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Original Research Article

# A novel hybrid approach to allocate renewable energy sources in distribution system

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ABSTRACT

The integration of renewable energy sources (RESs) based DGs into grid has a great importance in improving system reliability. Many methods were proposed in the literature for finding best locations for DG placement considering various criteria. Sometime, it becomes difficult for combined placement of different kinds of renewable based DGs, such as solar, wind and fuel cell. The criterion of minimizing total system cost was used previously by many researchers for locating the optimal sites for DGs using OPF formulations. In this case, three different cost functions are formulated for different kinds of renewable energy sources (RESs). By taking combined cost function of all the RESs in the OPF to identify location for each different kind of sources becomes very cumbersome task. It would be difficult to find the exact locations for various kinds of RESs that is where to place which type of RESs. In order to solve this difficulty, three different objectives have been considered separately for determining the optimal locations for each kind of RESs using mixed integer nonlinear programming (MINLP) method considering loadability, losses and cost. Having many alternatives with these three objectives, analytic hierarchy process (AHP) has been used to make a decision over getting the optimal locations for these different kinds of RESs. The proposed methodology has been demonstrated on 15-node radial distribution system and 69-node mesh distribution system.



## 1. Introduction

The global energy requirement has been rapidly increasing day by day due to rapid industrial growth. Hydro and fossil fuel plant will continue to be the chief sources of electric supply for a few years. Coal and nuclear based generation plants create environmental pollution due to the release of hazardous pollutants along with the disposal and storage of the radioactive wastes. Since the energy crisis in the 1970s, the focus on renewable energy has been the major agenda in several developed countries, especially the wind, biomass and solar energy sources. Now a days, the system planners in many country are thinking in this direction for a sustainable transition from fossil fuel based energy technologies. Also, Government started initiative by providing financial support to carry out research and development work in this direction [1]. Before the innovation of large generating units, small distributed generations (DGs) were in use to supply electricity but due to economy of scale, large generating systems were developed and the electricity is supplied at a cheaper price. However, recently due to many advantages associated with DGs, the interest in integrating DGs to the distribution system has been revived. DG is often used to illustrate a small-scale electricity generator, which can be owned and operated generally by distribution companies (DISCOs) or customer at distribution or sub-transmission level to maintain the quality and reliability in electricity supply. It can be renewable energy sources (RESs), based on wind, photo-voltaic, biomass, fuel cell or hydroelectric power, or conventional type viz. gas turbine, diesel engine. RES may be either connected to the local electric power grid or isolated from the grid in stand-alone applications. RES plays an important role in providing clean energy with reduction of carbon foot prints, and hence a crucial constituents of future sustainable development. The penetration of RESs in the network helps in achieving voltage control, reduction of power losses and improvement of system reliability. Due to the increasing awareness about environmental pollutions, mid-term and long-term targets have been set to reduce the emission intensity of energy supply in several regions of the world. Therefore, the environmental issue will play an important role in the future planning strategies. For this purpose, a comprehensive planning framework is necessary to evaluate the technical and economical

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characteristics of various DG technologies and choose an optimal planning scheme, which is the best compromise among these various characteristics. Therefore, considering the future scarcity of fossil fuels and the environmental damage caused by them, it is irrefutable that the use of renewable sources of energy is the best option for providing electricity.

An alternative approach under consideration by utilities is to satisfy demand locally and incrementally by investing in distributed generation. Distributed generation amenities are tactically sited to deliver electricity, where it is needed. Optimal location for the placement of DGs with minimizing of losses using gradient and second order methods is presented in [2]. In [3], a linear programming approach to determine optimal allocation of embedded generation on distribution networks is proposed. Optimal location and sizing of DG in a distribution networks using Genetic Algorithm (GA) has been discussed in [4]. The allocation and sizing of DGs for social welfare maximization and profit maximization using Locational marginal price (LMP) has been proposed in [5]. Optimal placement of distributed generation for profit maximization, reduction of losses and improvement in voltage regulation at various load buses in the distribution network is shown in [6]. In [7], a GA based methodology for optimal DG allocation and sizing in distribution systems, in order to minimize network losses, and guarantee high level of reliability and voltage improvement was proposed. A method to allocate and determine the size of DG for minimization of the active losses of the feeders using tabu search algorithm is presented in [8]. The application of solid oxide fuel cell (SOFC) systems to generate electric power and thermal energy required for residential use is discussed in [9]. Considering the way in which the early power utilities were operating to produce and deliver electricity, it is obvious that DG is not an entirely new concept. Utilities had their own assigned geographical territories, producing and distributing electricity locally. National grids then came into existence to form large interconnected systems that made power systems more economical and reliable.

Nowadays, a number of authors have been presented admirable results by using large number of multi-criteria decision analyses in energy management. In [10], analytic hierarchical process (AHP) is used to decide the hierarchy of the planning process and members constituting the hierarchy are allowed to rate each other and relative grading of weights was discussed. AHP method is used to solve the DG planning with uncertainties considering different objective was discussed in [11]. The Multi-attribute decision making approach is one of the best technical aid for strategic planning of electric utilities. It selects the best resource strategy with regard to the chosen attributes [12]. The decision maker is confronted with the deliberate planning studies with different options such as grid connection, hybrid systems and now the new option of micro-grid. Multi attribute decision making (MADM) will be the appropriate choice for justifying the new technology. Normally, in MADM problems the information available to the decision maker is often vague due to mistaken attribute measurements and flawed priority judgments [13].

In the proposed, the planning of RESs has been carried out by using a hybrid method consisting of both optimization and analytical hierarchy process. Three different optimal power flow (OPF) problems have been formulated and solved using the mixed-integer non-linear programming (MINLP) method, which provides optimal bus locations for RES at various load serving nodes and ranking of each of the optimal bus locations for the system. The optimization problem has been solved using GAMS solver [14]. With numbers of alternative bus locations and rankings obtained from three OPF formulations, the overall priority indices have been obtained by using Expert Choice based on an analytical hierarchy process algorithm. The results of AHP clearly indicate the ranking of optimal locations for various kinds of RESs. In AHP, first pairwise comparison have been made based on the ranking of DGs locations obtained from individual objectives. Finally, the pairwise comparison are made between main objectives considered for the RESs planning in the system. The important outcomes and their effects on appropriate locations and size i.e. including voltage improvement, voltage control, reduction of losses and transmission congestion, positive environmental impacts and enhance the reliability of the system. The effectiveness of the proposed approach have been tested on 15-bus radial distribution system [15] and 69-bus mesh distribution system [16].

## 2. Proposed framework for RESs planning

In this work, the main objective of placing RESs in the system is to improve loadability, reduce system loss and cost of each RES based DGs in the network. Therefore, the proposed approach has considered three objectives in the OPF formulation. The result of these OPF gives many alternative locations for RESs placement separately. The results, so obtained, have been used to arrive at overall optimal locations for the placement of different kinds of RESs by using AHP algorithm.

The overall hybrid scheme of obtaining the optimal location of RESs is given in Fig. 1. The dotted rectangles in the flow diagram demarcate the use of mixed integer non linear programming (MINLP) and analytic hierarchy process (AHP). As shown in Fig. 1, the MINLP is used to solve the three OPF formulations and AHP is used to find the overall RESs locations, which satisfies all the objectives equitably.

## 3. OPF formulation

For the planning of various kinds of RESs, three different OPF formulations have been used. The different objectives used in these formulations are (i) maximizing loading, (ii) minimizing system loss, and (iii) minimizing DG cost. Each objective has been calculated separately for each kind of RESs. With each of these objectives, the ranking of RES locations has been obtained.

The three OPF cases have been formulated by utilizing the following objective functions.

***Case A*:** Maximizing loading: It indicates the point where load demand reaches a maximum value and beyond that limit power flow solution fails to converge and the system can no longer operate in a stable state. In this work, the loading margin of the system for different levels of renewable energy penetration has been analyzed. The loading factor $\rho$ can be represented by the following relations:

$$\rho = f(P_g, P_d, Q_g, Q_d, V, \delta) \tag{1}$$

***Case B*:** Minimizing total system loss which consists of sum of all transmission losses. The total real power loss in a distribution system with $j$ branches can be formulated as

$$PLT = \sum_j P_{Lj} \tag{2}$$

***Case C*:** Minimizing cost of the DG system:
*Minimizing fuel cell cost:*

$$C_{fuel} = C_c + C_f + C_m \tag{3}$$

The annual investment cost $C_c$ is obtained from the total purchasing cost $C_{fc}$ disregarding the individual cell replacement cost during its lifespan $n$ years and is represented as,

$$C_c = C_{fc} * (i_r(1 + i_r)^n)/((1 + i_r)^n - 1) \tag{4}$$

where, $i_r$ is the annual interest rate.