Electric Power Systems Research 127 (2015) 165–176

Contents lists available at ScienceDirect

Electric Power Systems Research

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

Novel methodology for optimal reconfiguration of distribution networks with distributed energy resources

Parvathy Chittur Ramaswamy[a,b,*], Jeroen Tant[a,b], Jayakrishnan Radhakrishna Pillai[c], Geert Deconinck[a,b]

[a] KU Leuven, ESAT-ELECTA, Kasteelpark Arenberg 10, Heverlee 3001, Belgium
[b] EnergyVille, Dennenstraat 7, 3600 Genk, Belgium
[c] Aalborg University, Pontoppidanstræde 101, 9220 Aalborg, Denmark

ARTICLE INFO

Article history:
Received 14 July 2014
Received in revised form 22 April 2015
Accepted 7 May 2015
Available online 19 June 2015

Keywords:
Distributed energy resources
Distribution network
Grid reconfiguration
Optimization
Power loss
Switching

ABSTRACT

This paper develops three novel methodologies for optimal reconfiguration of distribution networks in the presence of distributed energy resources (DERs). The novelty is in achieving a non-conservative and robust solution to grid reconfiguration. The optimal solution is the minimum-loss-configuration of the distribution network taking into account the cost of switching and the grid operational constraints. The methods are based on the concepts of receding horizon control (RHC) and scenario analysis (SA) which inherently optimize switching costs and losses. The salient feature of incorporating RHC and SA is that it avoids the need to pre-define the period of change of configuration. The methods vary in their degree of robustness and conservatism. A robust configuration will not violate the constraints under any of the predicted DER variations called scenarios. A non-conservative configuration exploits better benefits with respect to the objective of reconfiguration under all scenarios. Depending on the desired level of robustness and non-conservatism, one of the three methods developed in this paper can be used to find the optimal configuration. The methods can be used for planning as well as for operation of the distribution network since they indicate the most frequently open switches in the network and the time at which they are to be operated.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

This paper deals with the optimal reconfiguration of electricity distribution networks, in the presence of distributed energy resources (DERs). DERs are defined as smaller power sources that can be aggregated to provide the power necessary to meet regular demand [1]. DERs, by definition will include photovoltaic (PV) generation, small-scale wind generation, bio-mass units, micro turbines etc. This paper considers distributed generation (DG) as well as electric vehicles (EVs) connected to the distribution network as DERs. DGs are defined as generating plants serving a customer on-site or providing support to a distribution network, connected to the grid at the distribution-level voltages [2]. The presence of DERs (e.g. PVs) in the distribution network is beneficial from an environmental point of view since they are based on renewable sources of energy. Other forms of DERs (e.g. EVs) provide storage and flexibility to the distribution network [3]. However, the uncertainty associated with DERs is the main challenge in including them in a distribution network. As DER penetration in distribution networks increases, the variation in network voltage and current also increases due to DER variation. This leads to uncertain power flows in the feeders resulting in grid congestions and increased grid losses. Distribution grid reconfiguration (GR) is one of the methods deployed by distribution system operators (DSO) to overcome this power loss. GR involves opening and closing of switches (hereafter referred to as 'switching') available in the distribution network in order to change its configuration. While GR helps in reducing the losses by balancing the loads in the distribution network [4], the additional switching results in increased operation and maintenance (O&M) cost. In this context, this paper discusses the optimization problem that minimizes power loss and switching cost in the presence of DER uncertainty simultaneously meeting voltage limit, radiality and load serving constraints.

The impact of load variation on GR was researched from the 1990s. The beginning of the last decade saw research on the impact of the DG in GR [5]. Under normal operating conditions of distribution networks, power loss reduction using GR was studied

* Corresponding author at: KU Leuven, ESAT-ELECTA, Kasteelpark Arenberg 10, 3001 Heverlee, Belgium. Tel.: +32 489001255.
E-mail address: ramaswamy.parvathy@gmail.com (P. Chittur Ramaswamy).

http://dx.doi.org/10.1016/j.epsr.2015.05.005
0378-7796/© 2015 Elsevier B.V. All rights reserved.

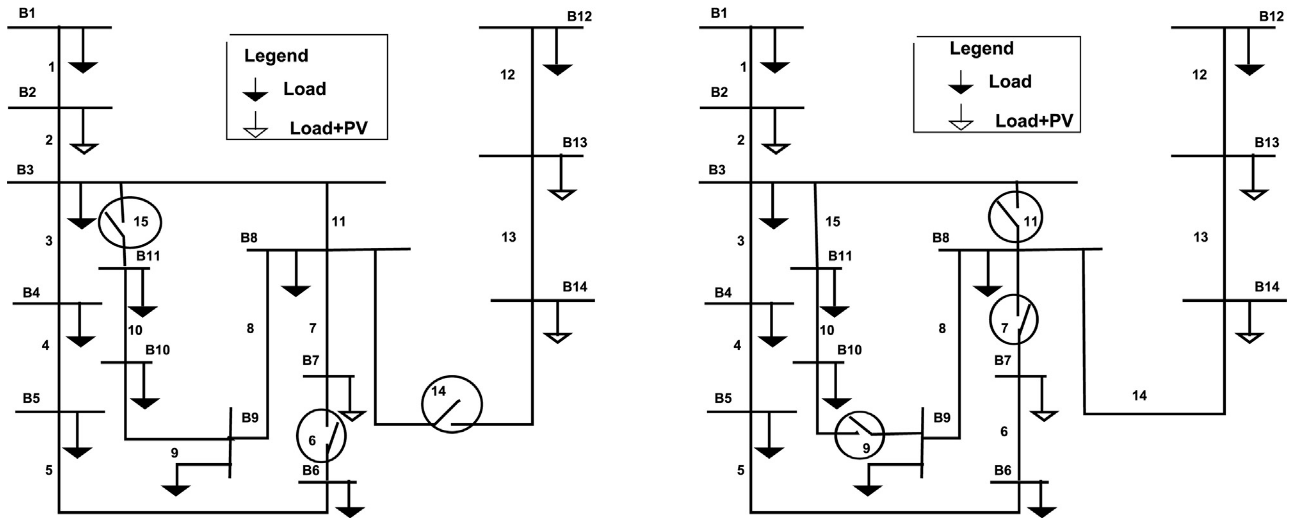

Fig. 1. Representing two different configurations of the same network by means of open switches (a) Configuration (6,14,15) (left) (b) Configuration (7,9,11) (right) [15].

[6–8]. Under emergency operating conditions like faults in the lines, transformers or protection devices, [9,10] focused on minimizing the number of interrupted customers. Time varying load analysis to reduce distribution losses through GR was dealt with in [4,11]. Recent years have shown increased focus on GR in the presence of DERs with their uncertainty. Refs. [12,13] discuss the variation of DG and [14] discusses variation of load and evaluate their impact on GR. However, an integrated approach which not only takes into account the benefit (i.e. loss reduction) and the cost (i.e. O&M cost of switches) of GR but also ensures that the optimal configuration does not violate the constraints during any of the predicted DER variations is missing in the literature on GR to the best of the authors' knowledge. This paper addresses the above mentioned aspect of GR in addition to the added advantage that the methods developed in this paper do not require a pre-defined period of changing the configuration.

The paper is organized as follows. Section 2 discusses the problem statement and the GR methodologies. Section 3 discusses the scope and the contribution of the paper to the literature on GR. The test distribution networks used for validation are discussed in Section 4 followed by the results of the simulations on these networks in Section 5. The main conclusions of this work are discussed in Section 6.

2. Problem statement and proposed methodology

This paper formulates an optimization problem which minimizes power loss and switching by reconfiguring a distribution network in the presence of DER uncertainty. The constraints include the limits in operation and safety of the distribution network such as the voltage limit, radiality and load serving constraints. GR, defined as altering the topological structure of distribution feeders by changing the open/closed states of sectionalizers and tie switches, will result in different configurations of the network. This is illustrated with the help of Fig. 1. It shows a medium voltage (MV) distribution network having 15 controllable switches. The switch numbers are indicated along the branches of the network. Fig. 1a shows a particular configuration of the network where switch numbers 6, 14 and 15 are open. Fig. 1b shows another configuration of the same network where switch numbers 7, 9 and 11 are open. Thus, the configuration of a distribution network is represented by the open switches.

As mentioned in Section 1, GR reduces the network losses. However, the switching involves operation and maintenance cost. Hence there has to be a balance between the benefit of loss reduction and the cost of switching. Finding this balance is complicated because of the uncertainty associated with the DERs in the network.

2.1. Application of receding horizon control & scenario analysis

The determination of the optimal configuration of the network that minimizes the power loss and the switching should consider the present and future load and generation values due to the following two reasons:

1. The future optimal configurations derived from the future load and generation values will influence the current optimal configuration, because the switching is to be minimal in addition to loss minimization.
2. The current optimal configuration will in turn influence the future optimal configurations, since any switching that is required in the future will take the current optimal configuration as the initial condition. This is explained in Fig. 2. For example, if the optimal configuration of a distribution network is C1 at time $T+1$, C2 at time $T+2$ and C1 again at time $T+3$, then it calls for a switching C1 → C2 → C1 at times $T+1 \rightarrow T+2 \rightarrow T+3$ as shown in Fig. 2a. This switching sequence is optimal with respect to the objective of power loss minimization. However, it will be suboptimal with respect to the objective of minimizing the switching since it involves a higher number of switching when compared to the configuration remaining as C1 from time $T+1$ to $T+3$ as shown in Fig. 2b. This interdependence of the present and future values is the fundamental concept behind Receding horizon control (RHC) as well. The RHC optimizes for the current time keeping in mind the forecasts of the future. It solves a finite or infinite horizon open-loop optimal control problem at every sample time and sets the control input according to the optimal profile until the next sample time. Updating states using measurements before each optimization results in feedback control [16]. RHC is already widely used in the petrochemical industry. The use of RHC in electrical power systems is relatively recent. RHC for wind power smoothing is shown in [17]. Voltage coordination is achieved by distributed RHC in [18].

The period until which the future values of load and generation are considered in determining the optimal configuration is called the prediction horizon (PH). Within the PH, there will be various temporal sequences of predicted values of load and generation.

Download English Version:

https://daneshyari.com/en/article/704630

Download Persian Version:

https://daneshyari.com/article/704630

Daneshyari.com