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Application of GAMS and GA in the Location and Penetration of Distributed Generation

Alireza Dehghani Pilehvarani, Mojtaba Hakimzadeh, Mohammad Jafari Far, Reza Sedaghati

***Abstract*—**Distributed Generation (DG) can help in reducing the cost of electricity to the costumer, relieve network congestion and provide environmentally friendly energy close to load centers. Its capacity is also scalable and it provides voltage support at distribution level. Hence, DG placement and penetration level is an important problem for both the utility and DG owner. DG allocation and capacity determination is a nonlinear optimization problem. The objective function of this problem is the minimization of the total loss of the distribution system. Also high levels of penetration of DG are a new challenge for traditional electric power systems. This paper presents a new methodology for the optimal placement of DG and penetration level of DG in distribution system based on General Algebraic Modeling System (GAMS) and Genetic Algorithm (GA).

***Keywords*—**Distributed Generation, Location, Loss Reduction, Distribution Network, GA, GAMS.

I. INTRODUCTION

DISTRIBUTED power generation is a small-scale power generation technology that provides electric power at a site closer to the customers than the central generating stations. Distributed generation provides a multitude of services to utilities and consumers, including standby generation, peak chopping capability, and base load generation. Investments in distributed generation enhance onsite efficiency and provide environmental benefits, particularly in combined heat and power applications. A multitude of events have created a new environment for the electric power infrastructure. The key element of this new environment is to build and operate several DG units near load centers instead of expanding the central-station power plants located far away from customers to meet increasing load demand. Distributed Generation technologies can enhance the efficiency, reliability, and operational benefits of the distribution system.

Power injections from DG change magnitude and even direction of network power flows. This causes an impact on network operation and planning practices of distribution companies with both technical and economic implications [1]–[3]. For instance, from the point of view of supply security, DG connection involves reviewing the design and adjustment of system protection devices; from the point of view of network operation, voltage profiles, energy losses, and maintenance and system restoration practices, in case of faults, are also affected [2]–[5]; and finally from the point of view of network design and planning, network reinforcement and additions should take into account future DG installations [6], [7].

To provide optimal reliability to customers, in case of multiple contingencies, the meshed low-voltage (LV) secondary networks are applied to major metropolitan areas and business districts. There is more effort involved in interconnecting DG with meshed networks compared to radial ones since the operation strategies are different [8], [9]. For instance, in meshed networks the reverse power flow from LV networks to medium-voltage (MV) networks is forbidden, which means the network protection will be tripped if the power flows from secondary side to primary side. Significant research effort has been invested in elucidating the advantages and disadvantages of DG for radial networks [10], [11] but there is a very limited amount of work in meshed networks. The operational benefits of DG employment are as follows:

- The production of safe, clean, reliable and efficient electrical energy is possible through DGs. Along with that cost of electrical energy is very low, with no or low emissions.
- DGs directly provide power in the vicinity of the loads and help in reducing the loadings on feeders.
- When DGs introduce in the distribution system it reduces the cost of distribution system because there is reduction in the number of electric elements such as transformers, feeders, capacitors etc.
- DGs with their modern power electronic interface devices can be interconnected to the grid to achieve special power quality, reliability, and voltage profile requirements,
- Customer-owned DGs can help customers by providing some portion of their demands during their peak load periods and by feeding the excess power to the grid during their light load periods. This way, they can get some revenue back from the electric utility.

II. PENETRATION LEVEL ASSESSMENT PF DISTRIBUTED GENERATION

Distributed resources such as photovoltaic, fuel cells, engine generator sets etc. offer electric utilities an alternative to large transmission and distribution (T&D) system capacity investments [3]. If DG is placed properly in the network, it can relieve capacity constraints on the generation, transmission, and distribution systems and defer the need to build new facilities as well as reduce the utility's energy generation requirements [5]. This paper presents a method to estimate how much a utility can afford to pay for these alternatives when the change in system capacity due to the distributed resource is constant from year to year and when there is no uncertainty.

Alireza Dehghani Pilehvarani, Mojtaba Hakimzadeh and Reza Sedaghati and are with Department of Electrical Engineering, Ahram Branch, Islamic Azad University, Ahram, Iran (e-mail: m.hakimzadeh@yahoo.com).

Mohammad Jafari Far is with Department of Electrical Engineering, Andimeshk Branch, Islamic Azad University, Andimeshk, Iran.

Deploying distributed resources can result in both of capacity and variable cost savings as well as capacity and variable costs [6].

A. Capacity Cost Savings

The first category of cost savings is capacity cost savings. T&D capacity costs that are avoided due to DG are calculated using marginal costing module [12], [13]. The marginal costing module accepts inputs on the utility's marginal generation and bulk transmission costs, annual marginal energy costs, and annual growth related investments (k_t in constant $) for a particular T&D planning area over some planning period (T years). The marginal T&D capacity cost (C in $/kW) is calculated to be the difference between the present value cost of the existing plan and the present value cost of the plan that is deferred by reducing demand by 1 kW (i.e., years of deferral is equal to 1 kW divided by annual load growth during the deferral period, L). r is the discount rate and i_t is the T&D investment escalation rate in year t.

$$C = \sum_{t=0}^{T} \frac{k_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{k_t (1+i_t)^{\frac{1}{L}}}{(1+r)^{t+\frac{1}{L}}} \quad (1)$$

The marginal cost (C) is annualized to each year in the planning period (C_t, for t = 0, ……, T) and the annual marginal costs allocated to each hour in each year (C_{th}, for t = 0,……, T; h = 1,…., 8760) using weighting factor (W_{th}) based on hourly loads. This result in a marginal T&D cost for each hour of each year of the planning period.

$$C_{th} = C_t \cdot W_{th} \quad (2)$$

The avoided local T&D costs equal the present value of the marginal T&D cost (C_{th}) times the sum of individual demand reductions (ΔD_{th}) due to various DGs.

$$Capacity\ Cost\ Savings = \sum_t \frac{C_t}{(1+r)^t} \sum_h W_{th} \Delta d_{th} \quad (3)$$

The marginal capacity cost (C) is calculated by determining the point at which the utility is indifferent between investing in a capacity expansion plan immediately or deferring the plan. In order to accomplish this, the present value cost of the existing plan must equal the cost of a distributed resource plus the present value cost of the deferred plan minus any salvage value of the plan (S) that remains at the end of the planning period. The distributed resource has a price of C (in $/kW), capacity of I (in kW) and its life is the same as the expansion planning period. Assuming a constant escalation rate of I, a discount rate of r, and growth related investments in year t of k_t,

$$C = \left[\frac{\sum_{t=0}^{T} \frac{k_t}{(1+r)^t}}{I} \right] \cdot \left[1 - \left(\frac{1+i}{1+r} \right)^{\frac{I}{L}} \right] + \left(\frac{S}{I} \right) \cdot \left(\frac{1}{1+r} \right)^T \quad (4)$$

B. Variable Cost Savings

The second category of cost savings is variable cost savings. Variable cost savings are based on energy production and distributed resource location. The variable cost saving associated with a distributed resource equals the present value of the avoided variable costs. The investment has an annual energy output/energy savings of E, a life of T years, r is the discount rate, e is the variable cost escalation rate, and V_o (in $/kWh) is the current variable cost.

$$Variable\ Cost\ Saving = \sum_{k=0}^{T-1} (V_o) \cdot \left(\frac{1+e}{1+r} \right)^k \cdot E \quad (5)$$

where the present value marginal variable cost (V) for a technology with an annual energy output/energy savings of 1kWh for T years is

$$V = (V_o) \cdot \left[\frac{1+r}{r-e} \right] \cdot \left[1 - \left(\frac{1+e}{1+r} \right)^T \right] \quad (6)$$

C. Distributed Resource Cost

The capacity cost of a distributed resource is the present value of the investment's capital cost. If P is the price (in $/kW) of the DG and F is the factor that converts this to a present value cost (it is the factor that accounts for taxes, insurance, rate of return etc.) then the capacity cost associated with DG is (P).(F). A distributed resource is cost effective if there is positive net present value associated with the investment.

$$Net\ Present\ Value = \sum_j C^j M^j + \sum_k V^k E^k - (P)(F) \quad (7)$$

The first summation term is Capacity Cost Savings. The second term includes variable cost savings and the third term is the present value capital cost of the distributed resource investment. The Net Present Value of the system is considered as an objective function and this objective function is maximized using GAMS. GAMS provides compact representation of large and complex models in terms of high level language. Basically the design of GAMS has incorporated ideas from relational database theory and mathematical programming. Relational database theory provides a structured framework for developing general data organization and transformation capabilities. Mathematical programming provides a way of describing a problem and a variety of methods for solving it. GAMS is capable of solving linear, nonlinear, mixed integer, mixed integer nonlinear optimization problems.

III. Optimal Location by GA

Genetic algorithms are a family of computational models that rely on the concepts of evolutionary processes. It is a well known fact that according to the laws of natural selection, in the course of several generations, only those individuals better adapted to the environment will manage to survive and to pass on their genes to the succeeding generations (survival of the fittest). The basic idea of a genetic algorithm is quite simple. First, a population of individuals is created in a computer, and then the population is evolved using the principles of variations, selection, and inheritance. Random variations in the populations result in some individuals being more fit than others (better suited to their environment). These individuals have more offspring, passing on successful variations to their children, and the cycle is repeated. Over time, the individuals in the population become better adapted to their environment. The basic components of GA can be briefly described as follows:

1. Population Initialization

After deciding the type of chromosome representation, the first step in the GA is to create an initial population. This is usually achieved by generating the required number of individuals using a random number generator that uniformly distributes numbers in the desired range.

2. Objective and Fitness Functions

The objective function is used to provide a measure of how individuals have performed in the problem domain. In the case of a maximization problem, the fit individuals will have the highest numerical value of the associated objective function. This raw measure of fitness is usually only used as an intermediate stage in determining the relative performance of individuals in GA. The fitness function is normally used to transform the objective function value into a measure of relative fitness.

3. Selection

Selection is a process of determining the number of times a particular individual is chosen for reproduction and thus the number of offspring that an individual will produce.

4. Crossover (Recombination)

The basic operator for producing new chromosomes in the GA is that of crossover. Like its counterpart in nature, crossover produces new individuals that have some part of both parent’s genetic material

5. Mutation

In natural evolution, mutation is a random process where one allele of a gene is replaced by another to produce a new genetic structure. In GAs, mutation is randomly applied with low probability, typically in the range 0.001 and 0.001, and modifies elements in the chromosomes. Mutation acts as a safety net to recover good genetic material that may be lost through the action of selection and crossover.

6. Reinsertion:

Once a new population has been produced by selection and recombination of individuals from the old population, the fitness of the individuals in the new population may be determined. If fewer individuals are produced by recombination than the size of the original population, then the fractional difference between new and old population sizes is termed as a Generation gap and to maintain the size of the original population, the new individuals have to be reinserted into the old population.

7. Termination of the GA

A common practice is to terminate the GA after a pre-specified number of generations and then test the best quality of the best members of the population against the problem definition.

IV. Results Simulations

The sample system considered is typical balanced M.V Distribution system with one substation and five distribution feeders. This is partly the feeder data of Kumamoto system. The base values of three phase power and line voltage are 10 MVA and 4.6669 kV respectively.

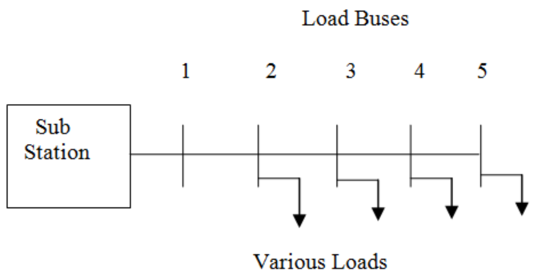

Fig. 1 The example of M.V. distribution network

TABLE I
Data of Feeder (P.U.)

	Feeder1	Feeder2	Feeder3	Feeder4	Feeder5
R	0.003145	0.00033	0.006667	0.005785	0.014141
X	0.075207	0.001849	0.030808	0.014949	0.036547
P_L	0	0.0208	0.0495	0.0958	0.0442
Q_L	0	0.0021	0.0051	0.0098	0.0045

The Optimal Power Flow of the sample system is solved using GAMS. The objective function to be maximized is cost saving, with system voltage as a constraint. The planning study is conducted with planning period of 30 years, discount rate of 11.2%, escalating rate of 3.5% and additional load growth of 200 kW per annum. The Photovoltaic cell is considered as a source of DG, with capital cost of $ 3500 per kW. Accordingly by calculating capacity cost saving, variable cost saving and the capacity cost of the DG, and considering the operating cost curve for grid, the actual penetration level of DG in distribution system is evaluated. This comes around 17% with respect to the additional load growth.

For optimal placement of DG in distribution system Genetic Algorithm Toolbox from MATLAB is used as an optimization tool because in normal course of time we have to perform around 32 different combinations for finding the global optimum, instead of that we can achieve the global optimum by just considering 10 to 12 combinations in GA. Here the main objective is to reduce the transmission and distribution losses and maintain the system voltage profile within safely operating range. The electricity safety, Quality and Continuity Regulations have proposed that the allowable voltage variations for the system between 50V and 1000V should be ± 10%.

Initially the random population with arbitrary position of DG at various nodes is considered. The fitness function i.e. reduction of system losses and system terminal voltage is calculated for each string of chromosomes. The crossover and mutation is performed on the parent population so as to evaluate the offsprings. The new fitness function is evaluated by reinserting strong offsprings. The same procedure is repeated till the global optimum is achieved. It is observed that after five to six iterations global optimum is reached by placing the DGs near to the actual load growth locations. Thus for reducing transmission and distribution losses, DG can be considered as a most challenging option in coming future.

V. Conclusion

In this paper, an algorithm is proposed for solving the DG placement and penetration problem. The DG is a viable solution at a node provided that cost of grid electricity is higher than the DG electricity cost. DG, which includes the application of small generators scattered throughout the distribution network, offers a valuable alternative to traditional sources of electric power for industrial and residential applications. DG can be incorporated into distribution planning as an option along with traditional feeder and substation options. In place of rigid capacity planning rules, the planning process needs to incorporate more detailed simulations of capacity constraints. The optimal placement and penetration level assessment of DG in distribution system will minimize the cost of power losses and investments incurred on grid upgrades. This is because of the fact that DG located near the load injects active power (current) to satisfy the demand, which in turn reduces the power taken from the distribution substation.

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