Intelligent Techniques for Planning Distributed Generation Systems

S. Santoso, *Senior Member, IEEE,* Nitish Saraf, *Student Member, IEEE,*
G.K. Venayagamoorthy, *Senior Member, IEEE*

***Abstract*—Including Distributed Generation (DG) in distribution systems often requires in-depth analysis and planning. This panel paper will present a few issues related to the planning of distributed generation, and will describe how intelligent systems methods can be used to help solve these issues. Investment and operating cost minimization, capacity determination and siting of distributed generators, islanding of power systems with DG, coordination of voltage regulators and capacitors with distributed generators in regulating feeder voltage profiles are a few subjects discussed in the paper.**

***Index Terms*—distribution systems, distributed generation, intelligent techniques.**

I. Introduction

DISTRIBUTED generation (DG) refers to the use of smaller-sized grid-connected generators, usually 10 MW or less, in electric power distribution systems. Since the generators are distributed and closer to the loads, DG potentially offers increased reliability and security of the electricity supply. DG technologies include reciprocating diesel engines, internal combustion gas turbines, and emerging clean power generation technologies such as fuel cells, microturbines, photovoltaic, and wind turbines [1].

Including distributed generation in distribution systems often requires in-depth analysis and planning. They usually include technical, economical, regulatory, and possibly environmental challenges. As in the majority of planning process, a cost function is normally constructed to represent the overall operating and investment costs of a distribution planning area [2]. Engineering parameters such as capacity, reliability, power losses, voltage regulation, power quality, load demand, to mention just a few are converted into costs associated with the operation and investment. There can be several cost functions based on various planning scenarios. A set of constraints functions are also assembled. They include voltage limits, available short-circuit capacity, overcurrent protective requirements, and so on. Cost functions and their constraints are solved using various optimization methods.

The purpose of this paper is to present and summarize a few distributed-generation related planning and control issues, and describes how intelligent techniques can be used to deal with those issues. These intelligent techniques include adaptive critic designs [3], evolutionary computation, fuzzy and soft computing [4], and swarm intelligence [5].

II. Intelligent Techniques

To obtain a better solution, there are optimization techniques known as meta-heuristics that make use of heuristics or rules. They are advantageous over the conventional mathematical programming techniques in terms of the flexibility of the cost function and constraints, and the efficiency of the algorithm which is capable of handling nonlinear mixed integer programming problems, and the evaluation of globally optimal solutions or approximate ones.

A. Genetic Algorithms

Genetic Algorithms (GA) have become increasingly popular in recent years in science and engineering disciplines. Solution coding and fitness functions are the most important issues in solving problems using GA. The fitness function has been constructed as the summation of the objective function and penalty terms for constraints violations [6]. GA makes use of the idea of natural selection in the evolution process of biology. The variable is regarded as genes that consist of many attributes. Creating new genes gives better solutions in optimization problems [7].

B. Simulated Annealing

Simulated Annealing (SA) is a process in which the optimization problem is simulated as an annealing process. It has the ability of escaping local minima by incorporating a probability function in accepting or rejecting new solutions. The natural process of optimization that takes place in a slowly cooling metal (annealing) guarantees that the structure of the metal reaches the crystal structure corresponding to the minimum energy. In this natural process, a transition from a structure corresponding to an energy level of E to that corresponding to $E+\Delta E$ takes place, with a probability given by the Boltzman function $e^{-\Delta E/kT}$. The temperature decreases the probability of such transitions determined by the Boltzman function becomes lower. The above process allows a slowly cooling metal to escape from crystal structures corresponding to local minimum energy states in its search for the globally minimum energy state. In SA, the objective function to be minimized is analogous to the energy in the crystal structure and the temperature is analogous to a control

S. Santoso and Nitish Saraf are with the Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, TX 78712.

G. K. Venayagamoorthy is with Department of Electrical and Computer Engineering, University of Missouri-Rolla, MO 65409, USA (email: gkumar@ieee.org).

parameter in the algorithm [8]. A main advantage of the SA method is that it does not require large computer memory.

SA and GA are effective for solving small size problems, but they do not work so well for large-scale problems due to the stochastic algorithm. On the other hand, tabu search is one of the deterministic optimization methods.

C. Tabu Search

Tabu Search (TS) is a powerful optimization procedure that has been successfully applied to a number of combinatorial optimization problems. It has the ability to avoid entrapment in local minima by employing a flexible memory system. TS is an extension of the hill-climbing method that evaluates solutions by repeating local search around a solution. The difference between the two is that TS has an adaptive memory called the tabu list that fixes some attributes not to get stuck in local minima. It aims at evaluating better solutions near a global minimum with the iterative process of simple rules or heuristics. The recent simulation results have shown that TS is better than SA and GA in terms of computational effort and solution accuracy [9].

TS has only one parameter called tabu length. Thus, it is easy to tune it up. Its algorithm is deterministic. Simulation experience has shown that the probabilistic search methods such SA and GA do not work so well in large-scale problems. The algorithm is based on the transition type algorithm that it keeps to find out better solutions under different restricted conditions. SA and GA correspond to the convergence type algorithm.

D. Parallel Tabu Search

Parallel tabu search (PTS) is developed to improve the performance of TS in terms of computational time and solution accuracy. PTS makes use of a couple of strategies to obtain better solution efficiently. One strategy is to decompose the neighborhood of TS into sub-neighborhoods. This allows handling the calculation of the neighborhood in a decomposed way and results in reduction of computational time. On the other hand, the other strategy is to introduce multiple tabu lengths into TS so that the diversity of solutions is obtained. It is expected that multiple search enables to find out better solutions efficiently. In other words, that gives more reliable solution search [9].

III. Distributed Generation Planning Issues

During the panel discussion, the following issues are planned to be addressed.

A. DG Investment and Cost Minimization

Distribution utilities are in the business of providing power to the end users through their existing networks of lines and substations, while making handsome and reasonable profits. To many utilities, DG is used to provide capacity relief during peak load demand periods and also to meet uncertain load growth. Therefore, in many cases DG applications are deployed for short term until the load grows sufficiently to justify constructions of distribution facilities. As a temporary solution, the question often asks - is there a business case for DG?

Intelligent systems techniques have been proposed to examine and evaluate planning scenarios and compare them against the so-called do-nothing scenario. There are two basic cost components in including DG. The first component involved the investment of DG equipment and its associated control and overcurrent protection. The second cost component involves the operation and maintenance cost (O&M cost). These two basic costs are represented in an overall cost function along with a set of constraints; hence it becomes an optimization problem. There are a number of intelligent system tools that can be used such as multiobjective evolutionary algorithms [10], probabilistic optimization techniques [11], genetic algorithms [12], simulated annealing and tabu search [13], [14].

Mori in [14] presented a problem of distribution network expansion planning with the objective of optimizing installation cost of feeders, installation cost of substation, capacity cost of substation, distribution network losses and outage costs. The problem is represented by a cost function and a set of constrains. The optimal solution is determined using the parallel tabu search method. It assumes that candidates of feeders, substations, and distributed generators are known. The method begins by setting initial conditions within an initial solution. The method then creates solution neighborhood around the initial solution. The cost functions are then evaluated for all neighborhood solutions. If the optimum solution is found in the neighborhood, consider it as a new solution. If this solution satisfies all the constraints and the iteration criterion, the solution is found. Otherwise, the method repeats the search process. Mori argues that the parallel tabu search is faster than the usual tabu search, and for large system, it performs better than simulated annealing and genetic algorithms.

B. Capacity Determination and Siting of Distributed Generators

Capacities and locations of distributed generators are often dictated by the objective of having DG and the infrastructure of the distribution system if it already exists. Load growth, cost of DG, and the technology of DG can play an important role in sizing and siting DG. Intelligent system techniques have been proposed to solve this problem [13], [15], [16], [17]. Celli et. al [17] for example uses a multi-objective evolutionary algorithm for sizing and siting the DG. The general formulation of a multi-objective optimization is as follows:

$$\min f(x) = \min([f_1(x), f_2(x), \ldots, f_m(x)]^{\mathrm{T}}) \quad [1]$$
$$x \in \Omega$$
$$c_j(x) = 0 \quad j = 1 \ldots n$$
$$h_k(x) \leq 0 \quad k = 1 \ldots p$$

where x, f_i, and Ω are a decision vector, an objective function, and the solution domain. Variables $c_j(x)$ and $h(k)$ are the constraints of resources for objective functions. In a multiobjective optimization, objective functions and a set of constraints are defined. It is not uncommon that objective functions can be contradictory and at odd among themselves. Objective functions can include costs of network upgrading (C_U), purchased energy (C_E), energy losses (C_L), and energy not supplied (C_{ENS}). Therefore, the objective functions are expressed as follows:

$$\min C(X(U)) = \min [C_U, C_E, C_L, C_{ENS}] \quad [2]$$

where $X(U)$ where is the power flow solution with scenario or condition U which represents the size and site of generators.

Due to competing objective functions, solutions are noninferior to each other. In other words, improvements in one objective function can make other objective functions to perform worse. Multiple noninferior solutions are found using a genetic algorithm and evaluated to determine the most optimum solution to the problem at hand.

Other methods of sizing and siting DG are of course available. Many of capacitor bank sizing and siting approaches can be applied to appropriate adjustments [18], [19], [20].

C. Power system islanding with DG [21]

Deregulation, continuous demand growth, and barriers to building new generation and transmission infrastructure are all contributing to the increased interest and usage of distributed generation. If the DG is utilized to export power back to the utility distribution system, loss of the main supply can cause a severe overloading of the DG units. Consequently, the voltage and frequency will certainly fall below the statutory limits. Hence, it is imperative to control the voltage in the islanding mode of operation. The potentialities of DG can be truly realized if islanded operation is allowed and bottom-up black start functionalities are implemented. Intelligent techniques can be used in siting and controlling DGs such that islanded operation without dropping voltage and frequency below statutory limits is possible.

D. Optimal placement of capacitors and distribution FACTS devices

Reactive compensation in distribution networks is a typical constrained optimization problem of great technical and economic importance which has been faced over five decades. It consists of determining installation points, types, sizes and operation control program of a certain number of compensation devices, such as capacitors and shunt FACTS devices, in order to maximize the profits obtained from system losses reduction. The extent of the benefits from shunt compensation devices installation depends on electrical network configuration and its load states. The net profit corresponds to the amount saved on reducing losses after discounting the investment in equipment acquisition and its installation. Intelligent techniques such as genetic algorithms and particle swarm optimization have used to solve the optimal placement – number, sizing, type and location of these shunt compensation devices.

IV. Summary

Intelligent systems techniques described in this paper allow DG planners to formulate and solve various planning scenarios. There are numerous technical publications in intelligent systems techniques devoted to distribution generation applications. A few planning issues involving DG investment and cost minimization, capacity determination and siting of distributed generators, power system islanding with DG, and optimal placement of capacitors and distribution FACTS were presented in the paper. Solutions to these issues were formulated and solved using intelligent system techniques.

V. References

[1] R. C Dugan, M. F. McGranaghan, S. Santoso, H. W Beaty, *Electrical Power Systems Quality,* 2nd ed., McGraw-Hill Co, 2003.

[2] R. C Dugan, T. E McDermott, G. J Ball, "Planning for Distributed Generation," *IEEE Industry Applications Magazine,* March/April 2001, pp. 80 – 88.

[3] R. Welch, G. K. Venayagamoorthy, "Comparison of Two Optimal Control Strategies for a Grid Independent Photovoltaic System", *IEEE Industry Application Society 41st Annual Meeting*, Tampa, FL, USA, October 8 – 12, 2006.

[4] R. Welch, G. K. Venayagamoorthy, "A Fuzzy-PSO based Controller for a Grid Independent Photovoltaic System", *IEEE Swarm Intelligence Symposium*, Honolulu, Hawaii, USA, April 1-5, 2008.

[5] Y. del Valle, G.K. Venayagamoorthy, S. Mohagheghi, J. C. Hernandez, R. G. Harley, "Particle Swarm Optimization: Basic Concepts, Variants and Applications in Power Systems", *IEEE Transactions on Evolutionary Computation,* to appear.

[6] A.H. Mantawy, Y.L. Abdel-Magid, S.Z. Selim, "Integrating genetic algorithms, tabu search, and simulated annealing for the unit commitment problem" *IEEE Transactions on Power Sytems,* Volume 14, Issue 3, Aug. 1999 Page(s):829 – 836.

[7] D. E. Goldberg, "*Genetic Algorithm in Search, Optimization and Machine Learning*," Addison Wwley Publishing Company, 1989.

[8] S. Kirkpatrick, C. D. Gelatto and M. P. Vecchi, "*Optimization by Simulated Annealing,*" Science, Vol. 220. No. 4598, pp. 671-680, May 1983.

[9] H. Mori and T. Hayashi. "An Efficient Method for Capacitor Placement with Parallel Tabu Search," *Proc. of ISAP'97*, pp. 387-391, Seoul, Korea, July 1997.

[10] A. Silvestri, A. Berizzi, and S. Buonanno, "Distributed generation planning using genetic algorithms," in *Proc. IEEE PowerTech*, 1999, p. 257.

[11] G. Celli, R. Cicoria, S. Mocci, F. Pilo, "Probabilistic optimization of MV distribution network in presence of distributed generation," in *Proc. PSCC Conf.,* Sevilla, Spain, June 24 – 28, 2002, pp. 1-7, paper S11-1.

[12] M. E. H Golshan, S. A Arefifar, "Distributed generation, reactive sources, and network-configuration planning for power and energy-loss reduction," in *IEE Proc.-Generation, Transmission, and Distribution,* vol. 153, no. 2, pp. 127 – 136, March 2006,

[13] M. Gandomkar, M. Vakilian, M. Ehsan, "Optimal distributed generation allocation in distribution network using Hereford Ranch algorithm," in *Proceedings of the Eight International Conference on Electric Machines and Systems, 2005*, vol. 2, 27 – 29 Sept. 2005, pp. 916-918.

[14] H. Mori, Y. Iimura, "Application of parallel tabu search to distribution network expansion planning with distribution generation," *Conf. Proc. 2003 IEEE PowerTech, Bologna,* 23-26 June 2003, 6 pages.

[15] M.R Vallem, J. Mitra, "Siting and sizing of distributed generation for optimal microgrid architecture," in *Proc. 37th Annual North American Power Symposioum*," pp. 611- 616.

[16] M. Mardaneh, G. B Gharehpetian, "Siting and sizing of DG units using GA and OPF based techniques," TENCON 2004 IEEE Region 10 Conference, pp. 331 – 334.

[17] G. Celli, E. Ghiani, S. Mocci, F. Pilo, "A Multiobjective Evolutionary Algorithm for the sizing and siting of distributed generation," in *IEEE Trans. Power Systems,* Vol. 20, no. 2, May 2005, pp. 750 – 757.

[18] M.E Baran, F. F Wu, "Optimal capacitor placement on radial distribution systems," in *IEEE Trans. on Power Delivery,* vol. 4, no. 1, Jan 1, 1989, pp. 725-734.

[19] S. Sundhararajan, A. Pahwa, "Optimal selection of capacitors for radial distribution systems using a genetic algorithm," in *IEEE Trans. on Power Systems,* vol. 9, No. 3, Aug. 1994, pp. 1499-1507.

[20] M.A.S Masoum, M. Ladjevardi, A. Jafarian, E.F Fuchs, "Optimal placement, replacement and sizing of capacitor banks in distorted distribution networks by genetic algorithms," in *IEEE Trans. on Power Delivery,* vol. 19, no. 4, Jan 1, 2004, pp. 1794-1801.

[21] W. Liu, D. A. Cartes, G. K. Venayagamoorthy, "Particle Swarm Optimization base Defensive Islanding of Large Scale Power System", *IEEE International Joint Conference on Neural Networks*, 16-21 July, 2006, pp. 1975-1981.