Multi-Objective Planning of Electrical Distribution Systems Using Particle Swarm Optimization

Abstract

Power system deregulation has opened a competitive market for power system utilities during the last decade. This motivates power system planners to design efficient, reliable, and cost effective power networks. Thus, electrical distribution system planning becomes an important research area in power system engineering. This planning is basically a multi-objective optimization problem to optimize various objectives, such as, minimization of capital investment cost, minimization of power loss, and maximization of network reliability. These objectives are optimized under the constraints of substation and feeder capacity, maximum allowable node voltage deviation etc. It is a challenge to devise an appropriate solution strategy as the objective functions are typically nonlinear, non-convex, and non-differentiable with integer and continuous decision variables.

In this thesis, a multi-objective planning model for simultaneous optimization of cost and reliability objectives of electrical distribution systems is formulated. The applicability of a popular class of evolutionary algorithm, i.e., particle swarm optimization (PSO), as an effective solution strategy, is investigated. PSO requires less computational bookkeeping and, generally, a few lines of implementation codes. Multi-objective PSO (MOPSO) based on Strength Pareto Evolutionary Algorithm-2 is used as the solution strategy for this multi-objective planning optimization. A modified cost-biased encoding/decoding scheme for representation of networks is devised and used in the MOPSO. For a comparative performance assessment with that of a deterministic planning algorithm, a planning algorithm based on dynamic programming (DP) is also developed and its performance is compared with that of the MOPSO for the same planning model to bring out the relative advantages and disadvantages of both planning approaches. The performance of the DP is found to be better. But, the DP suffers from the curse of dimensionality. This becomes a motivating factor to use the MOPSO in all subsequent investigations.

The proposed multi-objective planning model is further extended by incorporating sectionalizing switches and tie-lines into the planning. A new reliability indicator, i.e., contingency-load-loss-index (CLLI) is formulated and is used as the reliability objective for this model. This index can distinguish the reliability levels of different network structures (single/multi-feeder networks, networks with and without sectionalizing switches etc.).

A new guide selection mechanism for the MOPSO, i.e., HSG-MOPSO, is proposed and its performance is assessed on several multi-objective benchmark test problems. The performance comparisons indicate that better performance can be obtained with the HSG-MOPSO for more difficult test problems. A more generalized multi-objective planning considering both radial and meshed networks is proposed. The performance of the HSG-MOPSO is found to be better than those of several existing MOPSO techniques. The inclusion of distributed generation (DG) in the network planning is also investigated. Finally, the proposed planning model is extended by incorporating possibilistic load model and its performance is compared with that of the planning with deterministic load model and analyzed.

All the proposed planning models are validated on different test systems using various case studies. The performances of the proposed planning algorithms are critically assessed with several statistical tests and compared with some of the existing distribution system planning algorithms.

Key words: Distribution system planning, multi-objective optimization, Pareto-dominance, particle swarm optimization, cost-biased encoding, dynamic programming, distributed generation.