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Greenfield distribution network expansion strategy with hierarchical GA and MCDEA under uncertainty

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ABSTRACT

Distribution network expansion planning (DNEP) is becoming more complex in nature. Addition of new load centers, due to increasing conversion of greenfield areas into habitats, have generated need of more intense and highly structured planning strategies. Micro level work on distribution expansion planning has been ignored by most of the researchers mainly in Indian scenario. Since practical distribution networks are quite large, number of candidates (load centers) will be more and, hence, number of variables (electrical parameters and new load center feasible connections with the existing system) are remarkable. Optimizing a large system may result in significant decrease of accuracy and increase of computation time. For deciphering this issue, segmentation procedure has been applicable. For this purpose, a sensitivity analysis has been applied to find dependent variables. It is obvious that a correct segmentation can decrease computation time (as a single task is operated in segments simultaneously) while accuracy decreases negligibly. In present work, a scheme has been introduced to connect three greenfield load centers with existing primary distribution system by using hierarchical genetic algorithm (HGA). HGA is an integrated approach of analytical hierarchical process and genetic algorithm. The paper reports best selection of investment with finest voltage profile and least losses while maintaining radiality of the system. DNEP has been done at micro level and proposed methodology has been tested on a small dimension practical distribution system. The novelty of this paper is to optimize the best possible selection of connection of new load centers with existing system with the help of AHP and GA and results have been verified with advance optimal tool multiple criteria data envelopment analysis (MCDEA). HGA and MCDEA are applied to practical nine bus distribution system and the results are presented and compared.

Introduction

For more than a decade, electric power industry has been going through a process of transition and restructuring by moving away from vertically integrated monopolies to toward competitive markets [1]. This has been achieved through a clear separation between generation, transmission and distribution activities, as well as by creating competition among these sectors.

This restructuring process has created certain class of services such as frequency regulation, energy imbalance, voltage and reactive power control generation and transmission reserves, reliability in distribution network. These are essential to power system in addition to basic energy and power delivery services. Determinations of placement and rating of transformers and feeders are one of the main objectives of basic distribution network planning. Bus voltage and feeder current are two constraints which should be maintained within their standard ranges. Planning of DNEP becomes more complex when the load centers are located far from sources of power generation and infrastructure which results in voltage drop, line loss and poor system reliability. Long distance to supply loads causes a significant amount of voltage drop across distribution lines. Reactive power enhancement can be done to mitigate the voltage drop. This long distance also increases probability of occurrence of a failure. This high probability leads the reduced network reliability.

The DNEP problem is complex polynomial and, by its nature, it is mixed integer, nonlinear and non-convex [2]. While evaluating DNEP problems, merely considering investment which is the part more and most prominent one, most of power system quality

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aspects are ignored [3]. While increasing demand of power is fulfilled, quality must not to be compromised on behalf of investment. In present scenario, generation companies are growing at a fast pace, generally at sites far from load centers. But due to scarcity of distribution assets, huge amounts of power transactions are required to be reduced for security of distribution systems. In recent developments, electricity market-oriented and congestion-driven approaches are being used in DNEP.

Deterministic network expansion planning problem has been addressed in past. In most of the researches carried out so far, multi-objective optimization techniques have been given importance vis-à-vis single-objective optimization technique.

Extensive studies have been conducted on applying different optimization techniques to obtain appropriate expansion plans. These methods can be further classified into three type's viz. mathematical optimization, heuristic optimization and meta-heuristic optimization [4–20]. Solution for DNEP problem using heuristic techniques under uncertainty has been evolved since very long period [4]. Distributed generation can become potential candidate to act as an alternative distribution planning option [21] by providing opportunities to capture rescheduling benefit. Instead of evaluating a single optimal solution, generating sub-optimal solutions provide the planner more options for comparison with the results yielded by conventional methods [2].

Integrated planning instead of step-by-step planning has given more importance in [17]. Integrated planning provides better solution in terms of cost and reliability. But it must also be given due attention that step by step planning provides more deep information for taking decisions accurately. The radiality of distribution system should also be maintained [22], so that natural failure may not take place in system.

As wind power and solar power are subjected to limitations in geographical conditions, some particular parts of the network may become congested and need to be reinforced with more renewable energy generations [23]. A new network reinforcement planning method has been proposed which considers application of an active control system in order to curtail output of renewable energy generation, if necessary. It has also been suggested [1] that short term planning (1–4 years) is more reliable than long term planning (10 or more than 10 years). Asakura et al. [6] have compared these multi-solution providing techniques with that of experienced persons, who can provide very few options.

Active power and reactive power planning are generally interlinked, which must be done separately [1]. Separate planning, significantly, reduces the demand being served at various buses of system [3]. It is seen that sometimes reconductoring (up gradation) may also be helpful for existing network planning.

It is clear from all these research works that genetic algorithm (GA) alone will not be able to provide robust assessment for expansion problems. Rather modification in GA in one form or by incorporating other optimization techniques in GA produces more optimized results than conventional GA. It is not that GA has been implemented first time for expansion planning problems, but integrated analytical hierarchy process (AHP) and GA approach for DNEP solutions is unique. AHP has been found to be best suited to select the purposed new connections by assigning hierarchy to all available solutions on the basis of selected genes, i.e. voltage profile, investment and line losses.

Data Envelopment Analysis (DEA) has been established as one of the most advanced benchmarking methodology and practicable approach for evaluating relative efficiency of homogenous Decision Making Units (DMUs) [34]. As DEA efficiency measurement technique is comparative in nature, the results obtained from HGA have been duly verified and confirmed with DEA advance tool MCDEA and the authenticity of the above results has been evidenced corroboratively.

This paper reports best selection of investment with finest voltage profile and least losses while maintaining radiality of the system. DNEP has been done at micro level and proposed methodology has been tested on a small dimension practical distribution system. The paper presents the best possible selection of connection of new load centers with existing system with the help of AHP and GA and results have been verified with advance optimal tool multiple criteria data envelopment analysis (MCDEA). This paper provides step by step procedure to solve a DNEP problem while keeping voltage profile and losses equally important deciding parameters as compared to investment. In the following sections, the paper has been divided into following parts.

In Section 'Problem formulation', problem formulation has been carried out, in which all possible configurations to connect new load centers with existing system are determined. Then, reduced numbers of configurations are obtained by putting a cap on number of transformers in a potential path and maximum line length. In Section 'Population formulation and power flow analysis', conventional GA has been applied to obtain data (initial population) formulation for load flow analysis. Power flow studies have been done on the reduced population. In Section 'HGA', hierarchical genetic algorithm (HGA) has been applied on the output obtained from power flow studies to obtain best configuration of stage 1 most suitable for stage 2. In Section 'MCDEA model: stage 1 best selection for stage 2', results obtained from HGA are verified by multiple criteria data envelopment analysis (MCDEA) method. Results of present work are presented and discussed in Section 'Results and discussions', followed by conclusions and scope of future work in Section 'Conclusions and scope of future work'.

Problem formulation

During first phase of extension, two greenfield load center emerge on each side of the present grid system (having 1.5 MW and 1.25 MW capacities, respectively) are considered. In second phase expansion, a 3rd load location (at location 12) is to be included having 1 MW capacity. The testing distribution system with actual configuration is shown in Fig. 1. This feeder has nine load buses with rated voltage 11 kV. These new loads of stage 1 extension located at nodes 10 and 11 are to be connected with existing system. Fig. 2 shows eleven possible sites for new transformers numbered from 'a' to 'k'. Some of the feasible network connections are discarded as their utilization in optimization process merely increase the data base but are of no use.

There are 119 ways to connect new load center at location-10 with existing buses (4)–(9) via 4 new transformers and 343 ways to connect new load center at location-11 with existing system via 7 new transformers. These connections may be obtained from (1) and (2)

$$Bus_{10} = B\left(\sum_{m=3}^{6} {}^{n-m}C_{r-1} + {}^{n-3}C_r\right) + B \tag{1}$$

$$Bus_{11} = B\left(\sum_{m=0}^{6} {}^{n-m}C_{r-1} + {}^{n}C_r\right) + B \tag{2}$$

where n is highest number of transformers connected for any load center (which is 7 in present case), B is number of busses to which connections are feasible and r is maximum number of transformers which are kept fixed to evaluate total number of configurations. In (1) and (2), maximum 4 transformers in a potential path are considered. These two load centers can be connected to the system in 40,817 ways.

To reduce above figure to a feasible number, a cap of two transformers, maximum length of 1.3 km line length and not having