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DG allocation with application of dynamic programming for loss reduction and reliability improvement

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ABSTRACT

Distribution system companies intend to supply electricity to its customers in an economical and reliable manner whereas customers in most distribution system are outspread and connect to distribution system with different type of equipments. These equipment usually have various types and resistance together, that produce highest loss and lowest reliability for distribution systems and customers that are not appreciated in networks. Distributed generations (DGs) are one of the best reliable solutions for these problems if they are allocated appropriately in the distribution system. This paper presents multi-objective function to determine the optimal locations to place DGs in distribution system to minimize power loss of the system and enhance reliability improvement and voltage profile. Time varying load is applied in this optimization to reach pragmatic results meanwhile all of the study and their requirement are based on cost/benefit forms. Finally to solve this multi-objective problem a novel approach based on dynamic programming is used. The proposed methodology is successfully applied to a study case and simulation results are reported to verify the proposed approach.

1. Introduction

Distribution system planners endeavor to supply economical and reliable electricity to customers. It is important to design, operate and maintain reliable power systems with lowest cost and highest benefit. Reliability improvement and loss reduction are two important goals for electrical distribution companies. These companies follow, consider and test a lot of technologies, optimization programs, etc. to bring above economic benefits and provide electricity with high quality and reliability and prevent interruptions in system because cost of interruptions and power outages can result severe economic impact on utility and customers.

With recent advances in technology, use of distributed generation (DG) in the power distribution system can provide the most economical solution and keep network in proper situation. A lot of Papers and studies have been carried out in recent years to present methodologies in DG placement and sizing.

One of the criteria to search the optimal DG allocation is minimizing power loss or reliability improvement.

Several papers have been published that address the use of artificial intelligence algorithms, analytical approaches or load flow approaches to optimize DG placement [1–12] based on minimizing power loss. Authors in [1,2] solve the problem by analytical approach [3], employs non-linear programming [4], uses combination of genetic algorithm and simulated annealing [5,6], present genetic algorithm [7], submits tabu search method and [8] uses fuzzy approach for optimization of its algorithm [9,10], apply load flow approaches [11], uses sequential optimization and [12] uses heuristic approach.

All papers presented in [1–12] deal important problems and weaknesses that are listed on below mentioned clauses:

- All the simulations performed in [1–12] address a static load condition. Objective function optimization based on a single load point, such as the peak load, may not provide reliable results.
- Reliability aspects in above mentioned papers are not considered while applying DGs to a distribution system can contribute to improving system reliability.
- DG placement in network has not been considered with evaluating reliability and loss at the same time.

Also some papers have appreciated approaches in their methodologies like [13], but considering static load condition in their concepts may not lead to satisfactory results.

This paper tries to overcome above mentioned weakness and proposes a novel algorithm to optimize objective function. To follow this proper purpose, first time-varying loads are taken into

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account then multi-objective function are considered based on a cost/benefit form that enhance benefits of DG allocation in system to compensate system loss, system reliability and cost of purchased power from transmission line along the planning period. Finally; to solve this multi-objective problem a novel approach based on dynamic programming is used. In addition DGs are considered as constant power source such as photo cells, fuel cells or gas generators. Also in this paper, purchased active power price from transmission grid varies in different time of day and also cost of energy not supplied for different customers (residential, commercial and industrial) varies in different time of the day.

In the following sections, load modeling is presented in Section 2, mathematical formulation is explained in Section 3, and objective function is submitted in Section 4, dynamic programming method is illustrated in Section 5 and a case study is reported in Section 6. Finally, the conclusions of the paper are summarized in Section 7.

2. Load modeling

Accurate optimization of objective function is resulted based on input data and correct analysis of this data. One important data is definition of load pattern. Distribution system load varies in different time of day, therefore in this paper, load condition is considered in three stages (light, medium and peak load). Passed time in these three stages is registered and maximum load consumption in each load point is considered as input data for DG allocation algorithm.

Table 1 shows abbreviations of above mentioned descriptions.

"A" parameter in second column of Table 1 presents percentage of minimum load to maximum load of network and other parameters present situations of the network.

3. Mathematical model formulation

In this section, economical benefits and DG application costs are submitted and modeled. In this modeling, distributions system companies are responsible for providing customer demand, DG operation and distribution system management. All of these responsibilities are based on cost reduction and improving quality and reliability of customer service. Therefore costs and benefits of DG allocation in network can be expressed as follows.

3.1. DG costs evaluation

3.1.1. Investment cost

The cost of DG unit, investigation fee, site preparing for DG installation, construction, monitoring equipment, etc. are included in investment cost. These costs can be formulated as following equation.

$$C_1 = \sum_{i=1}^{NDG} \sum_{K=1}^{KDG} \mathrm{Cost}_{\mathrm{inv},iK} \tag{1}$$

3.1.2. Maintenance cost

Another yearly cost of DG allocation relates to maintenance cost. Maintenance cost includes annual mechanical and electrical inquiry and renovation cost. This cost is not related to placement of DG and is equal for all DG placements. This cost can be evaluated by:

$$C_2 = \sum_{i=1}^{NDG} \sum_{k=1}^{KDG} \mathrm{Cost}_{\mathrm{main},ik} \tag{2}$$

Present worth value of this annual cost with considering inflation rate and interest rate [14] in planning period is calculated below:

$$\mathrm{CPV}(C_2) = C_2 \sum_{t=1}^{T} \left(\frac{1 + \mathrm{InfR}}{1 + \mathrm{IntR}} \right)^t \tag{3}$$

3.1.3. Operation cost of DG

Since distributed generation shall trace load demands therefore it is required to have cost for its input source hence operation cost is equivalent to fuel cost. This cost and its present worth value are evaluated by:

$$C_3 = \sum_{i=1}^{NDG} \sum_{k=1}^{KDG} T_{\mathrm{J}} * \mathrm{DG}_{\mathrm{J},ik} * \mathrm{CG}_{ik} \tag{4}$$

$$\mathrm{CPV}(C_3) = C_3 \sum_{t=1}^{T} \left(\frac{1 + \mathrm{InfR}}{1 + \mathrm{IntR}} \right)^t \tag{5}$$

where N_{DG}: number of DG unit installed in network; K_{DG}: capacity of DG from 1 to 5 MW; $\mathrm{Cost}_{\mathrm{inv}}$: investment cost of DG sources ($/MW); $\mathrm{Cost}_{\mathrm{main}}$: maintenance cost of DG ($/MW-year); $\mathrm{DG}_{\mathrm{J},ik}$: Generated power by DG source installed in network in identified load level (MW); CG_{ik}: operation cost of DG sources ($/MW h); IntR: the interest rate; InfR: the inflation rate; CPV(): cost present worth; T_{J}: passing time (h/year)

3.2. DG benefits evaluation

3.2.1. Active power demand reduction from transmission line

In power system restructuring, electric utility distribution company purchases its power demand from transmission grid. Portion of this power demand is for distribution system customers and another one is spent in line and equipment loss. This power demand is evaluated by:

$$\mathrm{PT}_{\mathrm{NDG,J}} = \mathrm{PD}_{\mathrm{J}} + \mathrm{Loss}_{\mathrm{NDG,J}} \tag{6}$$

Distribution Company can supply portion of its power demand with considering DG in network and gets lower electric power from transmission grid. In this case electric power demand is calculated as below:

$$\mathrm{PT}_{\mathrm{DG,J}} = \sum_{i=1}^{NDG} \sum_{k=1}^{KDG} \sum_{L=1}^{Nloc} \left(\mathrm{PD}_{\mathrm{J}} - \mathrm{DG}_{\mathrm{J},ik} + \mathrm{Loss}_{\mathrm{J},ikl}^{\mathrm{DG}} \right) \tag{7}$$

Therefore reduction of active power demand can be formulated as following equation:

$$\begin{aligned} \Delta\mathrm{PT} &= \mathrm{PT}_{\mathrm{NDG,J}} - \mathrm{PT}_{\mathrm{DG,J}} \\ &= \mathrm{Loss}_{\mathrm{NDG,J}} + \sum_{i=1}^{NDG} \sum_{k=1}^{KDG} \sum_{L=1}^{Nloc} \left(\mathrm{DG}_{\mathrm{J},ik} - \mathrm{Loss}_{\mathrm{J},ikl}^{\mathrm{DG}} \right) \end{aligned} \tag{8}$$

And loss reduction based on presence of DG is evaluated by:

$$\Delta\mathrm{Loss}_{\mathrm{J},ikl} = \sum_{i=1}^{NDG} \sum_{k=1}^{KDG} \sum_{L=1}^{Nloc} \left(\mathrm{Loss}_{\mathrm{NDG,J}} - \mathrm{Loss}_{\mathrm{J},ikl}^{\mathrm{DG}} \right) \tag{9}$$

Therefore Eq. (8) can be formulated as following equation:

$$\Delta\mathrm{PT} = \mathrm{PT}_{\mathrm{NDG,J}} - \mathrm{PT}_{\mathrm{DG,J}} = \mathrm{DG}_{\mathrm{J},ik} + \Delta\mathrm{Loss}_{\mathrm{J},ikl} \tag{10}$$

Table 1
Load characteristic levels.

Load level (J)	Percentage of peak load (%)	Network condition	Passing time (h/year)
1	A–B	Light load	T_1
2	B–C	Medium load	T_2
3	C-100	Peak load	T_3