Renewable and Sustainable Energy Reviews 73 (2017) 854–867

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Optimal reconfiguration of distribution system connected with distributed generations: A review of different methodologies

Ola Badran[a], Saad Mekhilef[b], Hazlie Mokhlis[a,*], Wardiah Dahalan[c]

[a] Department of Electrical Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia
[b] Power Electronics and Renewable Energy Research Laboratory (PEARL), Department of Electrical Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia
[c] Department of Electrical Engineering, University of Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, 32000, Perak, Malaysia

ARTICLE INFO

Keywords:
Network distribution reconfiguration
Distributed generation
Optimization method
Heuristic methods

ABSTRACT

The Network Reconfiguration technique is a method which helps mitigate power losses from distribution systems. However, the reconfiguration technique can only do this up to a certain point. Further power loss reduction may be realized via the application of Distributed Generation (DG). However, the integration of DG into the distribution system at a non-optimal location may result in increased power losses and voltage fluctuations. Therefore, a strategy for the selection of optimal placement and sizing of the DG needs to be developed and at the same time ensure optimal configuration. Many heuristic and artificial intelligence methods have been proposed in the literature for optimal distribution network reconfiguration, DGs sizing, and location. This paper reviews some of the more recent methods for distribution network reconfiguration, DG placement, and sizing that are intended to minimize power losses and improve the voltage profile.

1. Introduction

An electrical distribution system is the final stage of an electrical supply system, and this is where electricity is distributed to individual customers. During power distribution, power could be lost in the form of heat caused by current flow (I^2R). The total power loss of a system could be quite high for large-scale distribution systems. According to [1], power losses on transmission and sub-transmission lines made up 30% of the total power losses, while losses in a distribution network system accounted for 70% of the total losses in power system network. Power loss directly affects the operational cost of a power system. In [2], it was estimated that operational losses amounted to USD 5,851.85, which was attributed to power system losses. Technically, power losses could also reduce the voltage profile of a system, especially in heavily loaded systems.

Power losses can be mitigated through established techniques, such as network reconfiguration. This is the process of altering the switches' state of the network, where it could be normally open (tie switches) or closed (sectionalizing switches). The former is used in line reconfiguration, whereas the latter is used to localize fault damages. These switches help isolate failed subsystems from the main system, preventing operational interruption of the main system. The topological structure of the network is altered by closing the open switches, and vice versa, which will reduce power losses and improve the overall voltage profile, provided that the optimum reconfiguration could be determined. This will allow the load to be transferred to less heavily loaded feeders, which decreases the overall power loss. Network reconfiguration in a distribution system involves planning and operation. In the former, network reconfiguration is required to identify the best configuration by changing the on/off tie and sectionalizing switches within the network [3–6].

Another technique that can be utilized to reduce power loss in a distribution system is the interconnection to a local power supply. The availability of a local power supply will allow power to be delivered to loads that are within reach, which will indirectly reduce power loss. Examples of a local power supply include Renewable Energy Sources (RESs), such as mini-hydro, wind, solar, and biomass [7–10]. This class of the power supply is typically regarded as "Distributed Generations" (DG), where it is defined as a small generating unit installed at strategic locations in the distribution system, predominantly close to the load centers. Its capacity is usually under 10 MW [11,12]. Power generated from DG based on RESs is increasing across the world, where its generation capacity shown continues trend of increment in different continent from 2009 to 2015, as shown in Fig. 1 [13].

It is predicted that DG penetration will exceed 25% of the total

* Correspondence to: Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia.
E-mail address: hazli@um.edu.my (H. Mokhlis).

http://dx.doi.org/10.1016/j.rser.2017.02.010
Received 26 August 2015; Received in revised form 18 January 2017; Accepted 2 February 2017

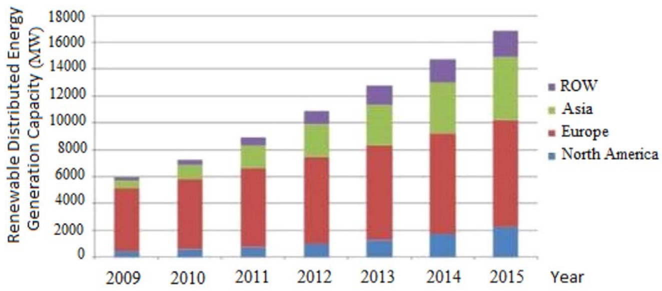

Fig. 1. Annual capacity of the additional renewable DGs across world markets [13].

generated power in the near future. Studies reported that the use of Renewable Energy DG could reduce carbon pollution by 60% from conventional power generation by 2050 [14]. DG leads to improved load balance, voltage profile, energy efficiency, and reliability, and so it is therefore prudent to ensure that DG is optimally sized and installed at suitable locations so that the aforementioned benefits will manifest itself in the system. Optimal DG placement involves determining the most suitable location that the DG should be installed in the system, while optimizing the size of the DG which involves selecting the amount of active power from DG that changes (0–100%) of the total active load. Unsuitable DG sizes will result in an increased power loss from the system. The loss of power is also compounded by increased operational costs, due to the fact that the installation of the DG and other associated equipments are a rather expensive undertaking. The above discussion serves to highlight the fact of the DG that is optimally sized and installed at the most suitable location will serve to reduce power losses from the system while also keeping it stable [15].

Recent works on network reconfiguration involved detailed studies on the optimization of the size of the DG and the most suitable location for its installation. In literature, there are numerous proposed techniques for network configuration, DG sizing, and placement that could result in reduced power loss. This paper will review some of the strengths and limitations of the more recent techniques.

2. Mathematical formulation of power losses

Changing the state of the aforementioned switches will change the topography of the distribution network. It is imperative to distribute the loads between the feeders in order to balance the load and avoid the feeders from overloading. The power loss equation for a distribution system is given by [16,17]:

$$P_{Loss} = \sum_{N=1}^{N} (R_N \times |I_N|^2) \tag{1}$$

where

P_{Loss}: the total active power losses in the network distribution.
N: the branch number.
R_N: the resistance in the branch N.
I_N: the current in the branch N.

The most common configuration of a distribution network is radial. The radial network is used in congested locations where the generated station is located at the center of the load. It has separate feeders and many power sources that operate in parallel, mimicking a tree. Each customer group is connected to one power source. The power is supplied to various areas in a community via the radial line as shown in Fig. 2. Most of the distribution networks are connected radially due to its simplicity, low cost, and simple maintenance; however, this configuration has the disadvantage of inducing more power outages. This will interrupt some loads in the event one or more of the lines are opened. Incidentally, this configuration also includes tie switches, which are used to reconfigure the network if faults or overloads occur

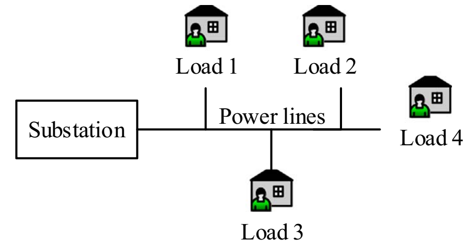

Fig. 2. A radial power distribution system.

[18,19].

Several constraints should be taken into account when trying to optimize both network reconfiguration and the size of the DG [20,21]. The following are the most common constraints:

(a) **Constraints of distributed generation operation:**

$$P_i^{\min} \le P_{DG,i} \le P_i^{\max} \tag{2}$$

where $P_i^{\max}$ and $P_i^{\min}$ are the upper and lower bounds of the DG size, respectively. All DG units should function within an acceptable limit.

(b) **Constraints of power injection:**

$$\sum_{i=1}^{k} P_{DG} < P_{Load} + P_{Loss} \tag{3}$$

where k is the number of the DG, P_{Load} is the total load of active power in the network, and P_{Loss} is the total active power losses in the network. In order to prevent power from being injected into the main source, the total load in the network needs to be larger than the total power output of the DG. Doing so will ensure a continuous power flow from the main source to the entire distribution system.

(c) **Constraint of power balance:**

$$\sum_{i=1}^{k} P_{DG} + P_{Substation} = P_{Load} + P_{Loss} \tag{4}$$

The principle of equilibrium stipulates that the supply of power must be equal to its demand. The summation of power losses and load should be equal to the total power generated from the DG units and substation.

(d) **Constraint of voltage bus:**

The bus voltage magnitudes should be kept within acceptable operating bounds via the optimization process in the following manner:

$$V_{\min} \le V_i \le V_{\max} \tag{5}$$

where $V_{\min}$ and $V_{\max}$ are the lower and upper bound of bus voltage limits, respectively, and V_i is the voltage magnitude at bus i_{th}. The acceptable voltages limits for each bus are 0.95 and 1.05 (±5% of rated value).

(e) **Constraint of radial configuration:**

The system's configuration should always be radial.

(f) **Constraint of isolation:**

After reconfiguration, all nodes or buses must be reactivated and energized to ensure that all loads are powered.

3. Methodologies of network reconfiguration and DG sizing techniques for planning purpose

Many methods have been developed for reconfiguration. However, not many take into account the optimal sizing of the DGs [20,22,23]. Reported works can be categorized into 'sequential' and 'simultaneous' techniques. For the former, the optimal size of the DGs needs to be determined prior to network configuration, while in the latter, optimal