Electrical Power and Energy Systems 78 (2016) 239–247

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Optimal voltage control in distribution network in the presence of DGs

José Raúl Castro [a,b,*], Maarouf Saad [b], Serge Lefebvre [c], Dalal Asber [c], Laurent Lenoir [c]

[a] Universidad Técnica Particular de Loja, Loja, Ecuador
[b] Ecole de technologie supérieure, 1100, rue Notre-Dame Ouest, Montréal H3C1K3, Canada
[c] Hydro-Quebec's Research Institute, IREQ, 1800, boul. Lionel-Boulet, Varennes, Québec J3X1S3, Canada

ARTICLE INFO

Article history:
Received 4 November 2014
Received in revised form 26 August 2015
Accepted 25 November 2015
Available online 17 December 2015

Keywords:
Distribution network
Coordinated Voltage Control (CVC)
Distributed Generation (DG)
Multi-Objective optimization
Power loss
On-load tap changer (OLTC)

ABSTRACT

Nowadays, integration of new devices like Distributed Generation, small energy storage and smart meter, to distribution networks introduced new challenges that require more sophisticated control strategies. This paper proposes a new technique called Optimal Coordinated Voltage Control (OCVC) to solve a multi-objective optimization problem with the objective to minimize the voltage error at pilot buses, the reactive power deviation and the voltage error at the generators. OCVC uses Pareto optimization to find the optimal values of voltage of the generators and OLTC. It proposes an optimal participation of reactive power of all devices available in the network.

OCVC is compared with the classical method of Coordinated Voltage Control and is tested on the IEEE 13 and 34 Node test feeders with unbalanced load. Some disturbances are investigated and the results show the effectiveness of the proposed technique.

Introduction

The climate changes and the new technologies have led to major changes in electricity generation and consumption patterns. The equipment connected to the distribution network is becoming more diversified including renewable energy that is known as Distributed Generation (DG), small energy storage, and smart meter. It consequently requires more advanced algorithms for voltage and VAR control.

The DGs may trigger variation of voltage and change the direction of power flow in the distribution network. The voltage rise depends on the amount of active and reactive power injected by the DGs. Some researches [1–3] have studied the impact on the voltage, the reduction of losses, and the determination the optimum size and location of the DGs. Also, improper DG size and inappropriate location may cause high power loss and problems in the voltage profile [3–5].

Other researches [6,7] represent the variation voltage in each control area by the variations at some selected buses called "pilot buses". Then, the aim is to keep the voltages at pilot buses within a fixed range around set point values.

On the other hand, it is common to use the on-load tap changer (OLTC) and switch shunt capacitors to control voltage in distributed network [8]. In some networks, these devices are operated locally without wide coordination with the others. In [9,10], the authors presents an approach using the DGs and OLTCs for voltage regulation and losses reduction.

Coordinated Voltage Control (CVC) in distribution network adjusts the voltage in pilot buses. CVC uses the multi-objective (MO) function to minimize the voltage variation at the pilot buses [10]. CVC in distribution networks adjusts the voltage on pilot buses located in the controlled area. To do so, it minimizes the MO optimization problem using a deterministic method. So, the problem to solve is to minimize the following objectives [9,10]: Objective 1: voltage deviation at pilot buses; Objective 2: reactive power production ratio deviation; and Objective 3: generators voltage deviation (OLTC + DGs).

In [11], the authors have made a comparison in distribution networks, between uncoordinated and coordinated voltage control, without and with DGs involved in the voltage control. The result indicates that using DG in the voltage control will reduce the losses, the number of OLTC operations and will decrease the voltage fluctuation in distribution network.

The authors in [10,12,13] solve the MO function converting the objectives into a single objective (SO) function; in this case, the objective is to find the solution that minimizes the single objective. The optimization solution results in a single value that represents a compromise among all the objectives.

* Corresponding author at: Universidad Técnica Particular de Loja, San Cayetano Alto, Electrónica, Ext: 2516, Loja, Ecuador.

E-mail addresses: jrcastro@utpl.edu.ec (J.R. Castro), maarouf.saad@etsmtl.ca (M. Saad), lefebvre.serge@ireq.ca (S. Lefebvre), asber.dalal@ireq.ca (D. Asber), lenoir.laurent@ireq.ca (L. Lenoir).

http://dx.doi.org/10.1016/j.ijepes.2015.11.081
0142-0615/

Previous researches adequately solved the problem of MO function using DG in distribution network. There is no research that is able to adequately coordinate the different areas of the distribution network and focus on the benefits that a better use of reactive power of DG can provide to the distribution systems with unbalanced load.

To overcome the problem cited above, this paper proposes a new technique called Optimal Coordinated Voltage Control (OCVC). OCVC is capable of coordinating different areas of the distribution network including all sources of active and reactive power present in the distribution network. OCVC uses Pareto optimization to solve all the different objectives of the Multi-Objective function separately and finds the optimal values so that the network gets lower losses. OCVC will also have a good performance with various disturbances that occur in the distribution network.

The original contributions of this paper are described as follows:

(a) Disturbances in distribution network are investigated.
(b) Optimal participation of reactive power of a DG at unbalanced distribution network.
(c) The minimization of the losses.
(d) The objectives of the MO function are resolved separately.

This paper is organized as follows. Section 'Coordinated voltage control in distribution network' presents the coordinated voltage control in distribution network. The Pareto Multi-Objective optimization is explained in Section 'Pareto optimization'. The proposed approach on Optimal Coordinated Voltage Control is explained in Section 'Optimal Coordinated Voltage Control'. Section 'Case study' presents a case study and some results using the proposed approach. Finally, a conclusion is given in Section 'Conclusions'.

Coordinated voltage control in distribution network

Nowadays, a hierarchical voltage regulation strategy with three levels has been developed by some electric utilities to prevent voltage deterioration and to allow a better use of existing reactive power resources. Each level acts with a different time constant: Primary voltage control (PVC) is locally performed by automatic voltage regulators (AVR), secondary voltage control (SVC) makes reactive power production–consumption balance and tertiary voltage control (TVC) is based on optimization methods taking into account economical and technical aspects of power system operation [10].

SVC is an important level for improving power-system voltage dynamic performance, where voltage deviation at pilot buses is minimized. This problem can be generalized to integrate voltage deviation at generators and reactive power generation. In this case, we talk about Coordinated Voltage Control (CVC) [10].

Problem formulation

The voltage in a distribution network at some selected buses (pilot buses), the reactive power production and the generator's voltage deviation are tied together. Any increase or decrease in voltage at pilot buses will increase or decrease the reactive power production and generator voltage respectively. Therefore, this problem can be formulated as an optimization problem as explained below:

Voltage at pilot bus

CVC in distribution networks adjust the voltage at pilot buses. In a mathematical form, the problem can be written as follows:

$$F_1 = \sum_{i\in P} \lambda_i \left[k(V_i^{ref} - V_i) - \sum_{k\in G} C_{i,k}^V \cdot \Delta V_k \right]^2 \tag{1}$$

where P and G are the sets of pilot and generator buses indices; V_i^{ref}, V_i and ΔV_k are set-point voltage, actual voltage and voltage deviation at bus i, i.e. the difference of voltage values between two computing steps; $C_{i,k}^V$ is the sensitivity matrix coefficient linking the voltage variation at bus i and bus k respectively; λ_i and k are weighting factor and regulator gain respectively.

Reactive power production

The second objective is the reactive power production ratio deviation. In OCVC, it represents the management of the reactive power of DG in the regulated area. This objective is modelled as follows:

$$F_2 = \sum_{i\in G} \lambda_i^q \left[k\left(q^{ref} - \frac{Q_i}{Q_i^{MAX}} \right) - \sum_{k\in G} C_{i,k}^Q \cdot \Delta V_k \right]^2 \tag{2}$$

where G is the set of generator buses indices; Q_i and Q_i^{MAX} are actual and maximum reactive power generations at bus i; $q^{ref} = \sum_{i\in G} Q_i / \sum_{i\in G} Q_i^{MAX}$ is the uniform set-point reactive power value within the regulated area; $C_{i,k}^Q$ is sensitivity matrix coefficients linking respectively voltage variation at bus i and bus k; λ_i^q and k are weighting factor and regulator gain respectively.

Voltage at generators

CVC in distribution networks adjust the voltage at the generators. The mathematical model for the third objective is as follows:

$$F_3 = \sum_{i\in G} \lambda_i^v [k(V_i^{ref} - V_i) - \Delta V_i]^2 \tag{3}$$

where G is the set of generator buses indices; V_i^{ref}, V_i and ΔV_i are the set-point voltage, actual voltage and voltage deviation respectively at the bus i, i.e. the difference of voltage values between two computing steps; λ_i^v and k are weighting factor and regulator gain respectively.

Optimization constraints

The constraints above considered the technical and economic issue of the distribution network. The voltage limits, voltage drop, reactive power and the weights are the main constraints [10,14,15].

Voltage constraints

The constraints of voltage on the pilot and generator buses are used to determine the safe operation values. In distribution networks an acceptable steady voltage range is considered within ±5% of the operating voltage at DG [16].

$$\begin{aligned} & V_i \in [V_i^{min}; V_i^{MAX}] \quad \text{for } i \in P \cup G \\ & |\Delta V_i| \leqslant \Delta V_i^{MAX} \quad \text{for } i \in G \end{aligned} \tag{4}$$

Reactive power constraint

In this work, the control and efficient management of the reactive power are the main objectives. Therefore, the control of the production of the reactive power of the DG is very important. In [1] an acceptable power factor for the DG is of ±0.91.

$$q^{ref} = \sum_{i\in G} Q_i \Big/ \sum_{i\in G} Q_i^{MAX} \tag{5}$$

where $|Q_i| \leqslant Q_i^{MAX}$