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Full Length Article

Optimal distributed generation placement in distribution system to improve reliability and critical loads pick up after natural disasters

Galiveeti Hemakumar Reddy *, Pranju Chakrapani, Arup Kumar Goswami, Nalin B. Dev Choudhury

National Institute of Technology Silchar, Silchar, Assam 788010, India

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ABSTRACT

The increase in frequency of natural disasters has necessitated the need of resilient distribution systems. Natural disasters lead to severe damage of power system infrastructure and the main grid may not be available to serve the loads. The integration of distributed generation (DG) into distribution system partially restores the loads after natural disasters and improves the reliability during normal operating conditions. After a natural disaster, objective of the system operators is to restore the critical loads as a priority. This enables the need of considering critical load pick up as an objective function while placing the DGs. A location based constraint is, thus, required to make sure the DGs are available to pick up the loads after natural disasters. Fuzzy multi criteria decision making (FMCDM) approach is used in this work to rank the load points and locations/feeder sections. This paper uses particle swarm optimization (PSO) to evaluate the optimal size and location of DGs using the proposed objective function. The obtained results are compared with the results of reliability as an objective function.

1. Introduction

In the recent decades, the power outages due to natural disasters have been observed to increase. The Hurricane Sandy in USA [1] and Hudhud cyclone [2] in India for instance left millions of customers without power supply for several days. During the disaster conditions, distribution systems are isolated from the main grids. This enables the restructuring of distribution systems with sufficient local generation to pick up the important loads.

DG integration increases the operational complexities in the distribution system and system performance reduces with improper locations. The proper location and size of the DGs enhances its benefits in the distribution system. In the literature, the optimal DG placement (ODGP) problem is solved by considering different objectives, voltage stability margin [3,4], voltage profile [5], power loss [6,7], energy loss [8] energy cost [9], benefit/cost ratio [10], voltage limit loadability [11] and reliability [12–14]. In reference [15], ODGP problem is solved to minimize the load shedding during the islanding operation. A comprehensive review is carried out to solve ODGP problem using various optimization techniques in [16]. The ODGP problem is solved as single and multi objective mixing two or more objectives [17,18].

From the literature, it is observed that researchers are concentrated only on the system performance considering normal operating conditions. A clear research gap is identified to solve the ODGP problem considering natural disasters. A natural disaster causes multiple damages in the distribution system which may lead to the unavailability of main grid supply and can be continued for several days. After a natural disaster, the aim of the distribution system operators is to supply power to the important loads and initiate disaster management activities. The DG integration is aimed to provide power supply to important loads and other disaster management activities. To solve the ODGP problem considering natural disaster scenario, is to maximize the critical load (important/emergency loads) pick up and assure the DG's availability to pick up the loads. The problems mentioned in the existing literature have not considered the natural disaster scenarios. The solution of ODGP problem considering the operational constraints may not assure the DG availability to pick up the loads.

Therefore, a new objective function is proposed i.e. maximization of critical load pick up considering the location based constraints. The proposed objective function requires prioritization of load points. Authors in [19] prioritized the load points by determining the weight of each load point which considers the current rating of load points. This method did not consider different load types (ex. hospital, public utilities, grocery, residential etc.) existing in the distribution system. The load points in the distribution system are combination of different load types and by the consid-

* Corresponding author.
E-mail address: 13-3-03-104@student.nits.ac.in (G.H. Reddy).

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eration of these, the load point prioritization problem becomes multi criteria decision making (MCDM) problem. The priority of a load point from the view of each load type is subjective decision and a fuzzy MCDM is presented to determine the weights of load points and ranking [20].

The DG placement and availability not only depends on the operational constraints, it depends on other factors also. The factors that will impact on the DG location selection and availability after a natural disaster are considered to ensure the DG availability. These factors are used to rank the feeder section for preferable DG placement.

In this paper, particle swarm optimization (PSO) method is selected to solve the ODGP problem. Authors in [21–24] shows the effectiveness of PSO algorithm for solving the optimization problems in engineering field.

Finally, the author's contribution in this paper is as follows:

1. A new objective function is proposed for ODGP problem called as critical load pick up considering weights of load points.
2. A new location constraint is proposed to overcome the risk of DG unavailability after natural disasters.
3. Fuzzy multi criteria decision making (FMCDM) is presented to find the non-dominated weights of load points, feeder sections and ranking is done using these weights.

2. Problem formulation

The objective of maximizing the critical load pick up is achieved by placing the DG near the critical loads. It requires the identification of critical loads precisely and effective DG placement.

2.1. Ranking of load points

Distribution system serves different types of loads which includes residential, commercial, grocery, public utilities, govt. offices and health care etc. The importance of different load types varies with different situations and different people have different types of opinions on the importance of a load type over another load type. These opinions are not objective, instead they are subjective. Ranking of load points based on its importance is easily done if each load point has only one type of load. But, it is not a realistic approach in distribution systems. The total load in a load point is a mix of different load types. Individual load types are the decisive parameters to rank the load points. The load point ranking problem is solved by using FMCDM approach and is explained in detail in later sections.

2.2. Ranking of feeder sections

The preferable DG location is decided by many factors and feeder sections are ranked according to these factors. The factors and their significance is explained as follows:

- Availability of feeder section: This factor considers the failure history of the feeder to make sure the DG is available when it requires.
- Vulnerability to weather conditions: This factor handles the sensitivity of feeder or location to severe weather conditions and give the assurance that feeder section is not affected by natural disasters.
- Space availability: The space is the major criterion for DG placement. The space includes rooftops for solar PV units and ground for installation of conventional DGs along with control facilities and fuel storage. This factor also includes the cost of the space.
- Public willingness: This factor handles the acceptance level of households near to the proposed DG location for its placement.
- Critical loads: This factor improves the importance of the location to place a DG as the critical load pick up is the objective. It is decided by considering loads surrounded by the proposed DG location.

Each factor has a certain degree of importance on the ranking of feeder sections. The opinions on each location are collected to find how much a location is favorable for placement of DG considering each factor. These opinions are subjective in nature and FMCDM approach is applied to rank the feeder sections.

2.3. Fuzzy multi criteria decision making

The opinions collected for ranking of load points/feeder sections are subjective. The dependenacy of ranking on the many factors increases the complexity in the solution. In this work, a FMCDM approach [20] is presented to solve this complex ranking problem. The procedure of FMCDM is explained by taking load point ranking as a reference. The problem is solved in two steps: firstly, the weight of each load type is evaluated and then non-dominated weight for each load point is determined. The step by step procedure of ranking problem is as follows:

The experts' opinions are collected for all load types, the preference of a load type over other load types and these opinions are subjective in nature. Each subjective opinion is associated with positive number and these numbers are used to construct fuzzy reciprocal matrix (B) [25]. b_{ij} is an element in B and is defined as priority of ith load type over jth load type. The value of b_{ij} is determined using the following equation.

$$b_{ij} = \begin{cases} 4 & \text{if } i\text{th load type is strongly preferred over } j\text{th load type} \\ 2 & \text{if } i\text{th load type is weakly preferred over } j\text{th load type} \\ 1 & \text{if } i\text{th load type and } j\text{th load type are equally preferred} \\ 0.5 & \text{if } i\text{th load type is weakly not preferred over } j\text{th load type} \\ 0.25 & \text{if } i\text{th load type is strongly not preferred over } j\text{th load type} \end{cases} \tag{1}$$

The geometric mean method is used to find the fuzzy mean number corresponding to each row of B. The weight of each load type is evaluated using following equations [25]:

$$e_j = (b_{j1}(.)b_{j2}(.)\dots(.)b_{jm})^{1/m} \tag{2}$$

$$w_j = e_j/(e_1(+)e_2(+)\dots(+)e_m) \tag{3}$$

The weights are represented as triangular fuzzy number ($\tilde{w}_j = (w_j^l, w_j^m, w_j^r)$) and the fuzzy number is determined by

$$\begin{aligned} w_j^m &= w_j \\ w_j^l &= w_j^m - \varepsilon_l \\ w_j^r &= w_j^m + \varepsilon_r \end{aligned} \tag{4}$$

here, ε_l and ε_r are the spreads to left hand and right hand of triangular membership function respectively.

The decision of a load point is critical over other load points and should be made on the basis of various load types presents on that load point without comparing with other load points. The subjective ratings are collected from experts for a load point, how much the load point is important from the view of each load type. A triangular fuzzy number is assigned for each subjective rating and is shown in Table 1 as an example. The non uniformity in the numbers is due to the disparaging nature of the fuzzy variables which is considered from an expert's point of view. However, utilities can freely choose the range of subjective rating and associated triangular fuzzy numbers.

A fuzzy decision matrix $\tilde{D}$ is evaluated based on the subjective ratings collected for each load point from a set of K experts. $\tilde{x}_{ij}$ is