Electrical Power and Energy Systems 60 (2014) 59–66

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Application of Channel Components Transform to design shunt reactive compensation for voltage stability improvement

Iraj Rahimi Pordanjani *, Wilsun Xu

Department of Electrical and Computer Engineering, University of Alberta, Edmonton, Canada

ARTICLE INFO

Article history:
Received 18 March 2013
Received in revised form 23 January 2014
Accepted 25 February 2014
Available online 21 March 2014

Keywords:
Voltage stability
Shunt reactive compensation
Channel components transform

ABSTRACT

Channel Components Transform (CCT) is a network decoupling transform that has recently been proposed. The effective performance of CCT in voltage stability analysis and monitoring has been shown before. This paper extends the application of CCT to voltage stability enhancement. For this purpose, the CCT is used and a strategy for shunt compensation is proposed in order to improve the voltage stability of power systems. The proposed strategy is direct, effective and practical. The detail algorithms of the proposed strategy are presented in this paper. The strategy is also verified by case studies using standard test systems.

1. Introduction

Due to the increasing demand for electrical power, and economic and environmental restrictions for transmission capacity expansion, power systems are usually being operated close to their voltage stability limits. This situation is very risky since a disturbance could lead to a voltage collapse. Therefore, voltage stability is a major concern in the operation of power systems. Utilities have a keen interest to manage proper countermeasures to increase the stability margin of their systems without adding major transmission facilities if possible. For this purpose, a variety of methods can be taken into account [1]. Among them, reactive power planning (RPP) is one of the most effective ones since voltage collapse is typically associated with the reactive power demands of loads not being met because of limitations on the production and transmission of reactive power [2]. RPP can be performed both on the generation side and on the network side. On the generation side, RPP involves optimal reactive power scheduling to improve the stability margin. On the network side, RPP involves optimal allocation of Var sources such as capacitor banks, and static Var compensators (SVC).

Over the past few years, RPP has been a concern for several researchers and several methods have been proposed for this purpose. Refs. [3,4] show that the most commonly used methodology is to introduce voltage stability requirements into the optimal power flow. These kind of methods formulate a multi-objective optimization problem based on the distance to the voltage collapse point, minimum singular value, minimum eigenvalue, or others similar indices. However, these methods encounter some difficulties. First of all, when considering the voltage stability-related objectives, the formulated multi-objective problem becomes very complicated and very difficult to be solved. That is why several attempts have been made to use evolutionary algorithms for solving this optimization problem [3]. Therefore, these methods may not be practical for real power systems which are very large and interconnected. On the other hand, in the vicinity of the voltage collapse point, the voltage stability indices which are used as objectives present nonlinear characteristics, which make the convergence of these methods more difficult [5]. It should be noted that many useful methods have also been proposed for shunt compensation in distributions networks such as [6–9]. Those methods aim to improve the distribution network performance, but what we mean by RPP in this paper is to improve the transmission system capability.

We have recently proposed a new transformation called Channel Components Transform (CCT) to decouple power systems. Refs. [10,11] have shown that CCT can form a framework for voltage stability analysis and monitoring. Using the proposed CCT-based methods, it is possible to determine the critical (weak) buses [10], and the critical generators and branches [11] with respect to voltage stability. The CCT can also be used to propose efficient and practical methods to improve the voltage stability. As an example of those methods, the RPP on the network side which includes the allocation of shunt Var sources such as capacitor banks, and static Var compensators (SVC) is considered in this paper. Using the CCT framework, a direct and practical approach is proposed for shunt compensation to increase the voltage stability margin.

* Corresponding author. Tel.: +1 7804920163; fax: +1 7804921811.
E-mail addresses: rahimipo@ualberta.ca (I. Rahimi Pordanjani), wxu@ualberta.ca (W. Xu).

http://dx.doi.org/10.1016/j.ijepes.2014.02.021
0142-0615/

When planning a shunt compensation strategy, the location and the amount of reactive supports need to be determined. For this purpose, the CCT is used and a method for single-location shunt compensation is proposed first. The proposed method is also applied to some test systems and the results are investigated. The proposed method is then extended to multi-location compensation and the obtained simulation results are presented.

2. Overview of Channel Components Transform

Channel Components Transform proposed in [10] is briefly overviewed in this section. A general power system shown in Fig. 1 can be represented by a multi-port Thevenin circuit which has the following equation:

$$[V] = [K][E] - [Z][I] = [E'] - [Z][I] \quad (1)$$

where $[E]$ is the vector of terminal voltages or the internal voltages (if a generator's Q_{max} is reached) of the generators and $[V]$ is the vector of nodal voltages at the load buses. $[E'] = [K][E]$ is the open circuit voltage vector of the traditional multi-port Thevenin equivalent circuit.

Eigen-decomposition can be performed to diagonalize the $[Z]$ matrix of the Thevenin circuit as follows [10]:

$$[Z] = [T]^{-1}[\Lambda][T]$$

where $[\Lambda]$ and $[T]$ are the eigenvalue and eigenvector matrices of $[Z]$, respectively.

Applying the above decomposition to (1) will result in:

$$[V] = [K][E] - [Z][I] = [K][E] - [T]^{-1}[\Lambda][T][I]$$

$$[T][V] = [T][K][E] - [\Lambda][T][I] \quad (2)$$

If we denote $[U] = [T][V]$ as the transformed voltage, $[J] = [T][I]$ as the transformed current, and $[F] = [T][K][E]$ as the transformed voltage source, Eq. (2) can be represented as:

$$\begin{bmatrix} U_1 \\ U_2 \\ \dots \\ U_n \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ \dots \\ F_n \end{bmatrix} - \begin{bmatrix} \lambda_1 & 0 & 0 & 0 \\ 0 & \lambda_2 & 0 & 0 \\ 0 & 0 & . & 0 \\ 0 & 0 & 0 & \lambda_n \end{bmatrix} \begin{bmatrix} J_1 \\ J_2 \\ \dots \\ J_n \end{bmatrix} \quad (3)$$

The above equation can be represented by a set of decoupled circuits as shown in Fig. 2. Therefore, the above transformation has converted a complex network (Fig. 1) into a set of decoupled simple one-source, one-load networks (Fig. 2). The transformation is called Channel Components Transform (CCT). Consequently, each decoupled circuit in Fig. 2 is called a channel component (circuit).

Refs. [10,11] have shown that by analyzing the channel components, we can get important information about the actual system. Among channels of a system, there is one critical channel which is most responsible for the voltage collapse. Using the critical channel, useful information about the voltage stability characteristics

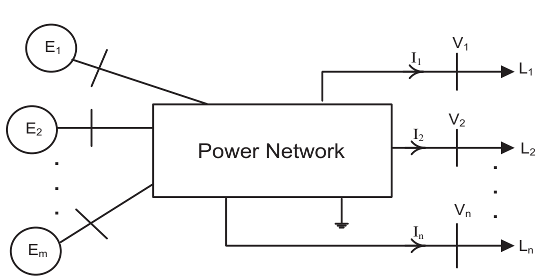

Fig. 1. A general electric power network.

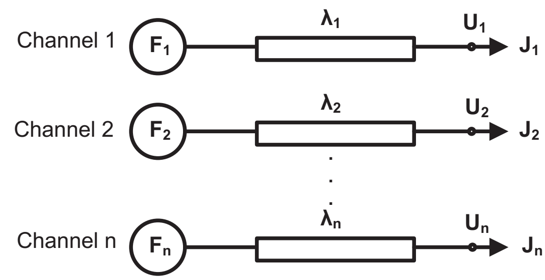

Fig. 2. Channel domain representation of the complex network.

of the system can be extracted. For example, buses, generators, and lines which are critical with respect to voltage stability can be identified [10,11]. The CCT can also be used for online monitoring and analysis of voltage stability [11]. The current paper aims to extend the application of CCT to voltage stability enhancement. For this purpose, a direct and practical approach for shunt compensation to increase the voltage stability margin is proposed in the next sections.

It should be noted that channel components represent a transformed version of the actual power system. Therefore, any variation of the actual system's parameters will result in a variation in channel circuit parameters. For example, if the system topology changes as a result of a line outage, the impedance matrix $[Z]$ will change. Therefore, the eigen-decomposition needs to be repeated which will lead to a new transformation matrix $[T]$. Variations which do not change the system topology such as variation in generator voltages or in load amounts, will not change the transformation matrix, but will change the channel circuit quantities such as voltage source $[F]$ or channel loads. Refs. [10,11] provide much more details about the effects of system parameter variations on the CCT results. For example, Section V.D in [11] showed the effect of contingencies on critical loads/generators identified by CCT. The results showed that the contingencies did not have any significant effect on the critical generators/loads identified by CCT in the large system under study. Note that the procedure proposed in the current paper considers the system with its existing conditions. However, if any change/variation occurs in the system, the proposed procedure can be easily repeated for the new conditions to determine if the results are affected.

3. Proposed method for single-location shunt compensation

The overall flowchart of the proposed method is illustrated in Fig. 3. As this figure shows, the proposed method consists of three steps. These steps are described in detail in the following sub-sections.

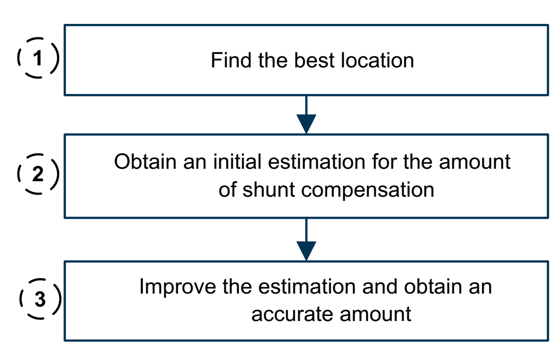

Fig. 3. Overall procedure of the proposed method.