Expert Systems with Applications 37 (2010) 6974–6978

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Fuzzy based reconfiguration algorithm for voltage stability enhancement of distribution systems

M. Arun, P. Aravindhababu *

Department of Electrical Engineering, Annamalai University, Annamalainagar 608 002, Tamil Nadu, India

ARTICLE INFO

Keywords:
Fuzzy logic
Voltage stability
Radial distribution systems
Network reconfiguration

ABSTRACT

Voltage stability has recently become a challenging issue in many power systems. The distribution systems are reconfigured with a view to reduce the system losses and offer a better voltage profile for the utilities. This paper presents a new fuzzy based reconfiguration algorithm that enhances voltage stability and improves the voltage profile besides minimising losses, without incurring any additional cost for installation of capacitors, tap-changing transformers and related switching equipments in the distribution system. Test results on a 69-node distribution system reveal the superiority of this algorithm.

1. Introduction

Progressive increase in energy demands and rapid depletion of the existing generation and transmission resources due to various economic, environmental and regulatory changes have evolved a new type of problem, referred to as voltage instability or voltage collapse in power systems. Voltage collapse is generally triggered by large disturbances such as loss of generation, transmission lines or transformers and characterized by a slow variation in system operating point due to the inability of the network to meet the increasing demand for reactive power in such a way that the voltage magnitude gradually decreases until a sharp accelerated change occurs. Many utilities around the world have experienced major blackouts caused by voltage instabilities (Arya, Choube, & Shrivastava, 2008; Kundur, 1993; Salama, Saied, & Abdel-Maksoud, 1999; Taylor, 1994).

In recent years, the distribution systems experience a sharp increase in load demand on account of the extensive growth of the utilities. Besides, with the advent of deregulation in the power industry, there is a greater focus on managing the network assets efficiently rather than reinforcing the network's capacity. The operating conditions are thus more and more closer to the voltage stability boundaries. In addition, distribution networks are subjected to distinct load changes everyday. In certain industrial areas, it is observed that under certain critical loading conditions, the distribution system suffers from voltage collapse (Prada & Souza, 1998). Hence there is an urgent need to explore ways to enhance voltage stability (VS) in distribution systems.

Network reconfiguration is a process of altering the topological structure of the distribution feeders by changing the open/close status of the sectionalising and tie-switches. During normal operating conditions, networks are reconfigured for loss reduction to reduce system real power losses, and achieve load balancing in order to relieve the network overloads. The voltage stability of the distribution systems can be enhanced, if the loads are rescheduled more efficiently by reconfiguring the network, that allows to smoothen out peak demands, improve the voltage profile and increase the network reliability. Although there are many research papers discussing the reconfiguration algorithms for loss minimisation of distribution systems (Carpaneto & Chicco, 2008; Carreno, Romero, & Padilha, 2008; Chang, 2008; Enacheanu et al., 2008; Sivanagaraju, Viswanatha Rao, & Sangameswara Raju, 2008; Zhu et al., 2009), hardly any work related to improvement of voltage stability through reconfiguration is reported (Kashem, Ganapathy, & Jasmon, 2000; Sahoo & Prasad, 2006; Sivanagaraju, Visali, Sankar, & Ramana, 2004).

In the last three decades, fuzzy logic has found its role in many interesting power system applications, such as, load forecasting, power system stabilizer design and reactive power control (Momoh & Tomsovic, 1995) because of its usefulness in reducing the need for complex mathematical models. Fuzzy logic employs linguistic terms which deal with casual relationships between the input and output variables. It becomes easier to manipulate and rig out solutions, particularly where the mathematical model is not explicitly known or is difficult to solve.

A new fuzzy based algorithm that uses the voltage stability index suggested in Chakravorty and Das (2001), for enhancing the voltage stability of a radial distribution system through network reconfiguration is proposed in this paper. This method attempts to improve the voltage profile and reduce the system losses in

* Corresponding author. Tel.: +91 4144 237360.
E-mail addresses: arunmano80@gmail.com (M. Arun), aravindhababu_18@rediffmail.com (P. Aravindhababu).

0957-4174/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2010.03.022

Nomenclature

EA-1 and EA-2	existing algorithm-1 and 2, respectively
FLS	fuzzy logic system
PA	proposed algorithm
VS	voltage stability
VM	voltage magnitude
VSI	voltage stability index
VM_{min}	minimum value of VM in the system
VSI_{min}	minimum value of VSI in the system
L, M and H	linguistic variables representing low, medium and high, respectively
l	distribution line
nt	number of tie-loops
$r_{km} + jx_{km}$	resistance and reactance of line-l
P_{km}	sum of real power loads of all the nodes beyond node-m plus the real power load of node-m itself plus the sum of the real power losses of all the branches beyond node-m.
Q_{km}	sum of reactive power loads of all the nodes beyond node-m plus the reactive power load of node-m itself plus the sum of the reactive power losses of all the branches beyond node-m
$P_m + jQ_m$	real and reactive power load at node-m
P_{Om} and Q_{Om}	nth-node real and reactive power load at 1.0 per unit of voltage, respectively
SI_t	suitability index of tie-line-t
V_k	voltage magnitude at node-k
α	load factor
ΔVSI_t	normalized VSI difference across tie-line-t
ΔVM_t	normalised voltage magnitude difference across tie-line-t
t	tie-line/tie-switch
s	Sectionalised switch

addition to enhancing voltage stability. The method is tested on a 69-node radial system and the results are compared with that of the methods suggested in Sahoo and Prasad (2006), Sivanagaraju et al. (2004).

2. Proposed reconfiguration algorithm

Modern distribution systems are large in nature and liable to face unexpected events. Though in some cases, these uncertainties are represented by probability, more often it is clear that the uncertain functions are intrinsically fuzzy in nature and difficult to handle effectively by probability. Fuzzy set theories offer a compromise in the sense better solutions can be found that cannot be easily determined by other methods and are readily applicable to power system problems (Momoh & Tomsovic, 1995).

The aim of the present work is to obtain an optimal switching combination that enhances the voltage stability of radial distribution systems based on the VSI suggested in Chakravorty and Das (2001). The algorithm uses fuzzy logic to search for the most suitable tie-switch to be closed in order to improve the VS of the system. The VSI, which varies between unity at no load and zero at voltage collapse point, for line-l or for node-m of Fig. 1 can be determined using

$$VSI(m) = V_k^4 - 4\{P_{km}x_{km} - Q_{km}r_{km}\}^2 - 4\{P_{km}r_{km} - Q_{km}x_{km}\}V_k^2 \quad (1)$$

2.1. Fuzzy logic system

The proposed fuzzy logic system (FLS) determines the suitability of each tie-line one by one and the one having the highest suitability value is chosen as the most appropriate tie-line-t for reconfiguration. The intuitive and heuristically chosen input variables for FLS are ΔVSI_t, the normalized VSI difference across tie-line-t and ΔVM_t, the normalised voltage magnitude difference across tie-line-t and the output linguistic variable is SI_t, the suitability index of tie-line-t for reconfiguration.

The fuzzy terms describing the identified variables are low (L), medium (M) and high (H). The sets defining the $\Delta VSI_t, \Delta VM_t$ and SI_t, for each tie-line-t are as follows:

$$\Delta VSI_t = \{L, M, H\}$$
$$\Delta VM_t = \{L, M, H\}$$
$$SI_t = \{L, M, H\}$$

A one-dimensional triangular and trapezoidal membership functions with the range of values as shown in Fig. 2 are chosen for input and output linguistic variables. The choice of membership degrees in the interval [0,1], does not matter, as it is the order of magnitude that is important. Especially relevant to this application of reconfiguration,

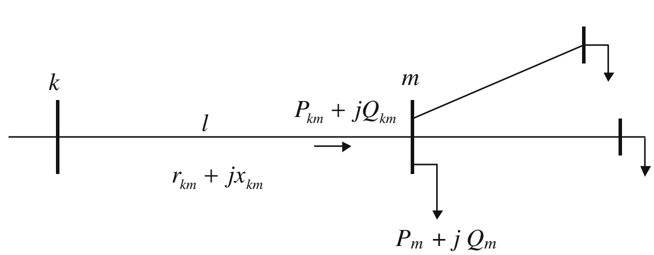

Fig. 1. Sample distribution line.

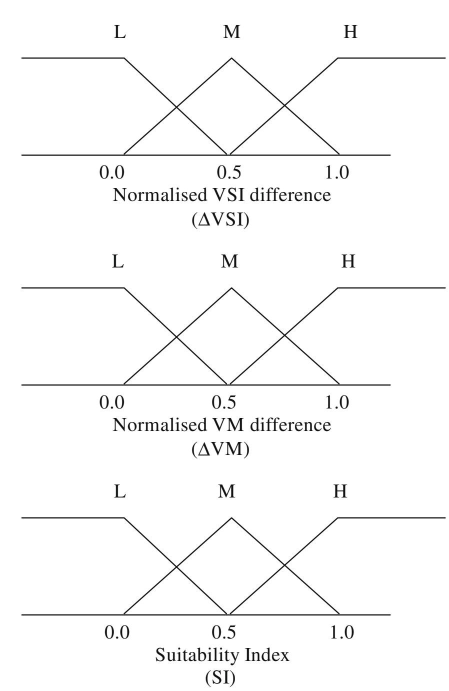

Fig. 2. Membership function chosen for linguistic variables.