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Multi-conductor feeder design for radial distribution networks

Ahmed R. Abul'Wafa*

Ain-Shams University, Electric Power and Machines, Cairo, Egypt

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ABSTRACT

A generalized model for choice of the optimal size of the ACSR type of conductor for each feeder segment is presented as an optimization problem using an efficient method based on branch wise minimization technique. The optimal conductors' sizes are determined by minimizing an objective function (total cost comprising of conductor depreciation cost and annual cost of losses) subject to the constraints on voltage at end load points and maximum current carrying capacity of the feeder segments (branches). Conductors' sizes are first selected according to upper closest maximum current carrying capacities (ampacities) from available conductors' sizes, and then upgraded through economic optimization. Next upgrading conductors in upstream branches of nodes whose voltages violate voltage constraints. The effectiveness of the proposed method (PM) is demonstrated through simulations on several IEEE benchmark Feeders. Due to space limitation only simulation results of two systems are presented. The first is a 69-node system, given by load point locations, their local demand with a graph interconnecting them solved as a module in distribution system planning. The second is an 85-node system for solving optimum reconductoring problem. The results obtained are encouraging.

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1. Introduction

Usually in practice, conductors used for radial distribution feeders are uniform in cross-section. However, the load at the head section of a feeder is high and it reduces as one proceeds on to the tail end of the feeder. Thus the use of a higher size conductor which is capable of carrying load to source point is not necessarily needed at tail end point. Similarly use of different conductor cross section for intermediate sections will minimize both capital investment cost and line loss. The use of a large number of conductors of different cross sections will result in increased cost of the inventory. Therefore the significant sub problem of optimal conductor size selection still needs further studies, using both intelligent and analytical approaches.

Mandal and Pahwa [1], presented a method for selection of optimal set of conductors. Several financial and engineering factors are considered to arrive at a solution, which will be the most economical when both capital and operating costs are considered. Simulations have been performed to obtain results based on different criteria and the results are compared. The problem of choice of the optimal size of conductor for each feeder segment is presented as an optimization problem using branch wise minimization technique in [2]. The method, applied on 26- and 32-bus systems did not guarantee claimed minimum voltage constraint for the 32-bus system. A judicious choice can, however, be made in the selection of number of size of conductor cross-section for considering the optimal design. In [3], a generalized model for optimal multiconductor size selection in radial distribution system planning is presented. The model takes into account non-uniform loading, load growth, load factor and diversity in load peaks at various load points along the feeder. The optimal conductor sizes are determined by minimizing the total cost consisting of cost of conductor and cost of losses and subject to the constraint on voltage drop at far end load points and maximum current carrying capacity of the feeder. To reduce the search space, logical decisions are developed and only those feasible solutions are considered for functional evaluation, which are close to the boundary of the constraints. Annual cost and computational time for 123-bus system from the developed method are better compared to GA results. However no evidence is given on compliance with voltage constraints. In [4], the harmony search algorithm with a differential operator inspired by differential evolution (HSDE) is used to solve the optimal conductor size selection problem. The objective function is modeled as a problem that minimizes the sum of capital investment and capitalized energy loss cost. Voltage constraints and the maximum current carrying capacity of the conductors are also considered in the evaluation of the objective function. The effectiveness of the proposed method is demonstrated through simulations on 16- and 85-bus systems. Voltage did not comply with the ±5% range. Thenepalle [5] selected the optimal size of conductor for radial distribution

* Tel.: +20 222639022; fax: +20 222639022.
E-mail address: Ahmedlaila.nelly.ola@gmail.com

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networks, using vector decoupled load flow method. It was observed that for IEEE 13-bus system, genetic algorithm yields higher loss reduction at the expense of higher cost when compared to conventional method. The study in [6] has presented an application of evolutionary strategy (ES) to solve the optimal conductor selection problem in a radial power distribution network. The objective function was optimized considering several conductors, subject to some technical constraints, which are the Kirchhoff's current law constraints for all the nodes, the capacity constraints for the feeders and substations, and the voltage drop constraints. The author proposed a simple and an efficient load flow method for radial networks based on current injection. Vahid et al. [7] had presented a technique for optimal placement of the capacitor banks and also optimal conductor selection in radial distribution networks to reduce the losses and enhancement of voltage. The objective function included the cost of power losses, capacitors and conductors. Constraints included voltage limit, maximum permissible carrying current of conductors, size of available capacitors and type of conductors. A new and efficient algorithm to the optimal selection of conductors of feeder sections of radial distribution networks, was presented in [8]. The optimization procedure, minimizes capital investment and power loss, subject to voltage drop and current carrying capacity constraints. A load flow technique based on a forward and backward propagation [9] is used. However compliance with voltage constraints is not clear in the paper. In [10], a mixed-integer linear programming model to solve the conductor size selection and reconductoring (CSSR) problem in radial distribution systems is presented. In the proposed model, the steady-state operation of the radial distribution system is modeled through linear expressions. The proposed model and a heuristic approach are used for the CSSR problem based on two different objective functions. The author presented the result of one test system of 50 nodes and two real distribution systems of 200 and 600 nodes in order to show the accuracy as well as the efficiency of the proposed solution technique. The voltage profiles from the proposed algorithms preserve the voltage limits. The solution of the CSSR was found with a computational time of 9 s for the 50-node system, 215 s for the 200-node system and 2375 s for the 600-node system. However iteration number is not clear in [10]. Intelligent methods based on colonial selection algorithm (CSA), was given in [11] for the optimal selection of conductors in radial distribution networks. The method is compared with a particle swarm optimization (PSO) algorithm to minimize the depreciation cost of feeder conductor, power loss and availability, subject to voltage drop and current carrying capacity constraints in order to improve productivity. The back/forward sweep method is applied for load flow solution. Simulations were carried on 69-bus & 30-bus radial distribution networks. Mozaffari Legha et al. [12] examine the use of imperialist competitive algorithm (ICA), for optimal selection of conductor type for planning radial distribution systems with the objective to minimize the overall cost of annual energy losses and depreciation on the cost of conductors and reliability in order to improve productivity. The power losses, voltage magnitude, and current flow magnitudes are calculated using the backward–forward sweep method. Voltage profile was within the voltage constraints. The performance of the proposed evolutionary approaches (ICA) in comparison with a conventional method is investigated using a 69-bus radial distribution network. In [13], an objective function is optimized to reduce the sum of capital cost and power loss cost and voltage deviation of radial distribution network of power simultaneously. This results in saving substantial amount of energy. To reduce the objective function, the authors found optimized type of conductor using Bacteria foraging algorithm (BFA) method and compared results with those obtained from imperialism competitive algorithm (ICA) method. The back/forward sweep method is applied for load flow solution of proposed radial distribution system. Although the objective function minimizes the sum of depreciation on capital investment and cost of energy losses and reliability the results did not show cost comparison. Georgilakis and Hatziargyriou [14] present an overview of the state of the art models and methods applied to the modern power distribution planning (PDP) problem, analyzing and classifying current and future research trends in this field.

In this paper a novel and efficient multi-conductor feeder design is presented to solve the optimal conductor size selection problem. The proposed approach can be a useful tool for radial distribution planning. This method is performed in two phases, both based on optimizing a proposed objective function: (1) Optimal economic conductor selection, (2) Rectification of voltage constraints violations by upgrading conductor sizes. The objective function is modeled as a problem that minimizes the sum of discounted conductors' cost investment and annual power and energy loss cost. Voltage constraints and the maximum current carrying capacity of the conductors are also considered in the evaluation of the objective function. The load-flow method proposed in [15] by the same author is employed during the optimization procedure. The effectiveness of the PM is demonstrated through simulations on a 69-node system, using a wide resolution of thirteen different sizes of ACSR conductors. Optimizations resulted in using seven types of these conductors. Further PM is applied on an 85-node system, using eight different sizes of ACSR conductors from [4] and optimizations resulted in using three types of these conductors. The simulation results from PM are compared with results using HSDE approach [4].

The rest of the paper is organized as follows: Section 2 states the optimization problem. Section 2.1 briefly describes objective function and constraints. It also gives the procedural steps for optimal conductor size selection. Moreover a flowchart of the proposed algorithm is given. Section 3 describes results and discussions. The resulting system cost, kW losses, voltage profile improvement and the final selected conductors from both economic criterion and final optimal conductor sizes are given. Meanwhile, the conductor sizes available in inventory are given. Section 4 details the conclusions and the future scope of the work.

1.1. Contributions

This paper presents a new methodology to solve the optimal conductor size selection problem. The proposed method can be a useful tool for radial distribution planning. This method is performed in two phases, both based on optimizing a proposed objective function:

(1) Optimal economic conductor selection.
(2) Rectification of voltage constraints violations by upgrading conductor sizes without incurring increase in cost.

Conductor selection starts from sizes of ampacities sufficient to carry currents obtained from load flow resulting in a suitable objective function. Further, branch conductor size are perturbed till branches' objective functions cease to decrease and voltage profile ceases to improve.

In the second phase, end load points nodes violating voltage constraint are sorted in descending order of voltage drop. Upgrading conductor sizes of upstream branches of these nodes is to rectify voltage constraints violations, not hindering economy of final optimal conductor selections. The proposed algorithm is capable to reach any required voltage profile.

The developed algorithm, in this paper yielded better results compared to HSDE algorithm [4] when applied on the 85-node system. Other test systems not presented due to space limitation are investigated reaching same conclusion.

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