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Optimal distributed generation allocation for reliability, losses, and voltage improvement

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Abstract

This paper presents a methodology for optimal distributed generation (DG) allocation and sizing in distribution systems, in order to minimize the electrical network losses and to guarantee acceptable reliability level and voltage profile. The optimization process is solved by the combination of genetic algorithms (GA) techniques with methods to evaluate DG impacts in system reliability, losses and voltage profile. The fitness evaluation function that drives the GA to the solution is the relation between the benefit obtained by the installation of DG units and the investment and operational costs incurred in their installation. The losses and voltage profile evaluation is based on a power flow method for radial networks with the representation of dispersed generators. The reliability indices are evaluated based on analytical methods modified to handle multiple generations. The results obtained with the proposed methodology for hypothetical systems found in the literature and actual distribution systems demonstrate its applicability.
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Keywords: Distributed generation; Power distribution planning; Reliability; Losses; Voltage control

1. Introduction

Distributed generation (DG) is related with the use of small generating units installed in strategic points of the electric power system close to load centers. The technologies adopted in DG comprise small gas turbines, micro-turbines, fuel cells, wind and solar energy, etc. DG can be used in an isolated way, supplying the consumer's local demand, or in an integrated way, supplying energy to the remaining of the electric system. In distribution systems, DG can provide benefits for the consumers as well as for the utilities, especially in sites where the central generation is impracticable or where there are deficiencies in the transmission system. In this context, the utilities obligation of providing access to distribution network for independent producers to install DG units confronts with the need of controlling the network and guaranteeing appropriate security and reliability levels. The uncertainties involved in system planning and operation become larger and certainly new methods need to be developed to analyze and to foresee the behavior of the system.

The planning of the electric system with the presence of DG requires the definition of several factors, such as: the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The impact of DG in system operating characteristics, such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated. The problem of DG allocation and sizing is of great importance. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. For that reason, the use of an optimization method capable of indicating the best solution for a given distribution network can be very useful for the system planning engineer when dealing with the increase of DG penetration that is happening nowadays.

The selection of the best places for installation and the preferable size of the DG units in large distribution systems is a complex combinatorial optimization problem. In [1], Lagrangian based approaches are used to determine optimal locations for placing DG, considering economic limits and stability limits. Recently, metaheuristics optimization methods are being successfully applied to combinatorial optimization problems in power systems. Among those methods, we can cite genetic algorithms (GA). In [2], a GA based DG allocation method is presented where the power losses in an existing network is minimized. The voltage profile and short circuit

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level are imposed during the optimization process. The problem of DG influence on reliability has been modeled in [3], where a bounded set theoretic approach to the evaluation of the frequency and duration with which a generation–transmission system encounters a state of failure is given, considering the effects of unconventional energy sources and the dispersed character of the stochastic system load.

The methodology proposed in this paper aims to optimize the allocation and sizing of DG units in order to minimize the electrical losses in primary distribution network and to guarantee acceptable reliability levels and voltage profile. The optimization process is solved by the combination of genetic algorithms (GA) techniques with methods to evaluate DG impacts in system reliability, losses and voltage profile. The fitness evaluation function that drives the GA to the solution is the relation between the benefit obtained by the installation of DG units and the investment and operational costs incurred in their installation. The losses and voltage profile evaluation is based on a power flow method for radial networks with the representation of dispersed generators. The reliability indices are evaluated based on analytical methods modified to handle multiple generations.

2. Impact of distributed generation

Distribution systems are designed on the assumption that electric power flows from the power system to the load. Therefore, if output fluctuations or a reverse flow from generators occurs on the grid because of DG, there is likely to be some influence on the overall system in terms of power quality or protection and safety. The potential impacts of DG are [4]:

2.1. Power security

(a) *Increase in short circuit current*. When a short circuit fault happens, fault current is supplied from both the power system and DG to the fault point. If the total fault current exceeds the capacity of the feeder's circuit breaker, the fault cannot be separated out, and so continues.
(b) *Deterioration of sensitivity to faults*. Depending on the location of the fault, the sensitivity of the relay system is liable to deteriorate. Fault current decreases on the feeder at the substation by supplying fault current from DG. For this reason, the relay system either may not be able to detect the fault or may be slow to detect it.

2.2. Power quality

(a) *Excess voltage*. The voltage of substation distribution lines is controlled by a programmed timer or line drop compensator (LDC). Generally, a single distribution transformer has several feeder lines, and the voltage for these lines is adjusted in a block. Additionally, an SVR compensates the voltage mid-way along the line in heavy power-flow or long transmission lines. The load of each feeder should be balanced proportionally to utilize these voltage control systems. If there are many DG connections concentrated on a specific line, the gap in the power flow among feeder lines widens because of the back-flow from the DG. This difference might cause the voltage profile of feeder lines to deviate from the proper range.
(b) *Voltage fluctuation*. The voltage of the local line system is likely to fluctuate if the output of DG changes over a short time, and this fluctuation would cause over- or under-voltage at the customer's receiving point. There is particular concern when generating systems that depend on natural conditions, such as wind power or solar photovoltaic generators, are interconnected to the local system.

2.3. Reliability

DG units can have a positive impact on distribution system reliability if they are correctly coordinated with the rest of the network. A common example of DG use is as generation backup, in which the unit operates in the case of main supply interruption [5]. A DG application that is gaining popularity is the injection of power into the network when the DG capacity is higher than its local loads. A typical example is a co-generation plant, where the DG owner is charged only for the difference between the energy drained from the distribution utility and the amount injected into the network.

When the DG is operating in parallel with the system, new considerations are introduced in the network operation and planning procedures. A simple alternative to model DG is as constant active and reactive power injections independent of the system voltage at the unit terminal bus. The DG model of negative load can have a positive impact in system reliability if the reliability evaluation model considers capacity constraints during system restoration after a fault. Another alternative is to model DG units as controlled voltage sources in which the terminal voltage is maintained at a constant value by reactive power injection. Under this circumstance, it should be avoided to treat all DG sources as available for dispatch by the utility whenever necessary, since the DG units are not necessarily property of the distribution utility. This problem can be solved by modeling the maximum amount of active power dispatchable by the unit and the periods when it will be available.

2.4. Losses and voltage profile

Distribution systems are usually voltage regulated through tap changing at substation transformers and by the use of voltage regulators and capacitors on the feeders. This form of voltage regulation assumes power flow circulating from the substation to the loads. DG introduces reversed power flows that may interfere with the traditionally used regulation practices [6]. For this reason, the inappropriate DG allocation can cause low or over-voltages in the network. On the other hand, the installation of DG can have positive impacts in

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