Reliable Distributed Generation Planning

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***Abstract*—In order to completely utilize the advantages of dispersed generation it holds compulsively to reform management and to re-validate the operations of distribution network. It hence follows picking up the optimal network topology and blending it with the optimal use of dispersed generation and retail market including real and reactive power. Also, minimization of related costs and satisfying technical and physical constraints is also the key issue to concentrate. This paper presents a methodology of filling the demand supply difference by load sharing by distributed generators integrated in the 24 bus IEEE RTS. The load is distributed so as to minimize the system losses. The saving in the cost of energy is also calculated to reduce the burden at consumer end.**

***Keywords*—Distributed generation (DG) planning, Reliability Test System, Composite customer demand function (CCDF).**

I. INTRODUCTION

Talk about the present, electricity market is undergoing restructuring with the changing conditions of law, technology, market and competition. This phenomenon is reflected in more than 120 countries. This is depicted in the global trend, where more and more energy conversion units are located in the heart of distribution. System [1-5].Current deregulation of the electric power system is the prime factor that is eventually encouraging the Independent ownership for distributed technologies. In the recent past, Distributed generation (DG) was investigated by working group of both CIGRE (The International Conference on large High Voltage Electric Systems) and CIRED (The International Conference on Electricity Distribution Networks) between the years 1997 to 1999 owing to which distributed generation is now considered as good and viable option, and it is expected that by 2015, 25% of the new generation will be distributed. In pursuance with the above, there is quite likelihood that the new generators will be independently operated as well as independently owned. Power systems to start with were originally developed in the form of local generation, supplying a local demand. Subsequent technological developments driven by economies of scale resulted in the development of large centralized grids connecting entire regions and countries. During the last decade, technological innovations and a changing economic and regulatory environment have resulted in a renewed interest in DG. To account for the broader perspective, distributed energy systems not only depend on technical aspects of energy deployment but also rely on non-technical aspects. In accordance with the World Bank, decentralization can span the levels of political, administrative, fiscal and market aspects [1], However, this paper primarily focuses on the technical and economic aspects of decentralization.

The integration of a distributed generator with distribution feeders is likely to have an impact on the operations and control of the power system; a system designed to operate with large, central generating facilities. Distributed generation (DG) devices can be strategically placed in power systems for grid reinforcement; thereby reducing power losses and on–peak operating costs thereby improving voltage profiles and load factors, differing or eliminating for system upgrades, and henceforth improving system integrity, reliability, and efficiency. Various objectives viz. loss minimization, social welfare maximization, Profit maximization under certain equality and inequality constraints, can go into the formulation of DG planning.

The paper is organized as follows: Section II, present a brief introduction to DG and thereafter, formulation of loss and economic objective function is highlighted. Section III, discusses the results. Finally, section IV concludes the paper along with the further scope of research.

II. DG-AN INTRODUCTION

Distributed generation is not new to the electricity industry. A lot of research and implementations have been accomplished in the area of distributed generation (DG) and the analysis of the relevant literature confirms with no universally agreed definition of distributed generation as yet [2].

In the literature, a large number of terms and definitions are used in relation to distributed generation.

--Anglo-American countries often use the term ‘embedded generation’ [3]

-- North American countries use the term ‘dispersed generation’.[3]

--In Europe and parts of Asia, the term ‘decentralized generation’ is applied for the same type of generation [3].

With respect to the rating of distributed generation power units, the understated different definitions are currently used:

1. The Electric Power Research Institute defines distributed generation as “A generation from ‘a few kilowatts up to 50 MW’” [4].
2. Preston and Rastler define the size as ‘ranging from a few kilowatts to over 100 MW’ [5].
3. Judith Cardell defines distributed generation as generation ‘between 500 kW and 1 MW’ [6].

4. The International Conference on Large High Voltage Electric Systems (CIGRE΄) defines DG as 'smaller than 50 –100 MW' [7].
5. International Energy Agency (IEA) defines as: Distributed generation as generating plant, serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages [8].
6. Willis et al. state that "DG includes application of small generators, typically ranging in capacity from 15 to 10,000 kW, scattered throughout a power system, to provide the electric power needed by electrical consumers [9].

A. DG Planning

The goal of the DG planning is to determine the DG type, capacity and placement in the distribution network such that some design objectives are optimized. Generally, the planners can evaluate DG's performance from two aspects: cost and benefit. DG planning may be constituted for one or more objective functions, such as minimization of losses, maximization of social welfare supply of active/reactive powers, improvement of voltage profile, formation of stable grid and sometimes for the use of FACTS controllers in congestion management [10].

The encapsulated key issues that should be considered in DG planning are

1. Intensity of distributed generation can be incorporated in the distribution networks.
2. Effect of distributed generation on the technical performance of the network.
3. Effect of distributed generation on the financial performance of the utility.
4. Changes required in technical design or commercial practice that will be effective within a distribution utility distributed generation strategy.

B. Formulation of objective function(s)

The main issues which are the key focus for the researchers are (a) Technical (b) Economic .The Economic objective is achieved, and the consumer is benefited by that, while the technical objective benefits the utility. In this paper, we are trying to accommodate all these issues taking one objective function at a time. We observe that simultaneously satisfying both the objectives individually is conflicting. So in future these objectives can be combined into a multi-objective function and its optimization. If due to any limitation (we will survey it in further studies) we are unable to make a single objective function we will make two or more objective functions and use multi-objective optimization.

I. *Loss minimization*

Analytical approach for optimal placement of DG with unity power factor is to minimize the power loss of the system. A "2/3 rule" is used to place DG on a radial feeder with uniformly distributed load, where it is suggested to install DG of approximately 2/3 capacity of incoming generation at approximately 2/3 of the length of line. In above approaches size of DG is not optimized. Line loading constraint is not considered during optimization. To change this, our objective will consist of loss minimization and also some technical constrains will be included to make it robust. The circumstance after and before distributed generations are connected with distribution systems is shown in Fig. 1 and Fig. 2.

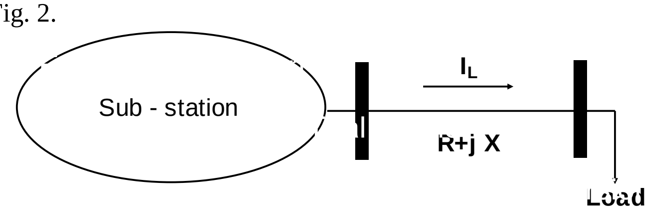

Fig.1 A simple radial distribution network

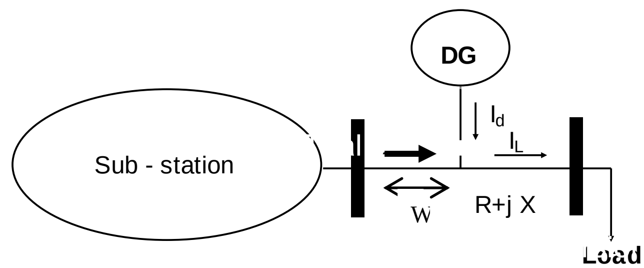

Fig.2 A distribution network with DG

As shown in Fig. 1 and Fig. 2, R+jX is the total impedance of lines; w is the percentage of the distance between DG and distribution substation occupy in the total line length; I_L, I_S, and I_d is the load current, the injection current of distribution substation and the injection current of distributed generation, respectively. P_L, Q_L is the active power of load and reactive power of load, respectively; U is the voltage of load; P_G, Q_G, is the active power of DG and reactive power of DG, respectively; $Loos_{LA}$, $Loos_{LB}$ is the network loss in Fig. 1 and Fig. 2, respectively.

When DG is not considered, the current and the loss can be formulated as,

$$\begin{cases} I_L = \dfrac{P_L - jQ_L}{U} \\ Loss_{LA} = I_L^2 Z = \dfrac{\left(P_L^2 + Q_L^2\right)}{U^2}(R + jX) \end{cases} \quad (1)$$

When DG is considered, the network loss of distribution systems can be divided into two parts. One is the line loss between distribution substation and DG, the other is the line loss between DG and the load. Then it can be obtained that,

$$\begin{cases} Loss_{LB1} = \left[\dfrac{(P_L - P_G)^2 + (Q_L - Q_G)^2}{U^2}\right](R + jX).w\% \\ Loss_{LB2} = \left[\dfrac{P_L^2 + Q_L^2}{U^2}\right](R + jX)(1 - w\%) \end{cases} \quad (2)$$

Thus, the whole network loss is as follows

$$Loss_{LB} = \frac{(P_L^2 + Q_L^2)}{U^2}(R + jX) +$$
$$\frac{(P_G^2 + Q_G^2 - 2P_L P_G - 2Q_L Q_G)w\%}{U^2}(R + jX) \quad (3)$$

So the change of network loss before and after DGs are connected into distribution systems can be obtained by (1) and (3), and as follows

$$\text{loss} = \text{Loss}_{\text{LB}} - \text{Loss}_{\text{LA}}$$

$$\frac{[(P_G^2 + Q_G^2 - 2P_L P_G - 2Q_1 Q_2 \times w\%]}{U^2} \times (R + jX) \quad (4)$$

It is evident from (4) that the impact of the connected DGs on the network loss is determined by the power of distribution systems and DGs.

The network loss would be increased if loss is larger than zero, and **w**herefore be decreased if loss is less than zero. The network loss would be kept unchangeable if loss is equal to zero. Thus the network loss could be decreased by reasonably changing the injection power of DGs when the injection power of distribution systems is unchangeable.

As a detailed distribution system, the injection power of DGs will be distributed among the load nodes. As a result, it can be decrease the network loss by optimizing the location and size of distributed generation. The eqn., (3) can be transferred to

$$Loss_{LB} = \sum_{i=1}^{n} S_i \quad (5)$$

Where N is the number of nodes in power grids; S_i is the injection power of the i^{th} node in distribution systems.

When the loss of active power is considered, the formulation for solving the minimal network loss can be expressed as

$$\min\left[loss = \sum_{i=1}^{n} P_i \right] \quad (6)$$

The equality constraints are as follows:

$$\sum_{k=1}^{L} P_k = C \quad (7)$$

Where L is the number of the selectable DG nodes; C is the t otal injection capacity. Furthermore, the equations of power fl ow should also be included.

The inequality constraints are as follows

$$\begin{cases} 0 \le P_k \le C \quad k = 1,\ldots\ldots\ldots, L \\ \sum_{1}^{L} n_i \le D \end{cases} \quad (8)$$

Where D is the maximum number of the installed DGs; n_i is equal to 1 or 0, and it represents whether DG is installed in the i^{th} node.

II. Economic cost:

Customer interruption costs can be evaluated with Customer Damage Function (CDF). The whole individual CDFs of a specified sector (that is, commercial, industrial, etc.) can be united into a representative cost function for that sector, designated as a sector Customer Damage Function (SCDF). The SCDF, as shown in Equation (9), can be aggregated in the system to produce a Composite Customer Damage Function (CCDF). The weighting used to produce a CCDF is usually done in terms of the per unit energy for each sector. CCDF is a suitable way to modeling the reliability worth [16]

$$CCDF_{S_i} = \sum_{i=1}^{T_{NS}} W_{S_i} \times SCDF_{S_i} \quad (9)$$

Therefore the objective is defined as follows:

$$J = \sum_{i=1}^{T_{NI}} U_i \times CCDF_i \quad (10)$$

Prior to placing the generators, we have to check whether sufficient transmission capacity is available to transfer the generated power. In case of inadequate transmission capacity, power interruptions will prevail, which shall finally result in customer interruption cost. This CDF stands minimum in case of suitable DG planning.

The final objective function used in the simulation is

min (ax + by)

x=Loss Function

y=Economic Cost Function

Overall, we are trying to optimize, the loss of the system that can be minimized and burden of the cost on the user is less.

From the above the problem of optimal network loss considering DGs, it can be concluded that the objective function for solving optimal network loss in the power network with DGs and lots of nodes is an optimal problem for solving a high dimension function. The injection power of every node should be determined by power flow. In addition to this when economic criterion is also considered, the complexity of the problem becomes manifold.

III. RESULT AND DISCUSSION

The IEEE 24 RTS bus system is used and to create power imbalance only 22 nodes are considered. This gap in the power is to be filled by the generator placed at different locations. In this work, we have considered that the power gap (supply and demand) can be generated by only 11 generators. However, the generators are randomly selected. Moreover, we have taken 11 generators; however, this number can be varied. The results are obtained by considering both loss objective and economic cost function. The simulation code is written in MATLAB. The obtained results are shown in Table I.

In Table I, Distribution of required gen into 11 generators based on gen cost and losses is presented, while the total required generation is 1.6 MW. The power gap is taken to be 1.6 MW to avoid the black-out. However, here we would like to state that, in this paper, we are more interested in the how this generation will be distributed on these 11 generators. It can be inferred from the results, that generated power is equally distributed among various generators, except generators 6, 8 and 11. The maximum generated power by a generator is 0.2191 MW. While the minimum generated power is 0. 0456MW.

If the function f_G represents the generation of without DG, then it can be written as $f_G = \sum_i c_i$ where C_i represents the cost of generation due to i[th] generator. Similarly, if we define f_{DG} represents the generation of with DG,then $f_{DG} = \sum_j c_j$ where C_j represents the cost of generation due to j[th] generator. It is noticeable that $i \neq j$. Then the cost saving due to the distributed generation can be defined as

$$f_G - f_{DG} = \sum_i C_i - \sum_j C_j$$

In the above test system, the cost saving while performing distributed generation is 63.3522 dollars. Because of the short length paper and space limitations intermediate results has not been introduced

In the future, work we are planning to make a single objective function, and will try to optimize the function, using multi-objective optimization techniques. In addition to this, we will also find out the location of the DG that need to be placed form the point of demand based on technical and economic criterion as in case of a large demand supply gap extra generator needs to be placed.

TABLE -I

GENERATOR NODE	DISTRIBUTED GENERATION [MW]
1	0.1179
2	0.1192
3	0.1080
4	0.1671
5	0.1170
6	0.2149
7	0.1724
8	0.2191
9	0.1365
10	0.1689
11	0.0456
TOTAL CAPACITY	1.6395

IV. CONCLUSIONS

In this paper, the technical and economical optimization problem in the system with DGs is stated. This paper deal with the DG planning problem considering the minimal network loss while, taken into consideration of the economic burden on the users. The further study will continue to deal with generator placement and their sizing while considering the technical and economic issues.

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