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Electric Distribution System Planning by Distributed Generators Installing in Restructured Power Market

F. Gharedaghi, H. Jamali, M. Deisi and A. Khalili
Dashtestan Branch, Islamic Azad University, Borazjan, Iran

Abstract: The large number of decision variables of long-term planning problem for improving the distribution system causes lots of complexities. The optimum allocation of Distributed Generation (DG) sources and determining their capacity in the deregulated electric market is a key way for capacity expansion of the distribution firm. In this study, a new approach is presented to determination the optimum location and capacity of DG sources in the deregulated electric market through the net present value analysis using an optimization model. This model aims to minimize the investment cost of the distribution firm, utility cost and the losses cost considering the anticipated load peak value. Considering the power market price anticipation to be indefinite, the proposed method is based on laying out the genetic algorithm and a fuzzy model to the power market price and the capacity expansion design of the distribution system during different time intervals is proposed along with two static and semi-dynamic methods. The efficiency of the proposed approach is well shown applying it to a sample network.

Key words: Distributed generation source, fuzzy model, net present value analysis, optimum allocation, power market.

INTRODUCTION

The investment designing for supplying the anticipated consumers required power in conventional distribution systems used to be carried out by adding new buses or increasing the capacity of the existing buses and connecting new feeders. Nowadays, the competitive condition of power market actuates the distribution firm planners towards seeking alternative economical and technical strategies such as applying DG sources. Due to the existence of risk and conditionality in power markets and because low investment costs of DG units, they are considered as an appropriate and acceptable choice for distribution networks expansion. The allocation and manufacturing process of DG units is carried out in a short time interval due to their small size. In addition, the DG units prepare the chance to provide more flexibility for power generation required fuel supplies (Dugan *et al*., 2001).

The distribution network can change from a mere consumer system to an active and power generative network due to the accessibility and flexibility of DG units in distribution voltage level. The investment on the DG sources can be propounded as an effective strategy in distribution systems expansion if the non-provided loads heavy penalty is well considered.

Several designing are presented for distribution networks expansion adding new buses in (Khator *et al.*, 1997; Quintana *et al.*, 1993). In (Brown *et al*., 2001) a successful omissive method is used to determine the optimum investigation ratio, which inhibits the transmission and distribution lines from ineffective expansion. In (El-Khattam *et al*., 2004), the optimum investigation at the presence of DG sources in the competitive power market environment is investigated.

In the restructured systems, the problem of distribution network development is knotted with other parameters such as the distribution network costs, which makes the development and expansion of the distribution network seem different from that of the conventional networks. Since the distribution firms, try to maximize their incomes, the payments on the distribution networks expansion in the restructured systems are accentuated in compare with the conventional networks and the distribution firms consider their costs and incomes as an important constraint in their covered network capacity expansion related considerations.

In this study, a comprehensive method is presented in order to determine the optimum place and capacity of installing in the distribution firms covered networks in three triennial designing processes via the static and semi-dynamic (Ramirez-Rasudo and Gonen, 1991) approaches. The main target of the optimization model is to minimize the distribution firms' investment costs, to minimize the utilization costs, to minimize the payments for the bought power, to minimize the penalty of interrupting a part of consumers load, and to minimize the losses in the distribution network. The conditionality in power market

Corresponding Author: F. Gharedaghi, Dashtestan Branch, Islamic Azad University, Borazjan, Iran

price anticipation is considered using a proper fuzzy model for the power price. The genetic algorithm is used in the applied optimization method.

METHODOLOGY

The expansion planning problem explanation: The basic target and the important subject of this paper fall in determining the optimum place and capacity of the further installed DG units from the distribution firms aims point of view during a long-term planning process. Here, it is assumed that the distribution firm is in charge of delivering power to the customers and utilizing the distribution network. The firm owns the following options to adopt the injecting power ratio to its covered network feeder with the customers growing consumption ratio:

- It can buy more power from the power generating firms through the transmission systems. This forces the distribution firm to expanse its exchange capability in the point of transmission system connection.
- It can install the DG units in the distribution networkto answer the consumption growth of the customers.

It can decrease the consumption level by interrupting the loads where it should pay the penalty of the non-provided power of the customers, which would be a high amount of money in the restructured systems.

The problem modeling: The problem investigated in this paper is the long-term planning carried out for distribution network capacity expansion knotted with another aim named as maximizing the distribution network benefits (Benefits= Incomes–Costs). In this problem, the distribution network faces with a set of specific customers and the amount of their consumed power. Therefore, the income value of the distribution firm is in proportion with the power retail price. In this paper, the retail price of the power sold to the customers by the distribution firm is known and is considered a constant value. Therefore, the problem of network capacity expansion is limited to the costs minimization considering the benefits and the anticipated load growth curve, from the distribution firms' point of view.

The proposed target function is applied to minimize the investment costs and utilizing DG units, to minimize payments for power purchase, and to minimize the losses compensation costs. The mathematical equation of the target function is explained as (1):

$$J = \sum_{i=1}^{M} \left(C^{fi} . P_{DGi}^{CAP} + C_{ri} . P_{DGi} \right) + \rho . P_{SS} + C_{Ue} . P_{Ue} + P_{loss} . \rho \tag{1}$$

where P^{CAP}_{DG} is the installed DG capacity, P_{DG} is the DG generated power, M is the number of buses DG is installed on, P_{SS} is the amount of power distribution firm buys, P_{Ue} is the non-provided power, C_f is the per hour DG investment cost, C_r is the per hour DG utilization cost, ρ is the power market price, and C_{Ue} is the non-provided power cost.

Different loading levels in different hours are modeled by hourly load curve. The target function J is in terms of Currency Unit per hour and the DG investment and utilization cost is in terms of cost per hour. Therefore, the proposed optimization is solved for each load curve period.

Equation (1) is minimized considering several utilization limitations to satisfy distribution network electrical constraints, DG utilization constraints, and investment sources constraints. These constraints are discussed in follows:

- The power flow constraint: the sum of the input power to distribution firm feeders (considering the feeder losses), the DG generated power amount, and the non-provided power amount should equal to the overall load requested power amount:

$$P_{SS} + \sum_{i=1}^{M} P_{DGi} = D + P_{loss} - P_{Ue} \tag{2}$$

  where, D is the total power amount consumed by the customers.
- Distribution feeder capacity constraint: the amount of power flowing the distribution feeder should not violate the thermal restriction of the feeder:

$$P_{line} \le P_{line}^{\max} \tag{3}$$

- The distribution network transformer capacity constraint: the total power delivered to distribution feeders from the transmission network should fall in the allowed capacity range of the transformer connecting the transmission system to the distribution network:

$$P_{ss} \le P_{ss}^{\max} \tag{4}$$

- Voltage drop constraint: the voltage drop constraints are specified depending on the voltage regulations regulated by the distribution firm:

$$0 \le V_{regulation} \le \Delta V \tag{5}$$

where ΔV is the maximum possible voltage drop.

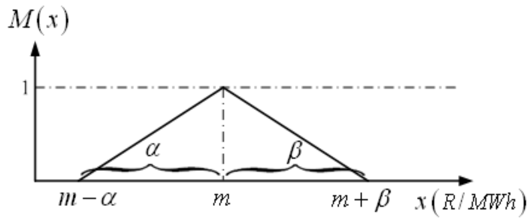

Fig. 1: The fuzzy model of power market price

- DG utilization constraint: the DG generated power should be less than the DG installed capacity:

$$P_{DGi} \le P_{DGi}^{CAP} \quad \forall\, i \in M \tag{6}$$

- The investment sources constraint: the distribution firms usually decide on the investment considering the financial constraints. These determine the limitations of the investment level:

$$\sum_{i=1}^{M} C_{fi} . P_{DGi}^{CAP} \le BCL \tag{7}$$

where, BCL is the maximum budget allocated by the firm to expand the covered network capacity.

The fuzzy model for the mutual contract price: In the investigated problem, the price of the mutual contract signed between the distribution and the generation firms is required. As depicted in (1), this price, as an important parameter impresses how the distribution firm plans for the expansion and faces with the customers' consumption increase. Since the anticipation of this price is accomplished due to the fuel, load, and the forthcoming power market prices anticipation, it is accompanied by risk and the conditionality. Therefore, applying fuzzy sets, used for conditional and imprecise values, is under consideration here. In the other words, a fuzzy digit (Fig.1) is used to indicate this price instead of using a definite digit. This is closer to the reality since it covers the conditionality of power market price anticipation. Therefore, the importance of such modeling to express the conditional values of market price falls in the fact that more real results would be obtained with good accuracy (Dubois and Prade, 1980).

$$M(x) = \begin{cases} \dfrac{x-(m-a)}{a} & m-a < x < m \\ \dfrac{(\beta+m)-x}{a} & m < X < \beta + m \end{cases} \tag{8}$$

Long time planning: The effect of time lapse should be considered in the planning process by determining proper time of structuring each project since the distribution system's load is time variable during the investigation period.

In this study, the following methods are used for long time planning:

- The static method
- The semi-dynamic method

In the static method, the system is optimized considering the maximum load level in the horizon year with concern to network configuration in the base year. In the semi-dynamic method, a static optimization is accomplished to feed the load in the base year initially. In continuous, the single stage successive expansion is accomplished in a way that the units selected as the candidate points in the first stage are selected in the base year and the optimization is carried out for the single stage successive expansion.

Genetic algorithm based optimization method: The Genetic Algorithm (GA) is based on the natural genetic mechanism. It aims to optimize a function called fitness function defined by the operator (Goldberg, 1989). The algorithm used here is the genetic algorithm with the fuzzy digits. Algebraic functions are applied on the LR fuzzy digits (Dubois and Prade, 1980). The fuzzy ranking by α incision method is applied to arrange the chromosomes fitness values (Dubois and Prade, 1980). Therefore, all the calculations of target function and fitness function in genetic algorithm are carried out by fuzzy digits and its rules (Goldberg, 1989).

The candidate points selection: In the restructured power industry sphere, it is necessary to concern about the profitability of the projects, hence the projects with low investment cost and high profitability are feasible. The net present value index is an example for the indices concerned in the financial evaluation of projects (Giri and Dohi, 2004). The following algorithm is followed in this paper in order to select the candidate points in each stage of the optimization process considering the net present value index:

- All consumption buses are selected as the candidate DG installing points and a random value is allocated as the capacity of each unit.
- The optimum solution is raised by minimizing (1) for each time interval of the load curve.
- The net present value of each selected unit in step 2 is calculated.
- The algorithm ends and the unit(s) selected in step 2 is (are) considered as the optimum solution if the net

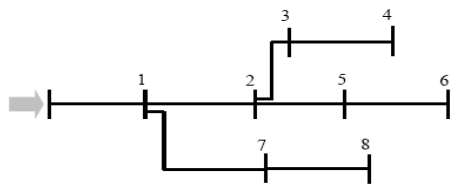

Fig. 2: Single line schematics of a sample feeder

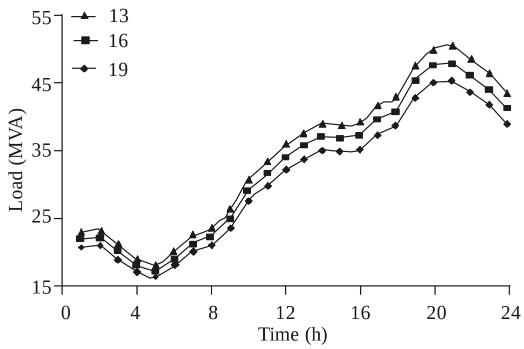

Fig. 3: The hourly load curve of the sample feeder

present value of selected unit(s) in step 2 is (are) positive. The next step is valid if the net present value of selected unit(s) in step 2 is not (are not) positive.

- The units which net present values are negative are eliminated and step 2 is repeated for the corrected candidate points set.

CASE STUDY

A real example is used here to evaluate the proposed method efficiency. In the presented example, a feeder from the Afsarie region of Tehran is investigated which is shown in Fig. 2. This feeder possesses eight buses, five of which are commercial-domestic buses, two just commercial, and one just domestic. In order to prepare the mentioned network for DG units installation, the Afsarie feeder load estimation results obtained in 2010 are increased with proper gauge. The power distribution lines are considered as 20 kV two-circuit overhead line to correct the resistance and the inductance of the lines. The transformer size connecting the distribution network to the transmission system is considered a 40 MVA transformer.

The base year is considered 2010 and 2019 is considered as the horizon year and the planning period is divided into 3 triennial intervals. Three curve sets are resulted for 2013, 2016, and 2019 considering the load growth rate for the commercial and domestic buses (Thirault *et al*., 2002). They are well illustrated in Fig. 3. The distribution firm has a mutual contract to buy 40 MW power from the transmission firm. The price of this mutual contract is considered *70 R/MWh* as a fuzzy digit with ±10% tolerance in which *R* is the currency. The

Table 1: DG capacity in different buses

	Power generated by new installed dg (mva)				
Load (MVA)	Bus 1	Bus 2	Bus 3	Bus 5	Bus 7
35	0	0	0	0	0
40	0	0.23	0	0.51	0.17
45	0.68	1.34	1.61	1.48	086
50	0.83	1.85	2.93	2.95	1.81
DG size (MVA)	1.00	2.00	3.00	3.00	2.00

capacity of installable DG units is considered graduated of 1MVA, while the DG installation and utilization costs are 0.5*MR/MWh* and 42*R/MWh* respectively and the non-provided power cost is considered 320*R/MWh*. The inflation and interest rates factors are applied as 15% and 12% respectively in order to change the current costs into present value and analyze the net present value (Thirault *et al*., 2002).

Static planning: According to the load curve of 2016, the location and the optimum size of DG units are achieved minimizing (1) where Table 1. shows the possible selections. The capacity required to install the DG units in different buses differs which is due to the difference of load patterns in different buses and consequently the difference in the losses rate in different distribution network lines.

As the location and the capacity of the initial candidates are determined, it is time to analyze the selected units economically in order to correct the candidate points. Table 2 shows the results of net present value analysis in which the candidate point's correction is applied and the units possessing negative net present value are omitted. Table 3 shows the results of candidate point's correction for the optimization end of applying which the net present value of all selected units posses positive value. It is necessary to mention that the net present value of DG units differs from each other and it is due to the existence of difference in installed capacity and generated power in different units.

Semi dynamic planning: In this method, the results of static planning are considered as the primary candidate points for planning in 2010. The results obtained for 2010, 2013 and 2016 and the candidate points correction process are shown in Table 3. These results make it possible to select the proper choices by investigating the suggested designs and considering the time length of selected issues execution.

The results of net present value analysis method presented in Tables III and IV in terms of currency per day. Comparing the results of proposed method with the conventional distribution system expansion method mentioned in (Khator and Leung, 1997), well shows that the optimum allocation of DG units removes the necessity of distribution system from structuring new feeders and increasing the transformer size, which connects the distribution system to transmission line. Consequently, the benefits of distribution firm increases through retailing

Table 2: The installation, profit, and net present value of DG units for 2019 applying static method

		Profit of dg units installation (currency unit/day)				
		Bus 1	Bus 2	Bus 3	Bus 5	Bus 7
Load (MVA)	35	0	0	0	0	0
	40	0	1.62	0	1.14	1.31
	45	14.91	28.27	9.64	38.13	57.75
	50	600.4	3095.7	602.4	2312	3105
Total Profit (Currency unit/Day)		423.3	963.2	2284.54	2236.45	1006.69
Operation cost of DG (Currency unit/Day)		387.9	879.2	1049.54	1351.55	921.39
Constant cost of DG (Currency unit/Day)		136.9	237.8	410.7	410.7	237.8
Total cost of DG (Currency unit/Day)		524.8	1117	1969.24	1726.25	1159.19
Net present value (Currency unit/Day)		-101.5	-153.8	324.3	474.2	-152.5
DG size (MVA)		1	2	3	3	2

Table 3: The results of applying static method for 2019

		Candidates check			
Step	Primary candidates	Bus	Size (MVA)	Net present value (Currency unit/day)	Deleted candidates
1	1, 2, 3, 4, 5, 6, 7, 8	1	1	- 101.5	
		2	2	- 153.8	
		3	3	324.3	
		5	3	474.2	
		7	2	- 152.5	
2	3, 4, 5, 6, 8	3	1	385.58	1, 2, 7
		4	2	836.73	
		5	2	721.53	
		6	3	1151.4	
		8	3	1170.3	

Table 4: The results of applying semi dynamic method in 3 triennial intervals

			Candidates Check			
Year	Step	Primary cndidates	Bus	Size MVA)	Net pesent vlue (Currency uit/day)	Deleted cndidates
2013	1	3, 4, 5, 6, 8	3	1	- 4.5	3, 4, 5
			4	1	- 24.3	
			5	1	- 1.8	
			6	2	674.2	
			8	3	981.53	
	2	6, 8	6	2	836.73	-
			8	3	1261.53	
			3	1	2.425	
2016	1	3, 4, 5	4	3	1021.11	
			5	3	- 415.49	
	2	3, 4	3	1	23.12	-
			4	3	1356.54	
2019	1	5	5	2	98.26	-

power to consumers and the money paid for expansion decreases.

CONCLUSION

In this study new method based on the fuzzy theory and genetic algorithm is proposed introducing and modeling capacity expansion of distribution network through allocation and capacity determination of DG units in restructured power market sphere. Here, it is tried to reach to more real results by covering the conditionality subject applying fuzzy modeling to express the power market price rate. In addition, it is tried to choose the best economic choice considering anticipated load peak value using the combination of net present value analysis approach and the genetic algorithm. Results obtained from static and semi-dynamic are presented to assist the designer to decide on the several short-term and long-term strategies and select the optimum choice considering temporal and locative conditions.

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