnitude of *h*th harmonic line admittance between buses *i* and *j*
$\delta_{ij}^{(h)}$	phase of *h*th harmonic line admittance between buses *i* and *j*
$\text{iter}_{\max}$	maximum number of iterations
iter	current iteration number
$\text{THD}_v^{\max}$	maximum total harmonic distortion ($\text{THD}_{v,i}$) of voltages at the IEEE-519 standard and
$\text{THD}_{v,i}$	total harmonic distortion of voltages at bus i
P_{loss}^{nc}	power losses before capacitor placement
P_{loss}^{c}	power losses after capacitor placement
ΔM	mismatch vector
ΔU	voltage correction
J	Jacobian matrix

Most of these techniques are fast, but they suffer from the inability to escape local optimal solutions. Simulated annealing (SA), tabu search (TS), and GAs are three near global optimization techniques that have demonstrated fine capabilities for capacitor placement [1–4], but the computational burden is nevertheless heavy.

A special approach of swarm intelligence based on simplified simulations of animals' social behaviors, such as fish schooling and bird flocking, is the particle swarm optimization (PSO) algorithm [17,18]. PSO, a self-adaptive search optimization, was first introduced by Kennedy and Eberhart [17], and is considered robust in solving problems featuring non-linearity, non-differentiability, and high dimensionality. PSO has been successfully applied to complex engineering problems, mainly in non-linear function minimization [19], optimal capacitor placement in distribution systems [20], shape optimization [21], dynamic systems and game theory [22], constrained optimization [23], multi-objective optimization problems [24], electromagnetic [25], control systems [26], planning of electrical systems [27], etc.

In this article, PSO with a newly defined fitness function is employed to determine the optimal capacitor placement and sizing, having taken into account fixed capacitors as well as potential harmonic interactions (losses, resonance and distortion factor) in presence of non-linear loads. Operational and power quality (PQ) constraints include the bounds of root mean square (rms) voltage, THD_v, the number/size of installed capacitors, and harmonic parallel resonances. In the proposed method, the suitability of number/size of installed capacitors and voltage are defined for each swarm based on the constraints bounds. Applied penalty functions represent the level of constraints satisfaction and are used with cost index (objective function) to determine the fitness function. These penalty functions are used to calculate the fitness function, while considering the uncertainty of decision making based on constraints and objective function. The results of the proposed method are presented for the distorted 18-bus and 33-bus IEEE test systems. The advantages of this method are compared with those published previously [12,13,15,16,28].

2. System model at harmonic frequencies

For modeling of a distribution system at fundamental and harmonic frequencies, the formulation and notations of [29,30] are used. System solution is achieved using the Newton–Raphson method and forcing the total (fundamental and harmonic) mismatch active and reactive powers as well as mismatch active and reactive fundamental and harmonic currents to zero.