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ScienceDirect
Electric Power Systems Research 78 (2008) 1485–1493
ELECTRIC POWER SYSTEMS RESEARCH
www.elsevier.com/locate/epsr

Sensitivity analysis based on transmission line susceptances for congestion management

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Received 2 October 2006; received in revised form 19 March 2007; accepted 10 January 2008
Available online 4 March 2008

Abstract

Transmission line limits impede power transfers and cause congestion greatly reducing the effectiveness of systems and increasing the cost of power transmissions. Through several methods, congestion can be effectively eliminated either by building a new transmission line or by increasing the capacity of the original line between congested zones. Both methods cause susceptance change and line capacity increase between nodes. Therefore, the sensitivity of a system to variations of its parameters becomes important in terms of operation and planning. In this paper, congestion relief as a function of line susceptances and line capacities is investigated. Mathematical derivations for calculating sensitivities based on line susceptances are given systematically, and numerical studies were performed by using sequential quadratic optimization programming to determine congestion in terms of line susceptances. It is shown that the optimum susceptance range becomes critical when the line parameters are changed dynamically by using thyristor-controlled series-compensators. To relieve congestion in the operation of a network may require tracking this optimal parameter range whenever system states change.

Keywords: Congestion management; Sensitivity analysis; Transmission planning

1. Introduction

The restructuring of the electric utility industry in many countries has provided open access to their transmission systems [1,2]. Generators and loads can access transmission system in a non-discriminatory and equitable manner. Open access to transmission systems is vital for healthy competition in power industry. As the number and magnitude of power transactions increase in open access, power transactions between generators and loads when implemented may sometimes congest the electric power network. Therefore, congestion management has become very important and difficult to deal with in the emerging deregulated electricity markets [3]. In a power market, transactions between producers and consumers are limited by line parameters, when the limitations exist for certain transactions, cost of electrical energy production will increase. Also, because of these limitations, in some regions market power may prevail. Electric markets need to set some rules or methods to manage the transactions to deal with congestion problem. Transmission congestion management may be categorized into short-term and long-term. The short-term transmission congestion management is based on rules and pricing [4–7]. The FERC expresses its preferences for market-based plans, and notes that the pricing and expansion program should be compatible with the pricing signals for shorter-term solutions to congestion management so that market participants can choose the least-costly response [8]. Congestion always increases the cost of electrical energy and persistent congestion in similar zones of transmission lines must be removed in the long-term by installing new lines or by utilizing FACTS devices so that competitive energy markets are accomplished through increased transmission capacities. The statistical methods proposed in literature may be used in congestion studies for long-term planning [9]. Grid planning is a long-term approach that requires decision-making tools to determine which part of a network should be developed in the future. Competitive markets expose transmission planners to new uncertainties. These are handled using a decision-analysis approach whose key contribution is quantifying and minimizing risk [10].

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doi:10.1016/j.epsr.2008.01.011

Long-term congestion relief between zones can be achieved through the strengthening of transmission lines. The strengthening of a transmission line can be accomplished either by building a new transmission line between the congested zones or by increasing the capability of the original line. There are many difficulties in most developed countries to building new additional lines to increase transmission capacity [11]. Power engineers may prefer the simple approach of constructing new lines to meet unexpected needs and to trade power over large regions. However, the reality is that the construction of new transmission lines is often opposed by local residents, landowners and environmentalists and, therefore, new lines may be difficult to achieve nowadays and it will become more difficult in the future. Therefore, engineers are looking for new ways of increasing transmission capacity without building new lines. Flexible AC Transmission System (FACTS) devices increase the capacity by loading the transmission lines up to their thermal limits and control the power flows by changing their parameters. FACTS from advanced energy management systems allows control of transmission flows without requiring new line construction. A study describing an analytical approach for operation of series-compensators to relieve power flow congestion has been published [12] in which changes in the direction and the amount of compensation have been determined according to sensitivity values derived from a DC power flow model under the assumption that generation dispatch is maintained. In this reference, a computer algorithm is proposed to relieve congestion while utilizing the controlled lines.

This paper is organized as follows: the subsequent section is devoted to the thyristor-controlled series capacitor (TCSC) model and brief information about this device is given. In Section 3, congestion relief as a function of line susceptance and line capacity is investigated based on the bid functions of supplies. To achieve this goal, mathematical derivations to calculate sensitivities based on line susceptances are given. Studies based on sensitivity analysis and sequential quadratic programming (SQP) are implemented in Section 4, using an example power system to determine the congestion regions in terms of line parameters and the total cost when line capacities and line susceptances are varied. In Section 5, effects of DC and AC power flow analysis are compared as the line susceptances are changed. Section 6 summarizes the conclusions of the work done in this paper.

2. Modeling of TCSC controller

FACTS devices control transmission flows and allow for expanded capability on a system without requiring new line construction in the short-term [11]. There are many various FACTS controllers [13]. Each of these controllers can act on one of the three parameters for power transmission; voltage (SVC), transmission impedance (TCSC) and transmission angle (phase-shifter). The thyristor-controlled series capacitor can vary the impedance continuously to levels below and up to the line's natural impedance to control the active power flow [14]. Because of this property, TCSC controllers are considered in our study.

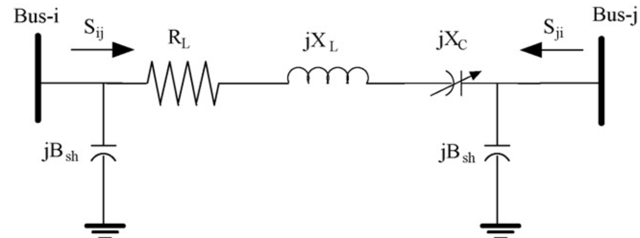

Fig. 1. A model of a TCSC.

Fig. 1 shows a series compensated transmission line represented by equivalent parameters connected between Bus i and j. During steady state, the TCSC can be considered as a static capacitor/reactor offering impedance jX_C. This impedance can be changed using TCSC controllers to bring impedance of the congested line to a level where no more congestion exists.

3. Sensitivity analysis based on line susceptances

The effect of altering the susceptance of various transmission lines in a system is calculated by the procedure described in Refs. [15] and [16]. Many numerical techniques in power flow studies, as in the case of congestion management and transmission pricing in a market-driven power system environment, concentrate on the use of DC power flow analysis because of the computational time advantage and greater understanding of the consequences [17]. Furthermore, there may be some loss of accuracy using DC approximation, but the studies show that the results actually match fairly closely with the full AC solutions in certain conditions [18,19]. Therefore, in this study, the so-called 'DC' approximation is used for the reasons mentioned above; that is, the real power losses are ignored and bus voltage magnitudes are approximated to 1.0 pu. Under these assumptions, reactive power flow is zero on each line and the admittance of an inductive line is given as $Y_{ij} = g_{ij} - jb_{ij}$, where the conductance is zero and the susceptance of the line is given as $b_{ij} = 1/\omega L_{ij}$. Susceptance is the measure of how much a circuit is *susceptible* to conducting an alternating current. Each transmission line connecting the busses are specified by its susceptance b_{ij} and by its maximum power flow limit $P_{ij}^{\max}$. The real power flow on Line $i-j$ can be written as

$$P_{ij} = b_{ij}(\theta_i - \theta_j) \quad \text{for } i, j = 1 \ldots n \tag{1}$$

where θ_i is the voltage angle at Bus i and, n is the number of buses. The total injection at Bus i is equal to the summation of the line flows and the load connected to the bus, that is,

$$P_{G,i} = \sum_j P_{ij} + P_{L,i} \tag{2}$$

If the net power injection to the ith bus is defined as $P_i \equiv P_{G,i} - P_{L,i}$, then, for each bus, we can write $P_i = \sum_j P_{ij}$. The total generated power needs to be equal to the total consumed power in a lossless transmission system; therefore, the