Optimal Placement and Sizing of Distributed Generation Sources Considering Network Parameters and Protection Issues

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Abstract—We propose a method for optimal placement and sizing of distributed generation (DG) sources in an existing distribution network. The method, which uses the genetic algorithm, provides improved network parameters (i.e., voltage profile, power losses, and short circuit levels) while keeping the existing coordination of protection devices unchanged. An important feature of the proposed method is the accommodations for transient short-circuit fault currents due to DGs and their connection/disconnection states, thus preventing undesired effects on the coordination of protection devices. To demonstrate the feasibility of the proposed method, we present simulated results for optimal placement of DGs in an existing distribution network.

Keywords-distribution generation; optimal placement; genetic algorithm; protection; network parameters

I. INTRODUCTION

Installation of Distributed Generation (DG) sources in a distribution network can bring about positive impacts such as voltage profile improvement and loss reduction. However, it can also cause negative impacts such as problems in coordination of protection devices or undesired increase in short-circuit level of the network. The severity of the impacts depends on the type, capacity, and location of DGs.

DG sources may cause bi-directional power flow, which in turn, change the radial nature of a network, causing many protection issues [1]. To accommodate for changes in the network, the existing protection scheme of the network should be modified accordingly [2].

Recently, several studies have been carried out for optimal placement and sizing of DGs in a network. For example, attempts were made to locate and size DG sources in a distribution network to improve voltage profile, loss reduction, and short-circuit level reduction [3-6]. In order to tackle the protection challenges, a number of methods have been devised, including use of Fault Current Limiters (FCLs) [7], use of adaptive protection schemes according to fault location by a Supervisory Unit Controller Unit (SRCU) [8], and use of multi-agent method [9]. The cost of implementing these methods is extremely high due to the required communicative infrastructures and new devices. As a result, electric utilities are often less enthusiastic in implementing these methods.

In this paper, we propose an optimal method for sizing and placement of DG sources with improved network parameters such as power loss and voltage profile while the coordination of protection devices are maintained. In the proposed method, we also consider the transient short circuit currents due to DGs and their respective connection/disconnection states, thus preventing undesired effects on the coordination of protection devices. To demonstrate the feasibility of the proposed method, we present simulations results for the distribution network commissioned by Zanjan Regional Electric Board, Iran.

II. PROPOSED METHOD

The objective function (OF) devised in the proposed method accommodates for three characteristics of the network. These are 1) network operational parameters (NOP), 2) transient behavior of DGs short-circuit fault currents (DGSC), and 3) DGs connection/disconnection states (DGCD).

To ensure that the network operational parameters (i.e., power losses, voltage profile and short-circuit level) attain the highest possible improvements, the following terms are included in the proposed OF [3].

$$OF_{\text{NOP}} = \sum_{k=1}^{n} (a \frac{P_{loss}^{withDG}}{P_{loss}^{withoutDG}} + b(V_{bus,k}^{withDG} - 1)^2 + \\ c(\frac{i_{sc,k}^{withDG} - i_{sc,k}^{withoutDG}}{i_{sc,k}^{withDG}})^2 + d \frac{CG_k}{S_{base}}) \tag{1}$$

where $P_{loss}^{withoutDG}$ and P_{loss}^{withDG} are, respectively, the power losses before and after installing DGs, $V_{bus,k}^{withDG}$ is the voltage level of kth bus after installing DGs, $i_{sc,k}^{withoutDG}$ and $i_{sc,k}^{withDG}$ are, respectively, the short-circuit level of kth bus before and after installing DGs, CG_k is the capacity of the installed DG at k^{th} bus in MVA, and a, b, c, and d are the respective weighting coefficients.

In the event of a short circuit fault, the current waveform of a synchronous DG can be divided into two components, namely the AC component, $i_{AC}(t)$, and DC component, $i_{DC}(t)$, as expressed below [10].

$$i_{AC}(t) = \sqrt{2}\, E_g \,.$$

$$\left[(\frac{1}{x_d^{"}} - \frac{1}{x_d}).e^{\frac{-t}{T_d^{"}}} + (\frac{1}{x_d^{'}} - \frac{1}{x_d}).e^{\frac{-t}{T_d^{'}}} + \frac{1}{x_d} \right].\sin(\omega t + \alpha)$$

$$(2)$$

$$i_{DC}(t) = \frac{E_g}{\sqrt{2}}.$$

$$\left[(\frac{1}{x_d^{"}} + \frac{1}{x_q^{"}}).e^{\frac{-t}{T_a}} \right].\cos(\alpha) + \frac{E_g}{\sqrt{2}}\left[(\frac{1}{x_d^{"}} - \frac{1}{x_q^{"}}).e^{\frac{-t}{T_a}} \right]\cos(2\omega t + \alpha)$$

$$(3)$$

The effects of $i_{AC}(t)$ and $i_{DC}(t)$ are incorporated in the proposed OF as follows,

$$OF_{DGSC} = \int_0^T (i_{ac}(t) + i_{DC}(t) - i^{withoutDG}(t))$$

$$(4)$$

To consider the connection/disconnection states of DGs, the following terms are included in the proposed OF.

$$OF_{DGCD} = \alpha.\sum_{i=1}^N (t_i)^2 + \sum_{k=1}^{N_C} (\beta_k B C_k)$$

$$(5)$$

$$BC_k = \begin{cases} 0 & \forall \Delta t_{kj} > \varepsilon \quad j=1,2,...,N_{CD} \\ 1 & \exists \Delta t_{kj} < \varepsilon \quad j=1,2,...,N_{CD} \end{cases}$$

$$(6)$$

where N is the number of relays, N_c is the number of conditions associated with the main and backup relays, N_{CD} is the number of DG connection and disconnection Δt_{kj} states, and is the time interval of operation of the kth pair relays (main and backup relays) in the state of jth connection/disconnection of DGs.

Finally, the proposed OF is formed using Eqs. (1), (4) ad (5), *i.e.*,

$$OF = \sum_{k=1}^n (a\frac{P_{loss}^{withDG}}{P_{loss}^{withoutDG}} + b(V_{bus,k}^{withDG} - 1)^2 +$$

$$c(\frac{i_{sc,k}^{withDG} - i_{sc,k}^{withoutDG}}{i_{sc,k}^{withDG}})^2 + d\frac{CG_k}{S_{base}}) +$$

$$\int_0^T (i_{ac}(t) + i_{DC}(t) - i^{withoutDG}(t)) +$$

$$\alpha\sum_{i=1}^N (t_i)^2 + \sum_{k=1}^{N_C} (\beta_k \times B C_k)$$

$$(7)$$

The genetic algorithm is used to minimize the derived OF (Eq. (7)). A detailed description of the algorithm is presented in [3] and is not repeated here for brevity.

SIMULATION RESULTS

To demonstrate the feasibility of the proposed method, we present simulated results for optimal placement of DGs in the distribution network commissioned by Zanjan Regional Electric Board, Iran. A single-line diagram of the network is depicted in Fig. 1. Further information of the network can be found in [3]. It is assumed that the selected DGs are rated 5 MW, 10 MW and 15 MW. The DIgSILENT software package (14.1.3) is used as the main analysis platform throughout this study.

Using the propose method, the locations and capacities of the DGs are given in Table I. The short-circuit levels of various busses before and after installing the DG sources are shown in Fig. 2. A comparison of the results in this figure shows that the new short circuit levels are within the rating limits of circuit breakers, and hence, there is no need to change them.

The differences in the operation times (Δt) of various pair relays (main and backup relays) before and after installing DG sources are shown in Fig. 3. As clearly seen, the coordination between the pair relays still exists, although installation of DG sources tends to reduce the relays operation times.

In Fig. 4, the network voltage profiles before and after installing DG sources are depicted. From this figure, it is clear that the installation of DGs improves the network voltage profile as the new voltage levels at all busses lie within the allowable limit of 0.95 pu and 1.05 pu. Similarly, Table II presents the values of power losses before and after installing DG sources, confirming that DG sources are capable of reducing power losses. The computed results show a reduction of power losses by 42.63 percent.

Finally, the sizing and placement indices of DG sources in Table III compare the proposed method and that described in [3]. In this table, I_{LP}, $VPII$ and ISC represent, respectively, the reduction of active power loss, the voltage profile improvement, and the increase in network short-circuit level after installing DGs, as defined in [3]. It is worth noting that maintaining relay coordination in the proposed method prevents using relatively larger amount of DG power (80 MW) as required in Ref [3], resulting in smaller values of I_{LP} and $VPII$. However, ISC in the proposed method takes a smaller value than that of Ref. [3] due to less penetration level of DGs in the network. Notice that a small value of ISC reduces the need for changing the respective circuit breakers, as clearly seen in Fig. 2.
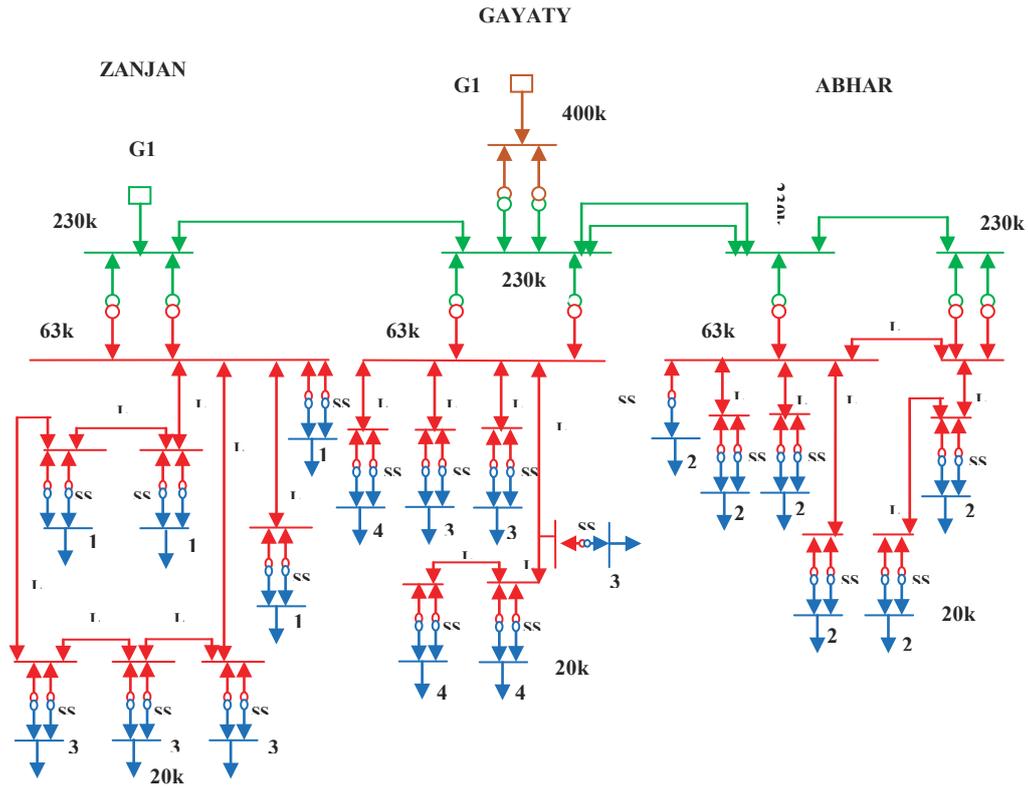
Figure 1.   A single-line diagram of the network under study.

TABLE I   COMPUTED CAPACITY AND LOCATION OF THE DG SOURCES IN FIG. 1 FOR OPTIMAL NETWORK OPERATION

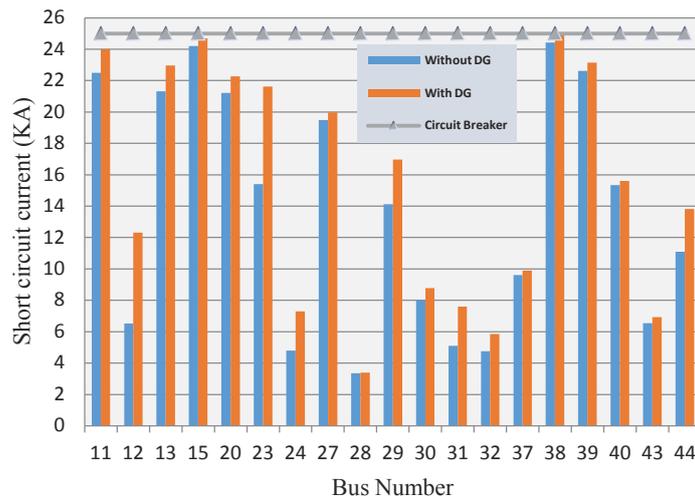| Location	Capacity (MW)	Location	Capacity (MW)
SS4	5	SS14	10
SS6	15	SS17	15
SS9	10		

Figure 2.   Variations of bus short-circuit levels in Fig. 1 before and after installing DG sources.
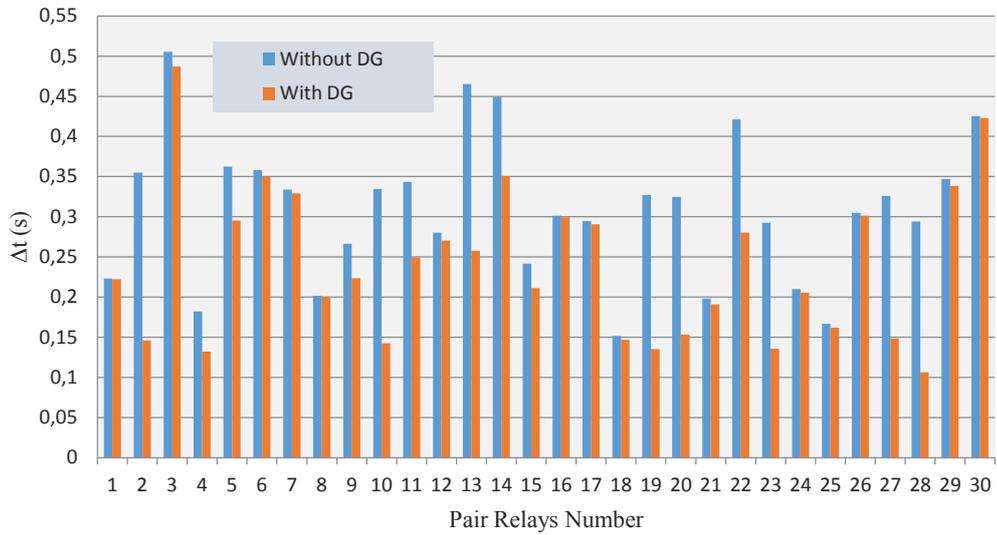
Figure 3.   Differences in the operation times (Δt) of various pair relays (main and backup relays) in Fig. 1 before and after installing DG sources.
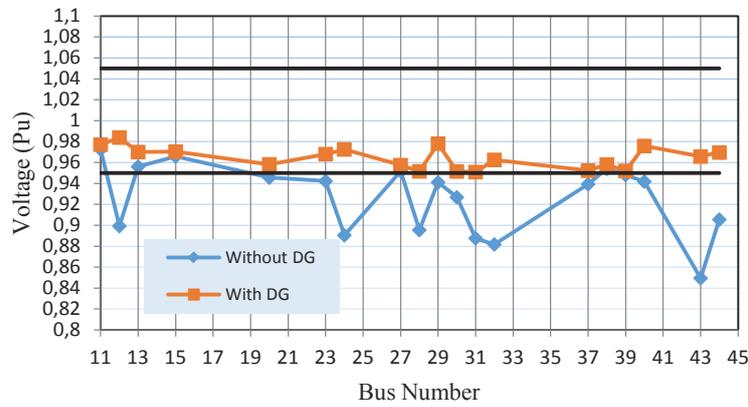

Figure 4.   Variations of voltage profiles in Fig. 1 before and after installing DG sources.

TABLE II   POWER LOSSES IN FIG. 1 BEFORE AND AFTER INSTALLING DG SOURCES

Power losses before installing DG sources (MW)	Power losses after installing DG sources (MW)
10.72	6.15

TABLE III   SIZING AND PLACEMENT INDICES OF DG SOURCES IN FIG. 1

Proposed method				Ref. [3]			
Installed DGs (MW)	*II_P*	*VPII*	*ISC*	*Installed DGs (MW)*	*II_P*	*VPII*	*ISC*
55	42.63	4.16	12.19	80	66.13	4.88	18.87

CONCLUSIONS

A genetic algorithm based method is proposed to determine the optimal location and size of DGs in a distribution network. The proposed method provides improved network parameters such as power loss and voltage profile while maintaining the coordination of protection devices. The method is an alternative for the conventional costly methods for overcoming the inevitable increased network short-circuit levels and its bi-directional power flow. An important feature of the proposed method is the accommodations for transient short-circuit fault currents due to DGs and their connection/disconnection states, thus preventing undesired effects on the coordination of protection devices. The feasibility of the proposed method is demonstrated by presenting simulations results for the distribution network commissioned by Zanjan Regional Electric Board, Iran. It has been shown that maintaining relay coordination in the proposed method prevents using a relatively large amount of DG power, thus limiting the degree of improvement in network parameters.

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