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# Simultaneous placement of DG and capacitor in distribution network

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ABSTRACT

In this study, the planning problem concerned with simultaneous placement of distribution generation (DG) and capacitor bank in the distribution network is investigated from a local distribution company's (DISCO's) viewpoint based on minimum total cost over the planning period and applying genetic algorithm (GA). The cost terms of the objective function include risk cost of load not supplied of the customers, cost of energy loss of the system, investment costs for purchasing the DGs and capacitor banks, and maintenance costs of the installed DGs and capacitor banks. Herein, the customers' load types including residential, commercial, and industrial are modeled in the planning problem and load model-based power flow is applied instead of the conventional power flow. In addition, the failure rate of the distribution feeder is modeled respect with magnitude of the current flowing through the feeder applying several mathematical functions such as linear, power, exponential, and logarithmic. Moreover, in order to achieve realistic results, economic factors such as inflation and interest rates and technical factors including yearly load growth, hourly variations of the load, and daily variations of the load are taken into consideration in the planning problem.



## 1. Introduction

Analysis of power systems' failure statistics indicates that distribution system has the lowest reliability, although forced outage in distribution system has a restricted effect on end user customers compared with outages in transmission and generation systems [1]. In addition, significant percentage of power and energy loss is related to distribution network due to radial structure of distribution network and high ratio of current to voltage in distribution network.

Distributed generation (DG) placement and shunt capacitor allocation as the effective measures are taken to decrease power and energy loss of distribution system and improve its reliability. During the last decades, optimal DG and capacitor placement problems based on different purposes and applying various optimization techniques have been topic of several research works [2–20]. Summary of the literature review regarding the DG placement, capacitor placement, and simultaneous placement of DG and capacitor problems has been presented in Table 1. The investigated studies have been categorized and characterized based on the optimization techniques applied to solve the problem, type of the objective function such as single or multi-objective function, considering or ignoring hourly and daily variations of the load demand, considering or disregarding model of the customers' load types including residential, commercial, and industrial, and modeling or neglecting the feeder's failure rate alteration due to DG and capacitor placement in distribution network. As can be seen in Table 1, in all the studied DG placement problems in the literature [2–8], feeder's failure rate has not been modeled, and also time varying load modeling and customers' load types modeling have not been done simultaneously. Regarding the capacitor placement problems [9–13], just the study presented in [13] has considered all the modelings in the problem. However, the above mentioned modelings have not been considered in the papers with the aim of simultaneous placement of DG and capacitor [14–18,20] and in [19] just variability of the load demand has been taken into consideration.

In this study, simultaneous DG and capacitor placement planning problem in electrical distribution network with the aim of minimum total cost of the system over the planning period is investigated from the local distribution company's (DISCO's) viewpoint applying genetic algorithm (GA) as the optimization technique. The cost terms of the objective function include energy loss cost, risk cost of energy not supplied of the system, investment costs for purchasing DGs and capacitor banks, and the installed DGs and capacitor banks maintenance costs. Herein, the system security constraints including apparent power limit of the lines and voltage profile limits of the system buses are taken into consideration in the problem over the given planning period. In the planning

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**Nomenclature**

*Indices and sets:*

| | |
|---|---|
| $b \in S_b$ | index and set of branches |
| $d \in S_d$ | index and set of days |
| $i,j \in S_i$ | indices and set of buses |
| $x \in S_x$ | index and set of customers' load types |
| $t \in S_t$ | index and set of hours |
| $l \in S_l$ | index and set of load levels |
| pp | index of planning period |
| $y \in S_y$ | index and set of years |

*System parameters and variables:*

| | |
|---|---|
| $\alpha,\beta$ | exponents of different load models |
| $\text{Cost}^{\text{Cap}}$ | value of cost for purchasing a capacitor bank |
| $\text{Cost}^{\text{DG}}$ | value of cost for purchasing a DG |
| $\text{Cost}^{M\text{-Cap}}$ | value of yearly maintenance cost of a capacitor bank |
| $\text{Cost}^{M\text{-DG}}$ | value of yearly maintenance cost of a DG |
| $\text{Cost}_{\text{pp}}^{\text{Invest-Cap}}$ | investment for purchasing capacitor banks over the planning period |
| $\text{Cost}_{\text{pp}}^{\text{Invest-DG}}$ | investment for purchasing DGs over the planning period |
| $PWV(Cost_{pp}^{Loss})$ | present worth value of the system energy loss cost over the planning period |
| $\text{PWV}(\text{Cost}_{\text{pp}}^{\text{Risk}})$ | present worth value of the system risk cost over the planning period |
| $\text{PWV}(\text{Cost}_{\text{pp}}^{M\text{-Cap}})$ | present worth value of maintenance cost of the installed capacitor banks over the planning period |
| $\text{PWV}(\text{Cost}_{\text{pp}}^{M\text{-MG}})$ | present worth value of maintenance cost of the installed DGs over the planning period |
| FFRM | Feeder's failure rate model |
| IFR,ITR | inflation rate and interest rate |
| $\lvert I_{y,d,t,b}\rvert$ | magnitude of current in $y$th year, on $d$th day, and at $t$th hour flowing through $b$th branch |
| $\lvert I_{0,b}\rvert$ | magnitude of current flowing through branch $b$ before DG and capacitor placement |
| $\text{Loss}_{\text{pp}}$ | value of system active power loss over the planning period |
| $\tau_l$ | duration of the $l$th load level |
| $\text{LNS}_{y,l,i,x}^{\text{FLS}}$ | load not supplied of customers with load type $x$, in $y$th year, in $l$th load level, and at $i$th bus during fault locating and switching |
| $\text{LNS}_{y,l,i,x}^{\text{FR}}$ | load not supplied of customers with load type $x$, in $y$th year, in $l$th load level, and at $i$th bus during fault repairing |
| $T_{\text{FLS}}$ | duration of fault locating and switching |
| $T_{\text{FR}}$ | duration of fault repairing |
| $N_{l,i}^{\text{cap}}$ | number of installed capacitor banks at bus $i$ in $l$th load level |
| $N_{l,i}^{\text{DG}}$ | number of installed DGs at bus $i$ in $l$th load level |
| $\text{OF}_{\text{PP}}$ | objective function of the problem over the planning period |
| $\pi_l^E$ | price of electricity in $l$th load level |
| $\pi_{l,x}^{\text{ENS}}$ | cost of energy not supplied of customers with load type $x$ in the $l$th load level |
| $P_{0i},P_i$ | value of nominal active power demand at operating point and current active power demand at bus $i$ |
| $Q_{0i},Q_i$ | value of nominal reactive power demand at operating point and current reactive power demand at bus $i$ |
| $R_b$ | resistance of branch $b$ |
| $\text{Risk}_{\text{pp}}$ | value of system risk over the planning period |
| $\lvert\text{MVA}_b\rvert$ | magnitude of apparent power flowing through branch $b$ |
| $V_{0i},V_i$ | value of nominal voltage at operating point and current voltage at bus $i$ |
| $\lvert V_i\rvert$ | magnitude of voltage at bus $i$ |
| $\gamma_b$ | length of branch $b$ |
| $Y_{ij}$ | admittance of line between buses $i$ and $j$ |
| $\varphi_{ij}$ | value of phase angle of $Y_{ij}$ in polar coordinate system |
| $\lambda_{0,b}$ | failure rate of branch $b$ before DG and capacitor placement |
| $\lambda_{f,b}$ | failure rate of branch $b$ after fully removing apparent power from the branch |
| $\lambda_b^{\text{Lin}}, \lambda_b^{\text{Pow}}, \lambda_b^{\text{Exp}}, \lambda_b^{\text{Log}}$ | failure rate of branch b related to linear, power, exponential, and logarithmic models |
| $\lambda_b^{\text{FFRM}}$ | failure rate of branch b considering FFRM |
| $\delta_i$ | value of phase angle of voltage at bus i in polar coordinate system |

*GA parameters:*

| | |
|---|---|
| $P^{\text{Mutation}}$ | mutation probability of genes |
| $N_{\text{ch}}$ | size of population |
| $a_{\text{ch}}$ | binary variable as the indicator for selection of the chromosome for the new population |
| $r_{\text{ch}}$ | random number in range of (0,1) |
| $P_{\text{ch}}^{\text{Selection}}$ | value of selection probability of the chromosome |
| $f_{\text{ch}}$ | value of fitness of the chromosome |
| $S_f$ | set of chromosomes fitness |

problem, inflation and interest rates as the economic factors and yearly load growth and hourly and daily varying load as the technical aspects are considered. In addition, the customers' load types such as residential, commercial, and industrial are modeled and load model-based power flow is applied instead of the traditional power flow. Furthermore, feeder's failure rate respect with magnitude of the current flowing through the feeder is modeled applying linear and several nonlinear mathematical functions such as exponential, power and logarithmic functions.

In this study, in order to closely study the technical advantages of DG and capacitor placement in distribution network, operation cost of the installed DGs, the wholesale market price, and the retail market price are supposed to be equal. Therefore, the economic benefits achieved due to existence of price difference between the wholesale and retail markets, and also because of utilization of the DGs instead of purchasing electricity from the wholesale market are ignored.

The remainder of the paper is organized as follows. In Sections 2–4, feeder's failure rate, customer's load type, and time varying load are modeled, respectively. The simultaneous capacitor and DG placement planning problem is formulated in Section 5. The proposed optimization technique for solving the planning problem is presented in Section 6. Section 7 is concerned with the numerical studies and results analysis, and finally Section 8 concludes the paper.

## 2. Modeling feeder's failure rate

DG and capacitor placement in distribution network locally supplies part of active and reactive power demands of the customers. Therefore, magnitude of the apparent power flowing through the feeder is reduced and as a result, magnitude of the current is decreased. Based on this, the active and reactive power losses are decreased and consequently temperature of the feeder is reduced. Since high temperature has destructive effect on the feeder such as