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Use of transmission line having SPFC for alleviation of line over load of transmission line of an interconnected power system

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ABSTRACT

This paper describes a method for alleviation of line over load in a line by regulation power flow in another line having Series Power Flow Controller (SPFC). For this purpose, the sensitivity relations between the line flow of the line with SPFC and the over loaded line are determined. These sensitivity relations are used to determine the required amount of change in power flow at the line with SPFC to reduced power flow of the over loaded line. IEEE 30 system is used to verify the applicability of the proposed method.

Introduction

The tremendous growth in electrical power demand accelerated the process of expansion of power system both in the generation level and transmission level. To meet the ever growing power demand, high power generating stations, such as super thermal power stations, nuclear power stations and Mega Hydal power stations were installed. In addition to this, the emerging de-regulated environment and open access in an electricity market, power system planning and operation need to address several aspects pertaining to participation of Independent Power Producer (IPP), Transmission System Provider and Distribution System Management, subjected to operational constraints – such as, maintenance of voltage profile, power frequency level, harmonics level and operating limits of transmission line(s). The transmission facilities are being overused owing to the higher industrial demands and deregulation of the power supply industry. Thus there is a need for exploring new ways for maximizing the power transfer capability of existing transmission facilities while, at the same time, maintaining acceptable levels of network reliability and stability. It is envisaged that a new solution to such operational problems will rely on the upgrading of existing transmission corridors by using the latest power electronic equipment and methods, a new technological philosophy that comes under the generic title of Flexible AC Transmission Systems (FACTS) – an acronym for flexible alternating current transmission systems. The FACTS controllers provide the most useful means and thus are used in regulating the power flows, maintaining transmission voltages within limits and mitigate the dynamic disturbance.

The Unified Power Flow Controller (UPFC) model has been incorporated into an existing FACTS Newton–Raphson load flow algorithm. Critical comparisons are made against existing UPFC models, which show the newly developed model to be far more flexible and efficient [1,2]. In thyristor controlled series compensator (TCSC) incorporated power system [3]; the state variable is the TCSC's firing angle, which is combined with the nodal voltage magnitudes and angles of the entire network in a single frame-of-reference for a unified iterative solution through a Newton–Raphson method. Unlike TCSC models, this model takes account of the loop current that exists in the TCSC under both partial and full conduction operating modes [4]. A versatile mathematical model of a UPFC in a single machine infinite bus system is proposed in literatures [5]. The model consists of a simple voltage source whose magnitude and angle depend on the UPFC control parameters. The existing transmission lines get congested due to availability of cheaper power, increased of system loads, incorporation of large number of private power producers, etc. New transmission lines may be added to avoid such congestion, which may not be economically viable. Using FACTS devices in the existing line(s) power flow may be regulated to avoid network congestion. For last two decades researchers developed new algorithms and models for power flow and optimal power flow incorporating FACTS devices so that cheap power can be made available to the customers without violating system stability. Still research is in progress to meet the present day congestion management problem with help of

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Nomenclature

Symbols

N	number of buses in the power system
P_{Gi}	real power generation at ith bus
Q_{Gi}	reactive power generation at ith bus
P_{Di}	real load at ith bus
Q_{Di}	reactive load at ith bus
P_i	real power injection at ith bus
Q_i	reactive power injection at ith bus
V_i	voltage magnitude of ith bus
V_j	voltage magnitude of jth bus
δ_i	voltage phase angle of ith bus
δ_j	voltage phase angle of jth bus
$G_{ij} + j\,B_{ij}$	element of Y-Bus matrix at ith row and jth column
P_{ij}	real power flow for the line connected between ith and jth buses
Q_{ij}	reactive power flow for the line connected between ith and jth buses
P_{ij}^{sch}	scheduled real power flow for the line connected between ith and jth buses for line with SPFC
Q_{ij}^{sch}	scheduled reactive power flow for the line connected between ith and jth buses for line with SPFC
$g_{ij} + j\,b_{ij}$	admittance of line connected between ith and jth buses
V_s	voltage magnitude of SPFC of the line with SPFC
θ_s	voltage phase angle of SPFC of the line with SPFC

FACTS devices efficiently [6]. Capitanescu and Van Cutsem [7] have proposed simple sensitivities to analyze unstable or low voltages caused by increased loads in the transmission lines. A generalized model of the modified power system, when FACTS devices have been incorporated is proposed in [8]. The FACTS devices only have influence on the vicinity where it is placed. A sensitivity analysis with respect to the settings of the device is used to identify the area of influence [9,10]. Lashkar Ara et al. [10] proposed a multi objective optimization approach to find the optimal location of FACTS devices. The objective is to find the minimum fuel cost, power losses and system loadability with and without minimum cost of FACTS installation costs. Flexible AC transmission systems, so-called FACTS devices, can help reduce power flow on overloaded lines, which would result in an increased loadability of the power system, fewer transmission line losses, improved stability and security and, ultimately, a more energy-efficient transmission system [11,12]. Since current limitation is major constraint for FACTS design, a current based model (CBM) is proposed in [13]. This model assumes the current as variable, which allows easy manipulation of the current restriction in optimal power flow evaluation. Accurate prediction of power system state has significant importance specially in bidding strategies, risk management and operational decisions. Consideration of this matter is very important, especially in systems with large penetration of renewable energies such as wind powers. The effect of the most versatile flexible alternative current transmission systems (FACTS) devices unified power flow controller (UPFC) on predictability of power system state has been studied. For this purpose, predictability indices are used which can quantify the ability of system prediction [14].

The work proposed in this paper aims at using a transmission line with SPFC device to alleviate line over load in a transmission line around its vicinity. For this purpose, the sensitivity relations between the line flow of the line with SPFC and the over loaded line are determined. These sensitivity relations are used to determine the required amount of change in power flow along the line with SPFC to reduced power flow of the over loaded line.

Load flow model for an interconnected power system

The expression for real and reactive power injections at ith bus of an interconnected power system (without any SPFC device) can be represented as:

$$P_i = \sum_{j=1}^{N} |V_i||V_j|\big(G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})\big) \quad \text{for } i = 1,\ldots,N \tag{1}$$

$$Q_i = \sum_{j=1}^{N} |V_i||V_j|\big(G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})\big) \quad \text{for, } i = 1,\ldots,N \tag{2}$$

For the convenience of representation the load flow Jacobian matrix, bus 1 is considered as a slack bus for an interconnected power system. Load flow Jacobian matrix for an interconnected power system is related to change in voltage and phase angle to change in real and reactive power injections as follows:

$$\begin{bmatrix}
\frac{\partial P_2}{\partial \delta_2} & \cdots & \frac{\partial P_2}{\partial \delta_k} & \frac{\partial P_2}{\partial \delta_m} & \cdots & \frac{\partial P_2}{\partial \delta_N} & \frac{\partial P_2}{\partial V_2} & \cdots & \frac{\partial P_2}{\partial V_k} & \frac{\partial P_2}{\partial V_m} & \cdots & \frac{\partial P_2}{\partial V_N} \\
. & \cdots & . & . & \cdots & . & . & \cdots & . & . & \cdots & . \\
. & \cdots & . & . & \cdots & . & . & \cdots & . & . & \cdots & . \\
\frac{\partial P_k}{\partial \delta_2} & \cdots & \frac{\partial P_k}{\partial \delta_k} & \frac{\partial P_k}{\partial \delta_m} & \cdots & \frac{\partial P_k}{\partial \delta_N} & \frac{\partial P_k}{\partial V_2} & \cdots & \frac{\partial P_k}{\partial V_k} & \frac{\partial P_k}{\partial V_m} & \cdots & \frac{\partial P_k}{\partial V_N} \\
\frac{\partial P_m}{\partial \delta_2} & \cdots & \frac{\partial P_m}{\partial \delta_k} & \frac{\partial P_m}{\partial \delta_m} & \cdots & \frac{\partial P_m}{\partial \delta_N} & \frac{\partial P_m}{\partial V_2} & \cdots & \frac{\partial P_m}{\partial V_k} & \frac{\partial P_m}{\partial V_m} & \cdots & \frac{\partial P_m}{\partial V_N} \\
. & \cdots & . & . & \cdots & . & . & \cdots & . & . & \cdots & . \\
. & \cdots & . & . & \cdots & . & . & \cdots & . & . & \cdots & . \\
\frac{\partial P_N}{\partial \delta_2} & \cdots & \frac{\partial P_N}{\partial \delta_k} & \frac{\partial P_N}{\partial \delta_m} & \cdots & \frac{\partial P_N}{\partial \delta_N} & \frac{\partial P_N}{\partial V_2} & \cdots & \frac{\partial P_N}{\partial V_k} & \frac{\partial P_N}{\partial V_m} & \cdots & \frac{\partial P_N}{\partial V_N} \\
\frac{\partial Q_2}{\partial \delta_2} & \cdots & \frac{\partial Q_2}{\partial \delta_k} & \frac{\partial Q_2}{\partial \delta_m} & \cdots & \frac{\partial Q_2}{\partial \delta_N} & \frac{\partial Q_2}{\partial V_2} & \cdots & \frac{\partial Q_2}{\partial V_k} & \frac{\partial Q_2}{\partial V_m} & \cdots & \frac{\partial Q_2}{\partial V_N} \\
. & \cdots & . & . & \cdots & . & . & \cdots & . & . & \cdots & . \\
. & \cdots & . & . & \cdots & . & . & \cdots & . & . & \cdots & . \\
\frac{\partial Q_k}{\partial \delta_2} & \cdots & \frac{\partial Q_k}{\partial \delta_k} & \frac{\partial Q_k}{\partial \delta_m} & \cdots & \frac{\partial Q_k}{\partial \delta_N} & \frac{\partial Q_k}{\partial V_2} & \cdots & \frac{\partial Q_k}{\partial V_k} & \frac{\partial Q_k}{\partial V_m} & \cdots & \frac{\partial Q_k}{\partial V_N} \\
\frac{\partial Q_m}{\partial \delta_2} & \cdots & \frac{\partial Q_m}{\partial \delta_k} & \frac{\partial Q_m}{\partial \delta_m} & \cdots & \frac{\partial Q_m}{\partial \delta_N} & \frac{\partial Q_m}{\partial V_2} & \cdots & \frac{\partial Q_m}{\partial V_k} & \frac{\partial Q_m}{\partial V_m} & \cdots & \frac{\partial Q_m}{\partial V_N} \\
. & \cdots & . & . & \cdots & . & . & \cdots & . & . & \cdots & . \\
. & \cdots & . & . & \cdots & . & . & \cdots & . & . & \cdots & . \\
\frac{\partial Q_N}{\partial \delta_2} & \cdots & \frac{\partial Q_N}{\partial \delta_k} & \frac{\partial Q_N}{\partial \delta_m} & \cdots & \frac{\partial Q_N}{\partial \delta_N} & \frac{\partial Q_N}{\partial V_2} & \cdots & \frac{\partial Q_N}{\partial V_k} & \frac{\partial Q_N}{\partial V_m} & \cdots & \frac{\partial Q_N}{\partial V_N}
\end{bmatrix}
\times
\begin{bmatrix} \partial\delta_2 \\ . \\ . \\ \partial\delta_k \\ \partial\delta_m \\ . \\ . \\ \partial\delta_N \\ \partial V_2 \\ . \\ . \\ \partial V_k \\ \partial V_m \\ . \\ . \\ \partial V_N \end{bmatrix}
=
\begin{bmatrix} \Delta P_2 \\ . \\ . \\ \Delta P_k \\ \Delta P_m \\ . \\ . \\ \Delta P_N \\ \Delta Q_2 \\ . \\ . \\ \Delta Q_k \\ \Delta Q_m \\ . \\ . \\ \Delta Q_N \end{bmatrix} \tag{3}$$

where

$$\Delta P_i = P_{Gi} - P_{Di} - P_i$$

$$\Delta Q_i = Q_{Gi} - Q_{Di} - Q_i$$

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{\substack{j=1 \\ i\neq i}}^{N} V_i V_j\big(-G_{ij}\sin(\delta_{ij}) + B_{ij}\cos(\delta_{ij})\big) \quad \text{for } i = 2,\ldots,N$$

$$\frac{\partial P_i}{\partial \delta_j} = V_i V_j\big(G_{ij}\sin(\delta ij) - B_{ij}\cos(\delta_{ij})\big) \quad \text{for } j = 2,\ldots,N,\ i \neq j$$

$$\frac{\partial P_i}{\partial V_i} = 2G_{ii}V_i + \sum_{\substack{j=1 \\ i\neq i}}^{N} V_j\big(G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})\big) \quad \text{for } i = 2,\ldots,N$$

$$\frac{\partial P_i}{\partial V_j} = V_i\big(G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})\big) \quad \text{for } j = 2,\ldots,N,\ i \neq j$$

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{\substack{j=1 \\ i\neq i}}^{N} V_i V_j\big(G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})\big) \quad \text{for } i = 2,\ldots,N$$

$$\frac{\partial Q_i}{\partial \delta_j} = -V_i V_j\big(G_{ij}\sin(\delta_{ij}) + B_{ij}\cos(\delta_{ij})\big) \quad \text{for } j = 2,\ldots,N,\ i \neq j$$