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Optimal allocation of combined DG and capacitor for real power loss minimization in distribution networks

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ABSTRACT

Optimal siting and sizing of Distributed Generation (DG) and shunt capacitor at the distribution networks for the purpose of real power loss minimization is drawing much attention of electric power utilities in the present days. Some inherent benefits of power loss minimization includes: reduction of power flow in feeder lines, releases stress on feeder loading, and hence increases their life time, adds opportunity to using the existing facility to serve any increased load demand, avoidance of power purchased from the grid and also the cost of loss compensating devices, reduction in customer bill, etc. In this paper, a method based on analytical approach for optimal allocation (sizing and siting) of DG and capacitor with the objective to minimize the total real power loss subjected to equality and inequality constraints in the distribution network is presented. A sensitivity analysis technique has utilized to identify the optimal candidate locations for DG and capacitor placement and the heuristic curve fitting technique is used to determine their optimal capacity in the networks. To validate the suitability of the proposed method, it has been applied to 12-bus and IEEE 33-bus test distribution systems. The obtained simulation results and comparison of different cases considered reveals that allocation of DG and capacitor combination results in significant loss reduction with good voltage profile and also release in the line loading in the power distribution networks.

1. Introduction

The electric power distribution networks usually operated at low voltage are connected to the high voltage transmission systems and finally supply power to customers at low voltage. The total power losses in the distribution network lines is high because of low voltage and high current in comparison to high voltage network, which in turn, causes increase in the cost of power and poor voltage profile along the distribution feeder. The total power loss in the distribution network is composed of two parts: real power and reactive power loss. The former loss is due to the flow of active component of current required by the load and the later is due to the flow of reactive component of current required to compensate the reactive power requirement of network components and hence to control of the system voltage. Among these losses, the effect of active power loss is very important because it reduces the efficiency of power transfer and deteriorates the voltage profile. The minimization of real power loss in the distribution networks is therefore of much significance compared to the transmission system. The task of power loss reduction and enhancement of energy efficiency of electric power delivery system mostly goes to electric power distribution. It is reported that as much as 13% of total power generated is wasted in the form of power losses at the distribution level [1]. The capacity of radial line is often limited, it is therefore, necessary to consider some alternatives methods so that the future load demands can be supplied ensuring supply quality and reliability.

Most distribution network components like motors and transformers are inductive in nature, so the network power factor will be lagging, and results in the reduction of the system's capacity, increase the system losses, and reduces the voltage. Shunt capacitors are used to alleviate some of these problems [2–4]. Apart from reduction in power losses, the shunt capacitors enhances the voltage profile, improves power factor and voltage stability of the system. Distributed Generation (DG) units can play a major role in distribution system planning in recent years as DG integration into the distribution system defers major system upgrade, reduces overall energy loss and improves the supply quality and reliability [5]. Even though, DG technologies have positive impacts on distribution system, there might be certain technical challenges with the inclusion of active DG units in conventional passive system. It is important to mention that DG units should be applied in an effective manner without causing degradation of reliability, system operation and supply quality. On the other hand, shunt capacitors, commonly deployed for reactive power compensation, can also be

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considered in parallel with DG units for distribution system expansion planning. It is evident that any loss reduction is beneficial to distribution utilities, which is generally the entity responsible to keep the losses at low levels. Loss reduction is therefore most important factor to be considered in planning and operation of DG [6].

The literature reports that the reactive power injected by shunt capacitors can effectively reduce system energy loss, relieve feeder loading and improve supply reliability [2,7]. Siting and sizing of shunt capacitors needs to be investigated carefully to avoid voltage rise problems, and hence to reduce the operating cost of DG units. Various methods may be used to reduce the power losses in distribution networks: capacitor placement, network reconfiguration, DG placement, and network reconfiguration in the presence of capacitor, network reconfiguration in the presence of DG and DG capacitor placement [8]. The optimal allocation of capacitors in power distribution networks with the objectives like minimizing power loss, system capacity release, minimization of capacitor cost and voltage profile improvement was presented in [9–13] using the optimization techniques, viz. GA [10,12,13], heuristic strategies [11], and analytical approach [9]. Optimal siting and sizing of DG in the distribution networks to minimize power loss were suggested in [14–17,20,18,19,21,22]. The optimization techniques like analytical approaches [14,15,18,21], genetic algorithm (GA) [17], artificial bee colony (ABC) algorithm [20], evolutionary programming (EP) [19] and GA–TS [22] were employed to arrive at the optimal solution.

Distribution network reconfiguration in the presence of DG to reduce power loss was presented in [23–26]. The optimization techniques utilized are GA, ant colony optimization (ACO), Tabu search (TS) and modified honey bee optimization (MHBMO), respectively.

Further, optimal allocation of DG and capacitor in the distribution network considering power loss reduction, minimizing the cost of DG and capacitor along with voltage profile improvement were proposed in [27–29]. The optimization methods used are particle swarm optimization (PSO), PSO, and differential evolutionary algorithm (DEA), respectively.

In [27–29], the optimal siting and sizing of the DG injecting only the real power and the capacitor combination is presented. It is reported in [30], that DG units with reactive power control can provide better voltage profile and lower losses. An analytical approach based on exact loss formula was presented to find the optimal size and location of DG to minimize the real power loss [22], however voltage constraint has not been considered. Recently, another fast analytical approach to find the optimal size of DG at optimal power factor has been proposed to minimize the power loss [18].

Most of the approaches presented so far model the optimal allocation of DG only. However, very few approaches [27–29] considered the optimal allocation of combined DG and capacitor, but release of line loading is not being considered and therefore needs further attention. The present paper considers the optimal allocation of DG and capacitor considering that DG is also capable to supply reactive power in addition to real power. The optimal allocation of DG and capacitor with the key objective to minimize the real power loss besides satisfying the network constraints of the distribution network is presented. Heuristic sensitivity analysis, i.e. both real and reactive power loss is being utilized to identify the optimal candidate locations for DG and capacitor placement, and the quadratic curve fitting technique is employed to determine their optimal capacity in the distribution networks.

This paper is organized as follows: followed by the brief introduction in Section 1, Section 2 gives the problem formulation, and the methodology proposed is discussed in Section 3. In Section 4, results and discussions are given for single DG capacitor as well as multiple DG capacitor allocation. Finally, based on the obtained results conclusions are given in Section 5.

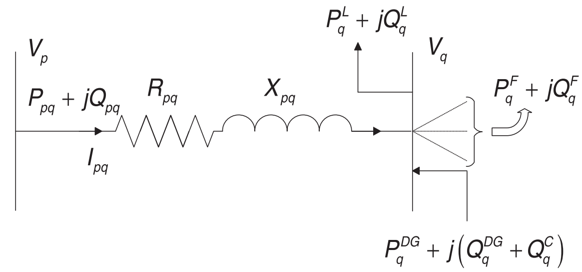

Fig. 1. Model of a branch connected between buses p and q.

2. Problem formulation

The problem of combined DG and capacitor allocation in distribution network with their suitable size is very important, because their improper allocation causes an increase in the system power loss and operating costs, reduces the energy efficiency. The main objective of the proposed study is to minimize the total real power loss (P_L) at peak load condition in the distribution network as given in Eq. (5), subjected to equality and inequality constraints in Eqs. (1), (2), (3), (7)–(10). During DG allocation, the voltage at various buses should be maintained at proper limits for safe and reliable operation of the power distribution system and the current flow in the line conductor must be within the permissible limit.

Consider a branch connected between nodes p and q of a radial distribution network as shown in Fig. 1. The real and reactive power flow through the branch and the terminating node (q) voltage (neglecting shunt conductance and susceptance) are given by Eqs. (1)–(3), respectively as [19,31]:

$$P_{pq} = P_q^F + P_q^L - P_q^{DG} + \frac{R_{pq}}{V_p^2}(P_{pq}^2 + Q_{pq}^2) \tag{1}$$

$$Q_{pq} = Q_q^F + Q_q^L - Q_q^{DG} - Q_q^C + \frac{X_{pq}}{V_p^2}(P_{pq}^2 + Q_{pq}^2) \tag{2}$$

$$V_q^2 = V_p^2 - 2(P_{pq}R_{pq} + Q_{pq}X_{pq}) + \frac{R_{pq}^2 + X_{pq}^2}{V_p^2}(P_{pq}^2 + Q_{pq}^2) \tag{3}$$

where $P_q^F = \sum_{\forall j|i=q} P_{ij}$ and $Q_q^F = \sum_{\forall j|i=q} Q_{ij}$

Here $P_{pq}(Q_{pq})$ are the sending end active (reactive) power flows and $R_{pq}(X_{pq})$ are the series resistance (reactance). $P_q^{DG}(Q_q^{DG})$ are the active (reactive) power injections by DG; Q_q^C is the reactive power injection by capacitor and $P_q^L(Q_q^L)$ are the total active (reactive) demand load at bus q. $P_q^F(Q_q^F)$ are the sum of active (reactive) power flows through all the downstream branches connected to bus q. V_q is the magnitude of voltage at bus q. S_B is a set of buses containing all the buses in the system. The value of current flowing through a branch connected between nodes p and q is given as:

$$I_{pq} = \sqrt{\frac{P_{pq}^2 + Q_{pq}^2}{V_p^2}} \tag{4}$$

Mathematically, the objective function is given as:

$$\text{Min } P_L = \sum_{\forall p,q|p,q \in S_B} I_{pq}^2 R_{pq} \tag{5}$$

The above objective function is subjected to the set of equality and inequality constraints as given below: