Electrical Power and Energy Systems 30 (2008) 563–568

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Congestion management by determining optimal location of TCSC in deregulated power systems

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ARTICLE INFO

Article history:
Received 29 July 2007
Received in revised form 18 June 2008
Accepted 15 August 2008

Keywords:
Congestion
Deregulated power system
Flexible AC transmission systems (FACTS)
Thyristor controlled series compensators (TCSC)

ABSTRACT

In a deregulated electricity market, it may always not be possible to dispatch all of the contracted power transactions due to congestion of the transmission corridors. The ongoing power system restructuring requires an opening of unused potentials of transmission system due to environmental, right-of-way and cost problems which are major hurdles for power transmission network expansion. Flexible AC transmission systems (FACTSs) devices can be an alternative to reduce the flows in heavily loaded lines, resulting in an increased loadability, low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement by controlling the power flows in the network. A method to determine the optimal location of thyristor controlled series compensators (TCSCs) has been suggested in this paper based on real power performance index and reduction of total system VAR power losses.

1. Introduction

In a competitive electricity market, congestion occurs when the transmission network is unable to accommodate all of the desired transactions due to a violation of system operating limits. Congestion does occur in both electrically bundled and unbundled systems but the management in the bundled system is relatively simple as generation, transmission, and in some cases, distribution systems are managed by one utility. The management of congestion is somewhat more complex in competitive power markets and leads to several disputes.

In the present day competitive power market, each utility manages the congestion in the system using its own rules and guidelines utilizing a certain physical or financial mechanism [1].

The limitations of a power transmission network arising from environmental, right-of-way and cost problems are fundamental to both bundled and unbundled power systems. Patterns of generation that result in heavy flows tend to incur greater losses, and to threaten stability and security, ultimately make certain generation patterns economically undesirable [2,3]. Hence, there is an interest in better utilization of available power system capacities by installing new devices such as flexible AC transmission systems (FACTS).

FACTS devices by controlling the power flows in the network without generation rescheduling or topological changes can improve the performance considerably [4–6]. The insertion of such devices in electrical systems seems to be a promising strategy to decrease the transmission congestion and to increase available transfer capability. Using controllable components such as controllable series capacitors line flows can be changed in such a way that thermal limits are not violated, losses minimized, stability margins increased, and contractual requirement fulfilled, without violating specific power dispatch. The increased interest in these devices is essentially due to two reasons. Firstly, the recent development in high power electronics has made these devices cost effective [7] and secondly, increased loading of power systems, combined with deregulation of power industry, motivates the use of power flow control as a very cost-effective means of dispatching specified power transactions. It is important to ascertain the location for placement of these devices because of their considerable costs.

There are several methods for finding optimal locations of FACTS devices in both vertically integrated and unbundled power systems [8–12]. In [8], a sensitivity approach based on line loss has been proposed for placement of series capacitors, phase shifters and static VAR compensators. Other works in optimal power flow with FACTS devices [9,10] have used optimization with different objective functions. In [13,14], the optimal locations of FACTS devices are obtained by solving the economic dispatch problem plus the cost of these devices making the assumption that all lines, initially, have these devices. In the presence of bilateral and multilateral contracts it would be difficult to use this objective.

Congestion in a transmission system, whether vertically organized or unbundled, cannot be permitted except for very short duration, for fear of cascade outages with uncontrolled loss of load. Some corrective measures such as outage of congested branch,

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doi:10.1016/j.ijepes.2008.08.007

using FACTS devices, operation of transformer taps, re-dispatch of generation and curtailment of pool loads and/or bilateral contracts can relieve congestion.

A method to determine the optimal location of TCSC has been suggested in this paper. The approach is based on the sensitivity of the reduction of total system VAR power loss and real power performance index. In Section 2 static modeling of TCSC is obtained. In Section 3 the objective function for using in OPF is presented. The optimal location is based on the minimizing the production and device cost. The proposed method has been demonstrated on two 5-bus systems. The results show that above algorithm is suitable for relieving congestion and getting economical results. Also at the end, line outage as a contingency analysis has been discussed.

2. Static modeling of TCSC

Fig. 1 shows a simple transmission line represented by its lumped π equivalent parameters connected between bus-i and bus-j. Let complex voltages at bus-i and bus-j are $V_i \angle \delta_i$ and $V_j \angle \delta_j$, respectively. The real and reactive power flow from bus-i to bus-j can be written as

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})] \quad (1)$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_{\text{sh}}) - V_i V_j [G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})] \quad (2)$$

where $\delta_{ij} = \delta_i - \delta_j$. Similarly, the real and reactive power flow from bus-j to bus-i is

$$P_{ji} = V_j^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_{ij}) - B_{ij} \sin(\delta_{ij})] \quad (3)$$

$$Q_{ji} = -V_j^2 (B_{ij} + B_{\text{sh}}) + V_i V_j [G_{ij} \sin(\delta_{ij}) + B_{ij} \cos(\delta_{ij})] \quad (4)$$

The model of transmission line with a TCSC connected between bus-i and bus-j is shown in Fig. 2. During the steady state the TCSC can be considered as a static reactance-jx_c. The real and reactive power flow from bus-i to bus-j, and from bus-j to bus-i of a line having series impedance and a series reactance are [15]

$$P_{ij}^c = V_i^2 G'_{ij} - V_i V_j (G'_{ij} \cos \delta_{ij} + B'_{ij} \sin \delta_{ij}) \quad (5)$$

$$Q_{ij}^c = -V_i^2 (B'_{ij} + B_{\text{sh}}) - V_i V_j (G'_{ij} \sin \delta_{ij} - B'_{ij} \cos \delta_{ij}) \quad (6)$$

$$P_{ji}^c = V_j^2 G'_{ij} - V_i V_j (G'_{ij} \cos \delta_{ij} - B'_{ij} \sin \delta_{ij}) \quad (7)$$

$$Q_{ji}^c = -V_j^2 (B'_{ij} + B_{\text{sh}}) + V_i V_j (G'_{ij} \sin \delta_{ij} + B'_{ij} \cos \delta_{ij}) \quad (8)$$

The active and reactive power loss in the line having TCSC can be written as

$$P_{\text{L}} = P_{ij} + P_{ji} = G'_{ij}(V_i^2 + V_j^2) - 2V_i V_j G'_{ij} \cos \delta_{ij} \quad (9)$$

$$Q_{\text{L}} = Q_{ij} + Q_{ji} = -(V_i^2 + V_j^2)(B'_{ij} + B_{\text{sh}}) + 2V_i V_j B'_{ij} \cos \delta_{ij} \quad (10)$$

where $G'_{ij} = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} - x_c)^2}$ and $B'_{ij} = \frac{-(x_{ij} - x_c)}{r_{ij}^2 + (x_{ij} - x_c)^2}$.

The change in the line flow due to series capacitance can be represented as a line without series capacitance with power injected at the receiving and sending ends of the line as shown in Fig. 3.

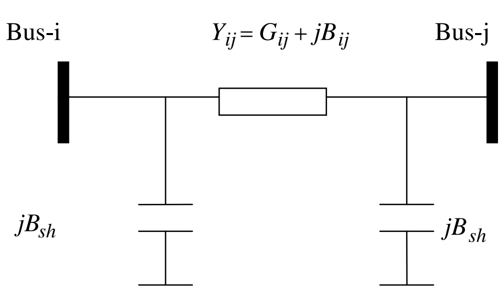

Fig. 1. Model of transmission line.

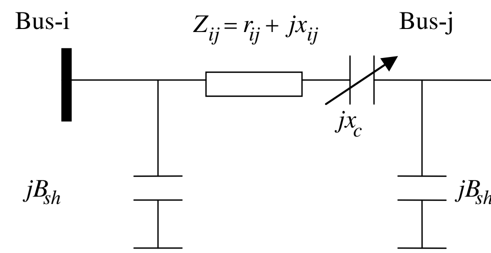

Fig. 2. Model of transmission line with TCSC.

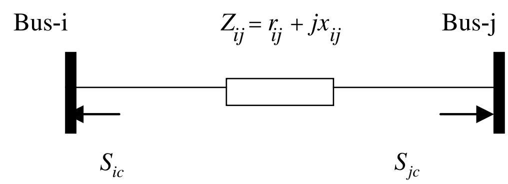

Fig. 3. Injection model of TCSC.

The real and reactive power injections at bus-i and bus-j can be expressed as

$$P_{ic} = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos \delta_{ij} + \Delta B_{ij} \sin \delta_{ij}] \quad (11)$$

$$P_{jc} = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos \delta_{ij} - \Delta B_{ij} \sin \delta_{ij}] \quad (12)$$

$$Q_{ic} = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij} \sin \delta_{ij} - \Delta B_{ij} \cos \delta_{ij}] \quad (13)$$

$$Q_{jc} = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij} \sin \delta_{ij} + \Delta B_{ij} \cos \delta_{ij}] \quad (14)$$

where $\Delta G_{ij} = \frac{x_c r_{ij}(x_c - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_c)^2)}$ and $\Delta B_{ij} = \frac{-x_c(r_{ij}^2 - x_{ij}^2 + x_c x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_c)^2)}$.

3. Objective function

Due to high cost of FACTS devices, it is necessary to use cost-benefit analysis to analyze whether new FACTS device is cost effective among several candidate locations where they actually installed. The TCSC cost in line-k is given by [16]

$$C_{\text{TCSC}}(k) = c \cdot x_c(k) \cdot P_{\text{L}}^2 \cdot \text{Base\_power} \quad (15)$$

where c is the unit investment cost of FACTS, $x_c(k)$ is the series capacitive reactance and P_L is the power flow in line-k.

The objective function for placement of TCSC will be

$$\min_{P_i} \sum_i C_i(P_i) + C_{\text{TCSC}}. \quad (16)$$

4. Optimal location of TCSC

4.1. Reduction of total system VAR power loss

Here, we look at a method based on the sensitivity of the total system reactive power loss with respect to the control variable of the TCSC. For TCSC placed between buses i and j we consider net line series reactance as a control parameter. Loss sensitivity with respect to control parameter of TCSC placed between buses i and j can be written as

$$a_{ij} = \frac{\partial Q_{\text{L}}}{\partial x_{ij}} = [V_i^2 + V_j^2 - 2V_i V_j \cos \delta_{ij}] \cdot \frac{r_{ij}^2 - x_{ij}^2}{(r_{ij}^2 + x_{ij}^2)^2} \quad (17)$$

4.2. Real power flow performance index sensitivity indices

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index [17], as given below