Electrical Power and Energy Systems 54 (2014) 187–197

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Real-time voltage control algorithm with switched capacitors in smart distribution system in presence of renewable generations

Omid Homaee, Alireza Zakariazadeh, Shahram Jadid *

Center of Excellence for Power System Automation and Operation, Dept. of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 4 November 2012
Received in revised form 5 July 2013
Accepted 13 July 2013

Keywords:
Distribution system
Renewable distributed generation
Switched capacitor
Smart grid
Voltage control

ABSTRACT

One of the most important responsibilities of Distribution System Operator (DSO) is to maintain the customer voltage within specified ranges. Capacitor banks have long been used to provide voltage support and to correct displacement power factor on distribution network. This paper presents a new approach for real time voltage control of distribution networks that has improvements over the conventional voltage control models. This approach will be active in emergency conditions where, in real time, the voltages in some nodes leave their permissible ranges. In the proposed model, it is assumed that renewable distributed generations are integrated in the distribution system, and the communication infrastructure of smart grid has already been implemented. Also, all the capacitors are fitted with Remote Terminal Unit (RTU) and are completely accessible and controllable. Unlike previous voltage control methods, the proposed approach does not need the load and renewable generation forecast data to regulate voltage. Moreover, the calculation time of the proposed approach is considerably reduced. The proposed voltage control algorithm is applied on two different models, and each presented model has a substantial improvement over previous models. DSO can choose one of them based on a trade-off between cost and power quality index. To verify the effectiveness and robustness of the proposed control scheme, the developed voltage control scheme is tested on a typical distribution network. The simulation results show that the proposed real time voltage control has the capability to maintain distribution voltage in specified ranges.

1. Introduction

Due to the development of renewable Distributed Generation (DG), which is installed in medium-voltage distribution grid, voltage control currently is a very important issue in distribution systems. Smart grid should provide new digital technologies such as monitoring, two way communication facilities, and automatic control to improve the overall performance of the distribution grid. Voltage control is one of these performances that is developed by utilizing new communication and monitoring equipments.

The presence of renewable DGs can affect voltage profile in the distribution network [1]; the output of these units is variable and this power variation has direct influence on voltage profile. One of the important equipment for voltage regulation in distribution network are shunt capacitors which are used to inject reactive power to eliminate voltage drops on long feeders, and to correct power factor. Initially, the distribution capacitors were installed in the traditional fashion as fixed installations. These fixed capacitor banks were switched manually on a seasonal basis. Therefore, for optimum and cost effective operation of these switched capacitors, it is necessary to coordinate them in a smart fashion. These capacitors can mitigate the voltage fluctuations and increase the consumer expected power quality if they are switched properly.

In the last decade, online monitoring of distribution network has been a hot topic in power system engineering. The new control system as well as communication link have been integrated to power system that help operators to manage the system efficiently. The Distribution Automation (DA) system provides Supervisory Control And Data Acquisition (SCADA) capabilities throughout the modern distribution system. The communication infrastructure supports measurement and control systems such as Remote Terminal Units (RTUs) in distribution substations or feeders. With this wide spread deployment of DA, the Distribution System Operator (DSO) can switch the distribution line capacitor banks in real time to dynamically maintain voltages of distribution nodes in an acceptable range.

Reactive power must be compensated to guarantee an efficient delivery of active power to loads, thus releasing system capacity, reducing system losses, and improving system power factor and bus voltage profile. Volt/VAr control (VVC) is an important issue in the daily operation of distribution systems, because the proper

* Corresponding author. Tel.: +98 21 77491223; fax: +98 21 77491242.
E-mail addresses: homaee@elec.iust.ac.ir (O. Homaee), zakaria@iust.ac.ir (A. Zakariazadeh), jadid@iust.ac.ir (S. Jadid).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.07.010

Nomenclature

$V_{max,i}$	maximum voltage nearby the *i*th capacitor
$V_{min,i}$	minimum voltage nearby the *i*th capacitor
$V_{dif,i}$	the difference between maximum and minimum voltage of *i*th capacitor
n	number of capacitors
S_j	capacity of each switching step in *j*th capacitor bank
$Step(j)$	step of *j*th capacitor
$Step_0(j)$	step of *j*th capacitor in previous period
Ns_j	number of switching steps in a *j*th capacitor bank
$V_{est,n,n+1}$	estimated voltage between RTU_n and RTU_{n+1} calculated by RTU_n
$V_{est,n+1,n}$	estimated voltage between RTU_n and RTU_{n+1} calculated by RTU_{n+1}
V_n	the voltage of the DG or capacitor's bus at which RTU_n is connected
$P_{n,n+1}$	the active power flow from RTU_n bus to RTU_{n+1} bus
$Q_{n,n+1}$	the reactive power flow from RTU_n bus to RTU_{n+1} bus
$P_{n,n-1}$	the active power flow from RTU_n bus to RTU_{n-1} bus
$Q_{n,n-1}$	the reactive power flow from RTU_n bus to RTU_{n-1} bus
$r_{n,n+1}$	the lines resistance between RTU_n and RTU_{n+1}
$x_{n,n+1}$	the lines reactance between RTU_n and RTU_{n+1}
r_n	resistance of line n
x_n	reactance of line n

dispatch of Volt/VAr devices not only reduces the total power loss, but also improves the voltage profile for distribution feeders. Capacitors are widely used in distribution systems for reactive power compensation, to achieve power and energy loss reduction, to improve service quality via voltage regulation and to achieve deferral of construction, if possible, via system capacity release [2]. Switched capacitors give further flexibility in the control of grid's voltage, power factor, and losses [3].

The objective of VVC is to supply controlled reactive power by switching optimally the switched capacitors installed in the distribution system such that the voltage drop and real power loss is minimum. Traditionally, this problem of optimal capacitor switching has been solved through various optimization techniques. However, as the time taken by these traditional optimization methods are quite significant, these methods may not be suitable for online application.

To manage voltage regulation issues and accommodate a wide variety of distributed generation, DG units need to be coordinated with traditional utility devices such as voltage regulators [4]. In [5], a multi-agent, optimal reactive power dispatching method was proposed for voltage support of DG units in a single feeder. The paper did not consider the shunt capacitors. In [6,7] the VVC problem is solved by optimization algorithm for a day ahead scheduling. Disadvantage of these methods is that they require forecasted daily load and power output of renewable distributed generation. In [8], daily VCC model in distribution systems using DG units has been proposed, which determines the active power values of DGs, reactive power values of capacitors and tap positions of transformers for the next day. Unfortunately, the computing time of these methods do not let them to be used in real time scheduling. In [9], an online voltage security approach has been reported in which the ancillary services provided by the electric loads enhance the voltage stability in power systems operation. In [10], to reduce the calculation time of solving the optimal capacitor switching problem, an artificial neural network-based approach has been developed. Also in [11,12], this problem is solved by neural network. These methods have the same drawback of requiring forecasted daily load, and DGs' effect on voltage profile was not considered in them. In [13] the problem of voltage regulation has been well addressed by studying the impacts of DGs on the voltage profile and the operation of step voltage regulators (SVR) and feeder shunt capacitors. In [14], a new approach for voltage regulators function's improvement in multiple feeders which include DGs was proposed.

In this paper, a new approach for control and coordination of switched capacitors in the distribution system in which there are some renewable distributed generation is proposed. The proposed method is performed based on the RTU data which are collected from the selected points of distribution feeders. These RTUs are installed on the capacitor bank nodes, and there are communication links between them. The maximum and minimum values of voltage nearby the capacitor buses is estimated according to measured parameter. In the proposed model, the capacitors are switched based on the measured parameters that are received from RTUs, and this approach does not need to access the load or renewable units forecasted data.

This paper is organized as follows. Section 2 details the capacitors' effects on distribution voltage profile. Section 3 specifies voltage estimation among capacitor buses. Section 4 explains proposed system structure. Section 5 discusses the simulation cases and results from case studies.

2. Capacitors effects on distribution voltage profile

While reactive powers injected by capacitors vary in some nodes of distribution network, the lines current will change. This is the cause of voltage change and accordingly voltage drops through the distribution network. To clarify the effect of a capacitor on distribution voltage drop, let us consider two-bus test system in Fig. 1. The voltage drop in this system is calculated based on alternation of capacitor reactive power injection.

Consider ΔP and ΔQ as the variation of line active and reactive power, the variation in voltage at bus 2 while the voltage value at bus 1 is kept constant is defined as follows:

$$\Delta V_2 = (R + jX)\left(\frac{\Delta P - j\Delta Q}{V_2^*}\right) \quad (1)$$

$$\Delta V_2 = \frac{(R\Delta P + X\Delta Q) + j(X\Delta P - R\Delta Q)}{V_2^*} \quad (2)$$

As the imaginary part of voltage drop is small, it can be neglected. Therefore, the voltage drop related to active and reactive power flow between buses 1 and 2 is written as follows:

$$\Delta V_2 = \frac{(R\Delta P + X\Delta Q)}{V_2^*} \quad (3)$$

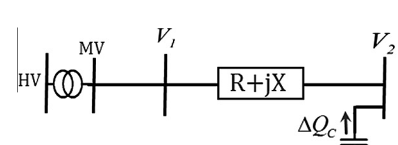

Fig. 1. Two-bus test system.