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Approach to Optimum Power Flow Problems using FACTS Devices

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Abstract: FACTS devices (SVC, TCSC) are used for controlling transmission voltage, power flow, reducing reactive losses, and damping of power system oscillations for high power transfer levels. In this paper, the mathematical techniques have been employed for optimal solution of power flow using FACT controller devices. Effect of change in reliability evaluation of power generation and transmission to estimate the ability of the system to perform its function of moving the energy provided by the generating system. This paper presents different types of FACTS devices and their benefits for transmission in electrical power system.

Keywords: FACTS Devices, OPF, Transmission systems.

I. INTRODUCTION

The first person to introduce the concept of Optimal Power Flow problem (OPF) was Carpentierin the year1962 [1]. OPF is a very large, non linear mathematical programming problem; it has taken decades to develop efficient algorithms for its solution . Many different mathematical techniques have been employed in the past for its solution .One can find an excellent literature survey of different techniques for solving OPF problem in [4]. Over 150 papers on the optimal power flow problem covering all the methods for solving the OPF has been explained in [4]. In recent years, intelligent techniques inspired by nature, such as Genetic Algorithm (GA), Differential Evolution Algorithm (DE), Particle Swarm Optimization (PSO), Simulated Annealing (SA) and Harmony Search (HS) have been the research focus for solving OPF problem. These techniques have been successfully applied for solving OPF problem.

Over the years, many methods have been proposed to model and analyze power systems with embedded FACTS controllers in steady state. This kind of analysis has been applied with different purposes, for instance, sensitivity analysis , optimal power system operation based on technical or economical considerations, sizing of different kind of devices , planning and allocation of such devices , dispatch analysis, voltage stability analysis or state estimation [1]. To give a common modelling framework for power flow calculations in power systems with embedded FACTS devices. The proposed method uses the node incidence matrix to avoid the problems derived from the widely used admittance matrix.

Further, in competitive electricity markets, generators compete to sell more power and consumers try to buy the most economical energy for more profit. However, the transmission network, as a medium between power generation and consumption centres, has a limited capacity as well as its own security concerns. Congestion in electricity markets occurs when the transmission network is unable to accommodate all of market desired transactions due to some violations in its operating limits [2]. Congestion in electricity markets, if not controlled, can lead to market power and oligopoly. Congestion management, the action of controlling the transmission system to observe its transfer limits, is perhaps the fundamental transmission management problem. Then, System Operator (SO), which is the responsible agency to keep the electricity market competitive and secure, should mitigate congestion using available facilities and/or market-based tools.

Moreover, in the present day scenario, due to increase in power demand, restriction on the construction of new lines, environment, unscheduled power flow in lines creates congestion in the transmission network and increases transmission loss. Effective control of reactive compensation on weak nodes improves voltage profile, reduces power loss and improves both steady state and dynamic performance of the system. With the development of FACTS devices, it has now become an obvious choice to use them in today's power system to extract maximum advantage out of it. The concept of flexible AC transmission system (FACTS) was first introduced by Hingorani [3]. For this, various optimization techniques including Fuzzy Logic (FL) is used for the optimal setting of power system variables, including Flexible AC Transmission Systems (FACTS) devices.

Power transfer limits and directions in transmission system are constrained by thermal capacities of transmission lines (i.e., the material of the line) and voltage magnitude and voltage angle deviations across the line. In case of short lines the first limit that is typically reached is the thermal limit of the line governed by material of the line. In case of medium length lines the voltage magnitude at the receiving end reaches the statuary lower limit, i.e., drops typically below 0.9 p.u. or 0.95 p.u. (limit varies depending on voltage level and country), before the thermal limit of the line is reached and such limits further increase in power transfer. This is generally referred to as voltage stability limit which, if exceeded, might lead to improper operation or disconnection of end-user devices and ultimately to wide spread black-outs. Finally, in case of long transmission lines, voltage angle at the receiving end is the first that hits the limit and restricts further increase in power transfer due to endangered angular stability of the system.

The thermal limits of the line are most difficult to alleviate as this would require change of material of the line (new conductors). Voltage and stability limits, however, could be increased by modifying line impedance and admittance and additional control of voltages and currents. FACTS devices offer possibility to influence line parameters (series and shunt impedances) and currents and voltages across the line and such increase allowed power transfer over existing lines without endangering system security [4].

FACTS devices installed in existing power systems have been successfully used for several purposes including congestion management, reactive power support and enhancement of system damping. Their use has been evolving ever since the Electric Power Research Institute (EPRI) introduced this technology, in 1980s. Several studies, based on OPF calculations, were carried out to determine the optimal placement of such devices in the system in order to get the most out of their capabilities. Some of the previous studies took into account the cost of FACTS devices as well, and showed that they could be a cost effective solution. Generally, there are still very few studies of economic benefits arising from installation of FACTS devices.

II. OPTIMUM POWER FLOW

OPF is a very large, non linear mathematical programming problem; it has taken decades to develop efficient algorithms for its solution . Many different mathematical techniques have been employed in the past for its solution.

A. FACTS Controller:

Present-day power systems are highly complex and widespread and operating much closer to their breakdown limits due to economical, environmental, political, and technical factors. This scenario makes the power systems more vulnerable to stability and security problems. Voltage stability has been recognized as one of these concerns and is referred to the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and/or after being subjected to a disturbance. The FACTS technology has provided the power system greater control of power, secure loading of transmission lines, greater ability to transfer power, prevention of cascading outages and damping of power system oscillations. Among the important FACTS controllers, SVC and TCSC are most suitable for the voltage control. This paper considers the steady state models of SVC and TCSC controllers in OPF formulation which are discussed in the following section.

1. Static Var Compensator

Static var compensators have been extensively used in power system applications to provide the controlled reactive power and voltage stability improvement. The SVC firing angle model has been used here for optimal power flow analysis [5].

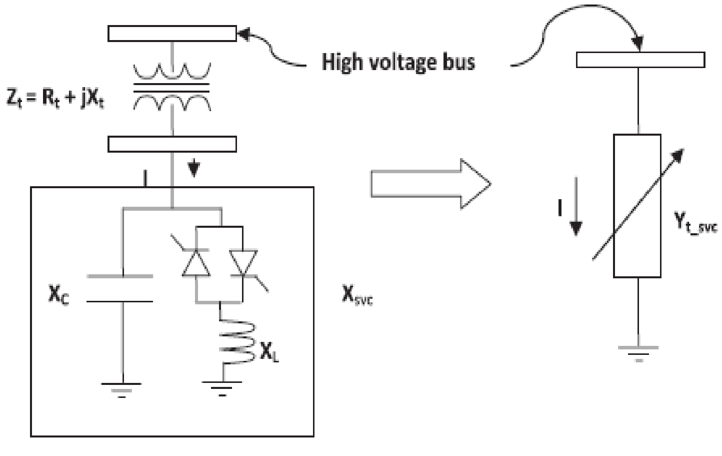

Fig 1. SVC connected to the transmission network via a stepdown transformer[5]

2. Thyristor controlled series compensator

TCSC is one of the most popular FACTS controllers, which allows rapid and continuous modulation of the transmission line impedance. Active power flow along compensated transmission line can be maintained at a specified value under a range of operating conditions. Figure 2 shows a schematic representation of TCSC which consists of a series capacitor in parallel with a thyristor controlled reactor (TCR). TCSC modifies the line reactance in order to control the power flow through the line [5].

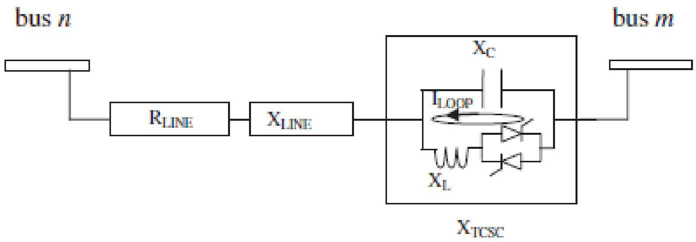

Fig 2. TCSC connected between bus n and m [5]

B. Congestion Management:

Congestion management, the action of controlling the transmission system to observe its transfer limits, is perhaps the fundamental transmission management problem. Different FACTS devices, used for congestion management are:

1. Priority list to determine the best locations of series FACTS devices:

In case of congestion in the market, the LMP (Locational Marginal Prices) in each bus may differ. The difference between LMPs of two terminal buses of a branch can be a measure of congestion on that branch. In other words, a larger LMP difference in terminals of a branch means a high level of congestion (this claim is confirmed below mathematically). Thus, the LMP difference can be used to find the most congested branches as the best locations to install series FACTS devices to improve the transfer capability of the most congested branches. It is noted that bus LMPs are a byproduct of the OPF optimization solution and they are determined after solving the OPF. The spot or nodal price of each bus (qi) is composed of three components, the marginal energy component (λ), the marginal loss component ($\lambda_{Loss,i}$), and the marginal congestion ($\lambda_{Con,i}$) as follows:

$$\rho_i = \lambda + \lambda_{Loss,i} + \lambda_{Con,i} \qquad (1)$$

where λ is the marginal energy component at the reference bus and it is the same for all buses [2]. Then, nodal price differences between two buses across branch i–j can be written as:

$$\rho_{ij} = \rho_i - \rho_j = (\lambda_{Loss,i} - \lambda_{Loss,j}) + (\lambda_{Con,i} - \lambda_{Con,j}) \qquad (2)$$

The LMP difference across a branch indicates the congestion level of that branch. As a result, branches with higher LMP differences can be assumed more congested and all branches can be sorted from congestion level point of view. The most preferred branches to locate series FACTS device are ones with the higher level of congestion: we get more benefit by installing the same FACTS device at a more congested branch. This can be used to construct a priority list of branches to locate the series FACTS device to mitigate congestion.

2. Modelling of TCSC:

Different models can be used for TCSC as a series FACTS device depending on the application and study. Locating TCSC along a transmission line changes the related entries in the network admittance matrix. However, some techniques are available to model TCSC without altering the original admittance matrix. One of the models, widely used in steady state applications of TCSC, is the power injection model. the TCSC in the power injection model is represented by four injected powers as follows:

$P_i^{TCSC}, Q_i^{TCSC}, P_j^{TCSC}, Q_j^{TCSC}$

Using the power injection model, the original lumped π equivalent circuit (before installing TCSC) of the transmission branch i–j can be modified with added equivalent power injections resulted from TCSC.

C. Reliability Evaluation of Power Generation and Transmission:

The purpose of assessing the reliability of a composite power generation and transmission system is to estimate the ability of the system to perform its function of moving the energy provided by the generating system to the bulk supply points. Reliability evaluation of composite generation and transmission systems is an important area of concern for system planners and operators [6]. Reliability assessment of power system is performed in the two distinct domains of adequacy and security. System adequacy relates to the existence of sufficient generation, transmission and distribution facilities within the system to satisfy the customer load demand. System security, relates to the ability of the system to respond to disturbances arising within the system.

There is relatively very little literature that considers FACTS as a component in composite system reliability evaluation. FACTS is a new upgraded power electronics technology that can increase the use-capacity of existing transmission and distribution assets of power systems. The conventional dc flow-based linear programming model used in composite system reliability evaluation method is converted into a non-linear optimization model to include the impact of FACTS devices on reliability of power system.

DC load flow-based linear programming model is widely used in composite power system reliability evaluation.

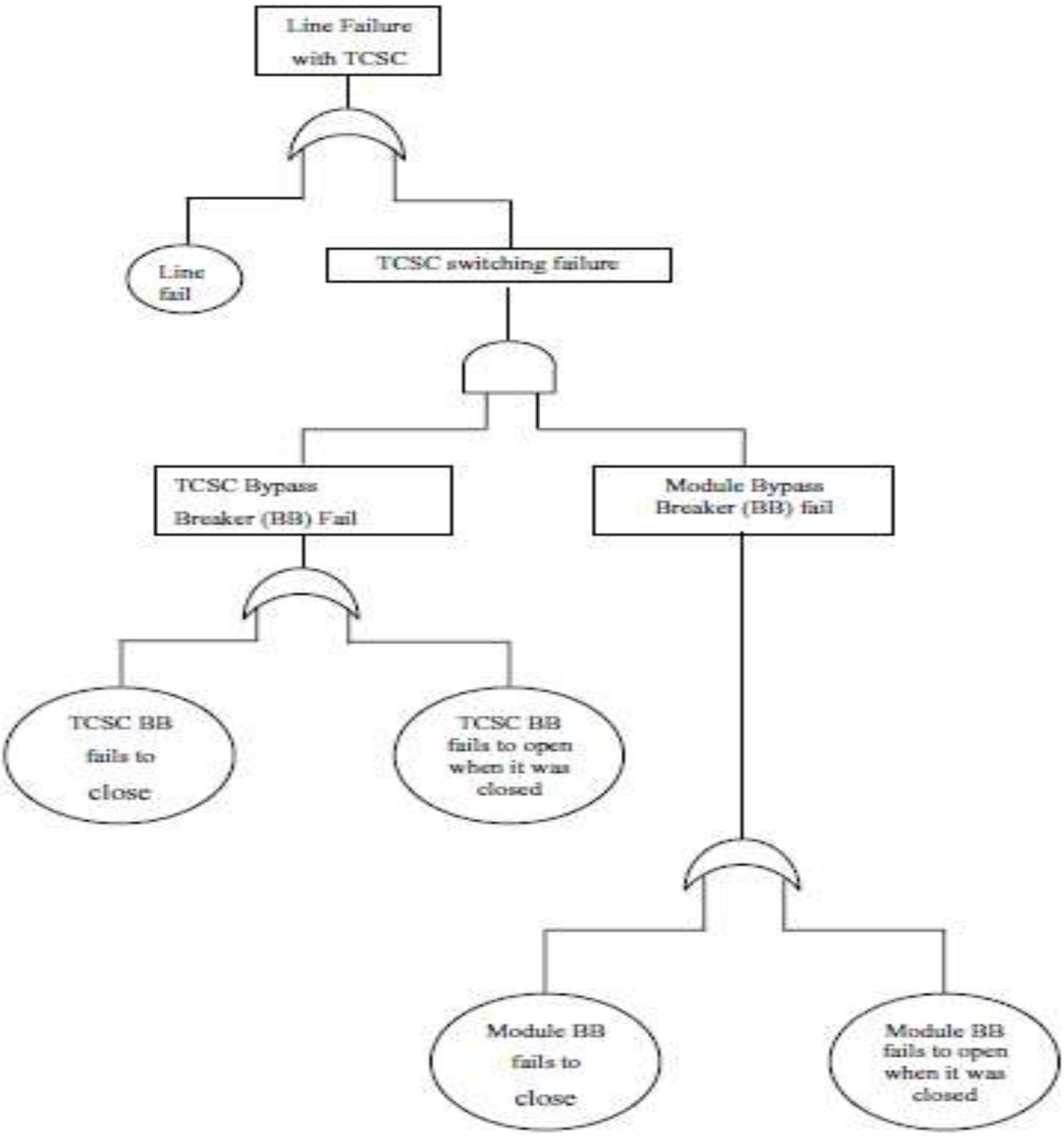

Fig 3 Line Failure Probability using Fault Tree Analysis

The objective of this evaluation is to minimize the system load. It can be formulated as follows:

$$\text{Min } Z = E \qquad (3)$$

III. COST AND BENEFITS OF FACT DEVICES

FACTS devices are becoming environmentally friendly. FACTS devices does not produce any type of waste hazard material so they are pollution free. These devices help us to deliver the electrical power more economically with better use of existing transmission lines while reducing the cost of new transmission line and generating more power. The basic technical benefits of the FACTS devices include:

(a) Problems of voltage limit
(b) Addressing in steady state applications
(c) Problems of thermal limits,
(d) Problems short circuit levels and
(e) Problems of sub-synchronous resonance

CONCLUSION

Due to increase in power demand, environmental considerations, recent trends in deregulation of electric utility require more effective use of transmission and generation systems. In this context, FACTS technology has achieved rapid advances to meet such objectives, and many FACTS devices such as static var compensator, thyristor controlled series compensation (TCSC), and power flow controller has been developed. In addition to this, an optimization model is proposed to use in composite power system reliability evaluation incorporating the impact of TCSC. The developed models and the results presented in this paper would be useful to power system planners for future expansion of system using FACTS technologies

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