Electrical Power and Energy Systems 52 (2013) 68–80

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

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

A new method for secured optimal power flow under normal and network contingencies via optimal location of TCSC

ThanhLong Duong [a,b,*], Yao JianGang [a], VietAnh Truong [c]

[a] Department of Electrical Engineering, University of Hunan, Changsha, Hunan, China
[b] Department of Electrical Engineering, Industry University of Hochiminh City, Viet Nam
[c] Department of Electrical Engineering, University of Technical Education Hochiminh City, Viet Nam

ARTICLE INFO

Article history:
Received 15 October 2012
Received in revised form 12 March 2013
Accepted 28 March 2013
Available online 22 April 2013

Keywords:
FACTS
TCSC
OPF
SCOPF
Min cut and secured optimal power flow

ABSTRACT

In the deregulated power industry, private power producers are increasing rapidly to meet the increase demand. The purpose of the transmission network is to pool power plants and load centers in order to supply the load at a required reliability, maximum efficiency and at lower cost. As power transfer increases, the power system becomes increasingly more difficult to operate and insecure with unscheduled power flows and higher losses. FACTS devices such as Thyristor Controlled Series Compensator (TCSC) can be very effective to power system security. Proper location of TCSC plays key role in optimal power flow solution and enhancement of system performance without violating the security of the system. This paper applied min cut algorithm to select proper location of TCSC for secured optimal power flow under normal and contingencies operating condition. Proposed method requires a two-step approach. First, the optimal location of the TCSC in the network must be ascertained by min cut algorithm and then, the optimal power flow (OPF) with TCSC under normal and contingencies operating condition is solved. The proposed method was tested and validated for locating TCSC in Six bus, IEEE 14-, IEEE-30 and IEEE-118 bus test systems. Results show that the proposed method is good to select proper location of TCSC for secured OPF.

1. Introduction

With features of the new electricity market and the network structure are becoming more complex, the System Operators are facing many challenges in terms of system operation to obtain economic benefit and security. Various factors such as

- Upgrading of the generation and transmission systems has not been adequate with the increasing in load.
- The creation of electricity markets has led to the trading of significant amounts of electrical energy over long distances.
- The number of unplanned power exchanges increases due to the competition among utilities and contracts concluded directly between producers and consumers.

Made the level of security of power systems weakened. Hence, power system security [1] has become one of the most important issues in the electricity market operation. In these markets, security is measured through "system congestion" levels, which have a direct effect on market transactions and electricity prices, and are represented by means of power transfer limits on main transmission lines between operating areas [2]. Better market and system operating conditions may be achieved when system security and economy are better accounted. Solution of this problem is known as Security Constrained Optimal Power Flow (SCOPF).

The SCOPF [3] is an extension of the OPF problem [4] which is used to obtain an economical operation of the system while considering not only normal operating limits, but also violations that would occur during contingencies. The SCOPF changes the system pre-contingency operating point so that the total operating cost is minimized, and at the same time no security limit is violated if contingencies occur. Although the SCOPF are still challenges related to computations, it is expected that the SCOPF will eventually become a standard tool in the electricity industry [5].

Various approaches to approximate this region in OPF models have been proposed. For example, in [6] has proposed an algorithm for solving SCOPF problem through the application of evolutionary programming (EP). A new robust differential evolution algorithm for SCOPF considering detailed generator model is presented in [7]. Florin Capitanescu and Louis Wehenkel [8] has proposed a new iterative approach to the corrective SCOPF Problem. Ref. [9] has presented a approach to solve an optimal power flow problem with embedded security constraints represented

* Corresponding author at: Department of Electrical Engineering, University of Hunan, Changsha, Hunan, China. Tel.: +18 874191546.

E-mail addresses: thanhlong802003@yahoo.com (T. Duong), yaojiangan126@yahoo.com (Y. JianGang), vatruong05@gmail.com (V. Truong).

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http://dx.doi.org/10.1016/j.ijepes.2013.03.025

by a mixture of continuous and discrete control variables, where the major aim is to minimize the total operating cost, taking into account both operating security constraints and system capacity requirements. In [10] has proposed of DC SCOPF approximation to improve iterative AC SCOPF Algorithms. A novel approach to pricing the system security by parallelizing the Security Constrained Optimal Power Flow (SCOPF) based market-clearing model is presented in [11].

Power systems are commonly planned and operated based on the (n_1) security criterion [12]. As the power system becomes more complex, more heavily loaded and the unexpected outages, has created overloads on the existing transmission lines and lead to unstable system. In this case, re-dispatching generation [13] and load shedding [14] to eliminate/alleviate emergency transmission line overloads is an important problem in power system operation but may not be acceptable by both power providers and customers due to their significant effect on the existing power transaction contracts. The use of controllable flexible AC transmission system (FACTS) [15] to improve transfer capability and eliminate/alleviate congestion, while still be able to obtain minimal cost, is one of main current issues. However, it is indicated that the effectiveness of the controls for different purposes mainly depends on the location of control device [16]. Therefore, the real question is "which location should the System Operators place FACTS on in order to achieve a defined goal". Determining the bottleneck of power system plays key role in reducing search space and number of FACTS devices need to be installed. The presence of bottlenecks in the transmission line affects the total supply cost, limiting the cheapest plants and forcing the dispatching of more expensive generators [17]. The above problem can be strongly reduced if FACTS devices are suitably installed in the transmission system with the aim of redistributing real power flows.

Many algorithms have been proposed to enhance the static security via optimal location of FACTS devices. In [18], Differential evolution (DE) algorithm is used to find out the optimal placement and parameter setting of UPFC for enhancing power system security under single line contingencies. In order to evaluate the suitability of a given branch for placing a TCSC, two index called thermal capacity index (TCI) and contingency capacity index (CCI) [19] are used to obtain secured optimal power flow under normal and network contingencies. Ref. [20] has presented principles about installation and operation of FACTS devices to enhance the steady-state security of power system. Momoh et al. [21] has suggested the phase shifters for security enhancement and obtained the parameters using the optimal power flow formulation.

In this paper (TCSC), which is one of the most effective FACTS devices, is selected. The objective of this paper is to obtain secured OPF solution under normal operation and contingency condition through the optimal utilization of TCSC and therefore enhancing the system static security. Utilization of the TCSC during (n_0) and (n_1) overloads is investigated. This is done by opening one of more important lines that have larger effect on remaining of the line and considering the effect of opened line on remaining of the system. If there is congestion in the network, attempt to set the installed TCSC in such a way that the OPF solution obtained without any overloads on the lines under network contingencies is termed as secured OPF. In order to evaluate the suitable location of TCSC, a Min-cut algorithm has been proposed to decide optimal location of TCSC to obtain secured OPF. The proposed method can identify the weakest location of the system and therefore helps the System Operators to operate the system in a more secure and sufficient way. Using this method, the number of branches which need to be investigated to determine the position of TCSC for secured OPF will be significantly decreased.

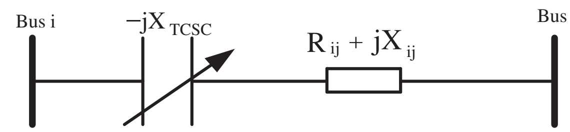

Fig. 1. Model of transmission line with TCSC.

2. Static modeling of TCSC

The effect of TCSC on the network can be seen as a controllable reactance inserted in the related transmission line [22]. Series capacitive compensation works by reducing the effective series impedance of the transmission line by canceling part of the inductive reactance. Hence the power transferred is increased. In this case study, TCSC only operates as a capacitor. The model of the network with TCSC is shown in Fig. 1. TCSC can be considered as a static reactance – jX_{TCSC} under steady state.

TCSC is integrated in the OPF problem by modifying the line data. The maximum compensation by TCSC is limited to 70% of the reactance of the un-compensated line where TCSC is located. A new line reactance (X_{new}) is given as follows.

$$X_{New} = X_{ij} - X_{TCSC} \tag{1}$$

$$X_{New} = (1 - L)X_{ij} \tag{2}$$

where $L = X_{TCSC}/X_{ij}$ is the degree of series compensation and X_{ij} is the line reactance between bus-i and bus-j.

The power flow equations of the line with a new reactance can be derived as follows.

$$P_{ij} = V_i^2 G_{ij} - V_i V_j (G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij}) \tag{3}$$

$$Q_{ij} = -V_i^2 B_{ij} - V_i V_j (G_{ij} \sin\delta_{ij} - B_{ij} \cos\delta_{ij}) \tag{4}$$

$$P_{ji} = V_j^2 G_{ij} - V_i V_j (G_{ij} \cos\delta_{ij} - B_{ij} \sin\delta_{ij}) \tag{5}$$

$$Q_{ji} = -V_j^2 B_{ij} + V_i V_j (G_{ij} \sin\delta_{ij} + B_{ij} \cos\delta_{ij}) \tag{6}$$

where δ_{ij} is the voltage angle difference between bus i and bus j

$$G_{ij} = \frac{R_{ij}}{R_{ij}^2 + X_{New}^2} \quad \text{and} \quad B_{ij} = \frac{X_{New}}{R_{ij}^2 + X_{ij}^2}$$

3. Problem formulation

The OPF is a constrained optimization problem that requires minimization of an objective function. One of the possible objectives of OPF is the minimization of the power generation cost subject to the satisfaction of the generation and load balance in the transmission network as well as the operational limits and constraints of the generators and the transformers [23]. The OPF is generally expressed in mathematical form as:

$$\min f(x,u) \tag{7}$$

Subject to

$$g(x,u) = 0 \tag{8}$$

$$h(x,u) \leqslant 0 \tag{9}$$

where $f(x,u)$ is the objective function. The equality constraints (8) are the power flow equations, while the inequality constraints (9) are due to various limitations. The limitations include lower and upper limits on generator real and reactive powers limits on voltage magnitudes, line and transformer maximum currents, and sets of