EMBEDDED GENERATION PLANNING IN PRESENCE OF RENEWABLE RESOURCES USING A PROBABILISTIC MULTI-OBJECTIVE OPTIMIZATION APPROACH

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ABSTRACT

So far, Distributed Generations (DGs) have been vast put in practice due to their evident roles in both technical and economical performance of power distribution systems. This paper investigates the presence of renewable energies once DG integration to the network has to be planned. A multi-objective optimization approach has been presented where the risk costs, the share of private investments, and imposed costs are considered as the main objectives. Performance-based regulation is also incorporated as an incentive mechanism in the DG planning process in presence of renewable energy sources (RES). The proposed scheme is adapted to the 37-Bus IEEE standard test system and the anticipated efficiency of the proposed method is well verified by then.

INTRODUCTION

Power distribution systems are always been under expansions since the ever-increasing trend of population growth continues. A power distribution network is composed of several substations connected to each other via some feeders, and altogether tries to meet the required consumer demands. Hence, distribution planners have to be sure of the adequate substation and feeder capacities to meet the required loads. This calls for some investments and is in need of comprehensive planning analysis to ensure the desired level of system reliability. In this respect, the supportive schemes can be of considerable importance in providing the utilities a means of investor absorptions to take part in the planning process of power distribution network.

Interests in distributed generations (DGs), as a part of long term planning, have been intensified due to their technical, economical, and environmental benefits. Experiencing the considerable appearance of new loads in power systems has so far lead to their common acceptance in power distribution systems [1].

The type and scope of DGs are significantly varied from country to country. This difference may also arise due to the different planning policies adopted for commercial purposes. Among the current DG technologies are fuel cells, combined heat and power (CHP), wind generations, micro turbines, hydro turbines and photovoltaic (PV) devices [1].

Due to the environmentally friendly feature of wind power, it has been recently been widely in practice as DGs in power distribution systems. This issue necessitates considering various objectives, once aiming to perform a distribution planning studies in presence of DGs with renewable energies. This also incorporates various uncertainties in wind turbines' production. They all should be considered when a regulatory framework is adapted. Different regulatory policies might have various impacts on the investors' behaviors, objectives, and the planning process of power distribution systems.

This paper aims to provide a probabilistic planning scheme on the basis of a multi-objective optimization approach to treat various contradictory economical/ technical criteria associated with the renewable integration in power distribution networks. In doing so, different objective functions are put at the point of concentration, i.e., minimizing total imposed cost of DGs projects, maximizing private investors' participation in RES projects, and minimizing the risk cost. The first classical objective shows the required budget for establishing the RES projects and other operation and maintenance imposed costs, while the second objective tries to provide the maximum feasible share of private investment through two effective economic factors in viewpoint of a private investor (capital rate of return and investment risk of projects). The last objective tries to offer a balance between the required investment of new RES projects and the imposed cost of interrupted load. A main incentive-based mechanism is considered as an input control factor by which the distribution system operator (DSO) can determine its target on the DGs integration supportive policy.

PROBLEM DESCRIPTION

This Section addresses some important issues associated with the DG placement problem in a restructured environment which are going to be analyzed as the paper major contributions.

Objective Functions

Distribution companies (Discos.) around the world have long faced a challenging subject, i.e., investigating the profitability of DG technologies. As it has been recently addressed in many papers and technical reports, DGs are attributed major consequences in distribution network losses, voltage profile, less dependency to the electrical energy market price, and reliability improvements through reducing the outage duration and frequencies. Hence, the procedure calls for a properly designed consideration to meet all the aforementioned objectives in such a way that the utilities' managers meet their technical and financial targets. The objectives associated with the planning process of DG penetration in distribution networks can play an important role in accordance with the utility perspectives. The introduced objectives in this paper are going to be more clarified and reasonably justified in the following.

Imposed Costs of DGs Projects

One of the major driving forces behind any investment opportunity is deemed to be the investment costs. Disco's annual budget, different reinforcement schemes, and their annual expenditures are among the constraints which have led to considering the total imposed cost as a classical objective. This has to be considered once the DGs projects are evaluated. The total imposed cost to the utility is comprised of DG's annual investment and operation costs, as shown in (1).

$$f_1 = \min \sum_{t=1}^{T}\sum_{i=1}^{N}\left\{ \frac{1}{(1+d)^t}.CC_i.P_{DG,i}^{nom} + \left(\frac{1+i}{1+d}\right)^t.P_{DG,i}^{nom}.\overline{CF}_{DG,i}.OC.8760 \right\} \quad (1)$$

where, T, N, d, CC_i, $P_{DG,i}^{nom}$, i, $\overline{CF}_{DG,i}$, OC respectively represent the planning period, number of new DG units, The capital cost of DG in the i^{th} bus, The nominal capacity of DG at the i^{th} bus, interest rate, The capacity factor of DG at the i^{th} bus, and The operation cost of DG.

The existent uncertainties in the electricity market price can affect the DG owners' revenue. The associated changes in DGs output power are modeled via a Capacity Factor (CF), as shown in (1). The electricity market price (and accordingly CF variations) is modeled applying a robust approach in dealing with the probabilistic problems, i.e., Point Estimation Method (PEM). The aforesaid method is going to be introduced later in this paper.

Risk Costs

The continuity of delivered energy to customers directly affects the profitability of a utility. On the other hand, the reliability level enhancement of distribution grid is interrelated with addition of some new components which conflicts with the classical planning concern (minimization of total imposed costs). Fundamentally, the total earned profit of utility is a function of both the investment cost and risk cost. The reliability level increases as the customer willingness to pay decreases. This illustrates that a compromise has to be needed and the two basic factors (company cost and customer willingness to pay) determine the optimum reliability level. The planning problem considering the reliability level as a constraint is defined as in (2).

$$\min \sum_{i\in N} C_i.n_i \quad \text{s.t.} \quad (2.a)$$

$$EENS_{DS} \le EENS_R \quad (2.b)$$

$$EENS_{DS} = \sum_{i=1}^{N} L_{a,i} U_i \quad (2.c)$$

In which, $EENS_{DS}$, $EENS_R$, $L_{a,i}$ and U_i respectively represent the EENS of Distribution system, The acceptable level of network reliability, The average load of the i^{th} bus and The undelivered energy associated with the i^{th} bus. The utility's total profit as a function of the desired level of reliability can be ranged from the optimal point with regard to the different $EENS_R$ values. Hence, the risk cost is here considered as an objective in the DG placement problem which is determined by:

$$\min \sum_{i\in N} EENS_i \times IEAR_i \quad \text{s.t.} \quad (3.a)$$

$$EENS_{DS} \le EENS_L \quad (3.b)$$

Private Investors' Participation Maximization

One of the most important dilemmas in a deregulated power system is the unwillingness of private investors to invest in the costly projects of installing new DGs. This is mainly due to shortage of appropriate economic incentives and the uncertainties associated with the cost recovery of a project. So, since the energy consumptions and the associated revenues are stochastic in nature, applying an influential probabilistic method allows the investor to determine the most opportunistic time to well start a project and acquire the maximum revenue returns by then. Moreover, it allows the private investors to select and validate the package of incentives required to support new investment in response to the aging and loading conditions of the distribution network. So, maximization of the private investments for DG integration is here offered as an objective. This contributes the vital economic signals and is introduced by (4).

$$f_3 = \max \sum_{i\in N} CC_i.n_i \quad (4)$$

To this end, this paper employs two unavoidable economical factors which show the main requirements of an investor (economic risk of the project and its rate of return) in line with the projects' attractiveness. So, the rate of return and the risk level of each DG candidate need to be checked in accordance with those of desired levels. These economic constraints are defined as shown in (5).

$$\sigma_{DG,i} \le \sigma_L \quad (5\text{-a})$$

$$RoR_{DG,i} \ge RoR_L \quad (5\text{-b})$$

Uncertainty Modeling

Predicted amount of future loads and the changeability in the forecasted electrical energy price impose major uncertainties in power systems planning studies. Moreover, wind turbines' productions have intermittency in nature and should be probabilistically modeled. These inherent uncertainties associated with the renewable energies together with the inability of current regulation policies in supporting the RES, have led to some challenging technical and economic concerns. In response, the need for a suitable structure which can be able to manage the probabilistic challenges in the planning procedure of power distribution networks seems imperative.

Monte Carlo simulation (MCS), analytical methods, and approximate methods can be accounted as the three main approaches of probabilistic modeling in power system studies. The large numbers of simulations are among the main shortcomings of MCS. Also, the analytical methods necessitate some mathematical assumptions in order to manage the problem. The PEM has been recently grown up in recent as an efficient method to handle the existent uncertainties [2]. The PEM uses deterministic routines in different stages of problem solving procedure with a much lower computational effort in comparison with MCS. Also, the lack of data information is incapable of impeding the PEM effectiveness.

INCENTIVE MECHANISM

Cost of service and rate of return regulations have been traditionally employed in utilities to guarantee a certain amount of return on investment or profit [3]. This resulted into a very low incentive for utilities to enhance their efficiency since their profit was dependent on their operating costs. In response, incentive-based regulation was introduced. Then after, price control regulations are combined and price and revenue caps were also involved. Service quality regulation was then born concentrated on the three main features of quality; continuity of supply, voltage quality and commercial quality. Reward/penalty mechanism (RPM) has been recently regarded as an efficient and applicable scheme in this category, which is adopted in this paper. As shown in Fig. 1, the histogram represents the random average energy not supplied (AENS) of a typical distribution system. This figure conceptually determines the amount of reward or penalty associated with each AENS value based on the pre-specified RPM. The interested reader is referred to [3] for more information about the RPM.

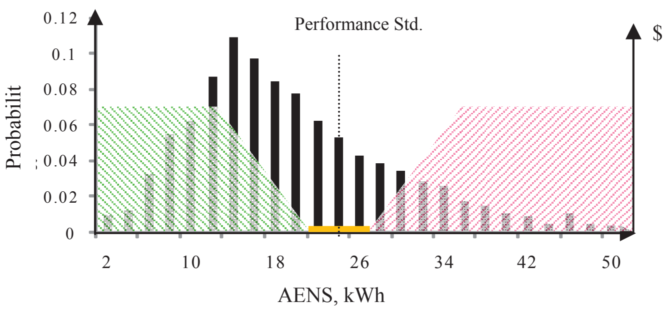

Figure 1. A probability distribution of AENS in an adopted regulatory policy [3].

In each step of the applied multi-objective optimization technique, i.e. NSGAII, a combination set of DG location and type would be created (a candidate scenario). The objectives are all calculated for each scenario. Using the probabilistic load model, the value of EENS for each load level can be determined. This answers the question in which load level, the utility should be penalized or rewarded. The expected reward and penalty can be calculated through (6).

$$PEN = \sum_{i=1}^{n} (P_{PEN_i})(pen_i) \qquad (6\text{-a})$$

$$REV = -\sum_{i=1}^{n} (P_{REV_i})(rev_i) \qquad (6\text{-b})$$

Where, P_{PEN_i} and P_{REV_i} are representatives of the probability of achieving the i^{th} value of the reliability index. pen_i and rev_i are set to be the values of penalty and rewards, respectively. As a result, the objective function associated with the risk cost can be re-writed as follows.

$$Risk\ Cost = \sum (EENS).(IEAR) + PEN - REV \qquad (7)$$

Now, we can be certain of the fact that NSGAII algorithm will find the optimal combinations of DG location and type which are attributed the least possibility of being in the regulatory penalty zone.

CASE STUDY

System Understudy

The test network used for the verification of the proposed algorithm is the IEEE 37-bus test feeder, whose single line diagram is as depicted in Fig. 3. The maximum demand at the end of the planning horizon is forecasted to be 4500 kVA with a forecasting error equals to 15%. The interested are referred to [4] for more information on the test network. It is assumed that Disco has to set a 10-year plan horizon to meet the peak demand. The here-used DG technology is micro turbine and wind turbines. The electricity market price is considered to be 0.06 $/kWh with a 20% standard deviation. During this time period, the rate of inflation, discount, and load growth are respectively assumed to be 9%, 4%, and 6% [4]. The outage costs associated with the customers in different load points are considered based on [5].

To decide where to have the DGs penetrated (candidate buses), a sensitivity analysis is performed. The sensitivity of the risk cost variations with respect to the net power injected into each bus, i.e., $(\partial RC/\partial P_{G,,i})$, are investigated through (8).

$$RCS_i = \frac{RC_{base} - RC_i}{RC_{base}} \qquad (8)$$

The sensitivity factors for different buses can effectively help the decision maker to select the appropriate candidates for DG installation. Among all the network buses, 16 critical ones are selected via the utility itself as the proper candidates.

Numerical Results and Discussions

The proposed algorithm based on a multi-objective optimization approach (NSGAII) is simulated and 41 optimal solutions were found. These solutions determine the best possible locations for DG installation, their technologies and capacities. To find the final optimal solution among the 41 available ones, a decision making approach should be employed. Here, a fuzzy decision making method is applied.

Fig. 2 depicts the risk costs of different optimal solutions of DG planning problem for two scenarios (considering reward/penalty regulatory mechanism and with no incentive). As can be seen, in all of the found plans, the PBR mechanism forces the optimization process to employ more DG (conventional/renewable) units for the sake of penalty reduction which subsequently decreases the risk cost. So, the distribution operator will expect to meet more rewards in various load levels.

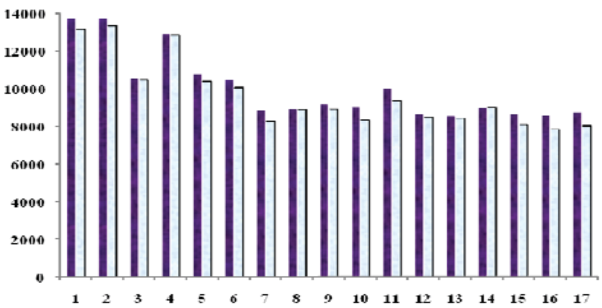

Fig. 2. The risk cost of some optimal plans with or without the incentive framework.

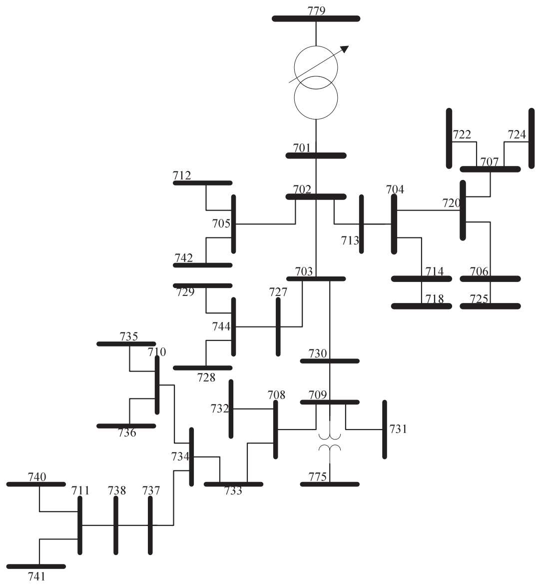

Fig. 3. The IEEE 37-bus test system under study.

Fig. 4 represents the percentage of different DG technologies (wind or micro turbines) in the obtained DG optimal plans. As can be seen, for each DG penetration rate in the optimal plans, the wind turbine could be an attractive and promising solution for future vision of distribution network. Although in some plans, the penetration of wind turbine is much lower than that of micro turbine, the results proves the ability of renewable energy in providing the utility with an assurance of required demand.

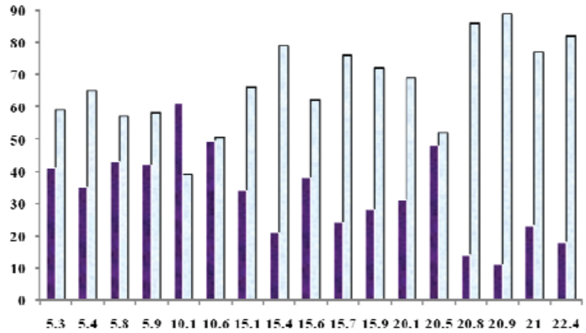

Fig. 4 Different DG technology penetrations in optimal plans.

CONCLUSION

This paper investigated the embedded generation planning in distribution networks focusing on the RES. Developing a multi-objective optimization framework handled via NSGAII, various inevitable criteria were considered. The wind turbine productions, predicted load behavior as well as the electricity price were probabilistically modeled through PEM. The reward/penalty scheme as the regulatory mechanism was taken into account to improve service reliability in the distribution networks. The proposed algorithm was implemented on the IEEE 37bus test system and the results prove its effectiveness. Also, the obtained results approved the well-founded claim of this paper for introducing renewable energy sources as trustworthy and justifiable candidates for distribution network reinforcement in coming years.

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