Literature Survey on Application of Thyristor Controlled Series Compensator (TCSC) in Power Flow Analysis

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Abstract* - This paper presents a literature survey on application of TCSC in power flow analysis. A case study is carried out on the role of Thyristor Controlled Series Compensator (TCSC) in the improvement of power transfer in transmission network. The paper underlines the research done on power flow analysis incorporating TCSC. The paper discusses the about the power flow analysis using Thyristor Controlled Series Compensator (TCSC) which can be characterized in different models. Literature review is presented on basis of the various aspects of power flow analysis using FACTS devices Thyristor Controlled Series Compensator (TCSC).

Keywords: Power flow analysis, FACTS devices, Thyristor Controlled Series Compensator.

I. INTRODUCTION

The power flow analysis is very important method of studying the different aspects of transmission system in a very efficient manner. The power flow analysis is also applied to power system to evaluate the cost of power system. At present it became necessary to meet the demand and supply power of good quality thus operating the transmission system at threshold limits. Now as the system becomes more and more complicated the problem of solving these complications rises [2]. The power flow analysis needs the system parameters which are represented by set of non-linear equations to solve the technical problems of the transmission system. Methods for example Newton-Raphson method, Gauss-Seidal method, and fast-decoupled method can be used for solving the given system equations. The required data for power system analysis is given by the comparison of the present system quantities utilizing nominal equipment's and FACTS devices. Using FACTS devices the increased power flow and voltage stability can be achieved in transmission system. Also the consequence of change in system can be predicted. The working of power system beneath variations of factors like interconnecting line loads, generator load, network configuration, addition of bus, can be studied using power flow analysis [4].

The concept of exercising power electronic based converters and solid state converters for controlling the characteristics such as voltage and angle profile, power flow, series and shunt impedance of power system is known as Flexible Alternating Current Transmission System (FACTS) [1]. With increasing requirement of electrical energy the old-fashioned methods of increasing power flow in transmission system is substituted with Flexible AC Transmission System (FACTS). The fundamental theory of FACTS technology is based on the idea of the transmission of power over long distance in cost-effective and economical manner by controlling various constraints of transmission system. The first presentation and application of first generation of FACTS devices were pioneered in Nebraska in 1974 [1]. FACTS controllers can be classified as: 1. Shunt type Controllers- Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), 2.Series type Controllers - Thyristor Controlled Series Compensator (TCSC), Thyristor Switched Series Reactor (TSSR), 3. Series and Series type Controllers - Static Synchronous series Compensator (SSSC), Interline Power Flow Controller (IPFC), and 4. Series and Shunt type Controllers - Unified Power Flow Controller (UPFC). These classifications of FACTS controllers show that all series type devices inject voltage in series with line and all shunt type devices inject current into the system at the point of connection [3]. The advantage of FACTS devices is that they increase the stability of transmission system by increasing the transfer capability of transmission lines. Also they help in providing the continuous power supply by minimizing the chances of voltage drop and frequency deviation. FACTS devices are eco-friendly and flexible by decreasing the requirement of new transmission line for improved power supply and also by reducing the installation time.

Thyristor Controlled Series Compensator (TCSC) is an important FACTS device which allows constant and continuous variation in transmission line parameters. TCSC is used to control the real power flow or the line current or the voltage or the angle in transmission line. TCSC comprise Thyristor Controlled Reactor (TCR) as a variable reactor connected in parallel with a series capacitor bank which makes a capacitive reactance compensator to control a smoothly variable series capacitor reactance in transmission line. Different network parameters are needed for power flow analysis using TCSC therefore some modelling techniques of TCSC are variable impedance modelling, firing angle modelling and power flow modelling [1].

This paper presents the literature survey on role of TCSC in power flow analysis for improving the efficiency of transmission system. The paper underlines the research done on power flow analysis incorporating TCSC. In power flow analysis Thyristor Controlled Series Compensator (TCSC) can be characterized in different models as discussed in next section.

II. CASE STUDY

In this section the literature survey is discussed on basis of the various aspects of power flow analysis using FACTS devices Thyristor Controlled Series Compensator (TCSC):

T. Overbye and D. Brown in [2], describes about the use of FACTS devices for power system stability enhancement. The author first discussed about the necessity of FACTS devices in transmission system. The paper is about the control of devices in transmission system network. It is made clear that with the development of analytic tools to improve the voltage stability of power system the system if becoming more and more difficult. The paper introduces a simple two bus system incorporating TCSC to understand the problem of voltage stability. The solution is drawn in graph to show the base case, after contingency and after TCSC with respect to reactive power load and real power load at the respected bus. Also the cross section view of parameter space is presented with respect to voltage magnitude and MVA load. The dynamic effects of TCSC switching and the method are demonstrated on IEEE 118 bus system. Enhancement of transient stability is also discussed.

The author in [3] discussed about the use of FACTS devices for power flow control and power flow studies for transmission system. The paper describes the types of FACTS device models based on parameter controlled by a particular device. The Jacobian matrix and power flow analysis convergence using the Newton-Raphson method in the presence of FACTS devices is shown with the required modifications in matrix structure. Due to the addition of FACTS devices in transmission network some losses also occur. The paper discusses about the standard rules of proper siting of FACTS devices. The paper illustrates the modelling of FACTS devices with the help of examples where the study is presented using a model based on actual interconnections. Also the advantages and disadvantages of FACTS devices are tabulated.

In [4] the author Xie Da et.al presents an algorithm to control the power in large systems using TCSC. The paper describes the modified equations of power flow for analysis of system using Newton algorithm when TCSC is installed at the exit of the bus and in middle of the line. The Newton algorithms for the improvement of current inflow when TCSC is operating are also proposed in the model. The power flow control expressions for two conditions of line with TCSC installed at exit of bus and when place in middle of the line are discussed.

C. R. Fuerte-Esquivel et.al in [5] describes about the power flow study of practical power networks employing TCSC model. Author introduces a modern power flow model for TCSC. In this model firing angle is taken as state variable to obtain the required compensation to get the specified real power flow. The model is incorporated with the Newton-Raphson algorithm to solve the large power networks reliably. The paper presents a model where TCSC firing angle is combined with the nodal voltage magnitudes and angles. The comparison of TCSC equivalent reactances is carried out to show the effect of capacitor stored charge. The power mismatch and TCSC parameter values are tabulated for 2172 node system. TCSCs are mainly designed to show a single resonant point.

In [6] the paper presents the power flow method using full Newton-Raphson algorithm for system having equipment and control of ULTC transformer tap control, voltage control, HVDC link control, TCSC to control real power flow or line current, SVC to provide reactive power utilized to improve the operating demand of power system. The paper demonstrates the statistical strength of the proposed model based on results on practical test system. A basic mathematical model is presented to get the faster convergence of the control equations for given system which is done using ANAREDE software. The developments of the software are described. The voltage stability analysis, contingency analysis, sensitivity analysis, graphical user interface and the convergence results are also discussed.

In [7] Ying Xiao et.al explains about the versatile model for the power flow control using all types of FACTS devices to derive the control parameters of the system. The paper basically proposes a decomposed power injection model (DPIM). A rectangular polar hybrid formulation is implemented for power flow control using Optimal Multiplier Newton-Raphson power flow method and Interior Point Linear Programming. The paper describes about the type of couple and the decoupled model. The classifications of all FACTS devices, steady-state function, DPIM components, control variables and parameters are tabulated. The proposed model is tested on modified IEEE-5 bus system.

S. Mukhopadhyay et.al in [8] presented the application of FACTS in Indian power system with full planning studies, project performance and design parameters of the given transmission network. The paper discusses about the on-going project on 400 kV line between Kanpur (U.P.) and Ballabhghar (Haryana) in the Northern grid in India. The paper emphasis on the project planned to be applied in two phases where TCSC and Fixed Series Compensation (FSC) are installed for compensation in transmission line to improve the dynamic performance. The paper briefly describes about the FACTS devices and its scenario in India. The results of series compensation in proposed line after installing TCSC are tabulated and the single line diagram of TCSC scheme is also shown.

In [9] author suggested a power flow solution using Newton-Raphson TCSC model in practical power networks. The proposed model is tested on IEEE 30 bus systems where the model can be applied to large networks without any computational problems. The paper discussed the modeling of TCSC for analysis in detail. A case study is carried out to observe the performance of proposed model and result for specified power flow and firing angles are tabulated where the table shows the increase in the real power flow in line with TCSC.

In reference [10] author at length discusses about the benefits of FACTS controllers in AC transmission system. The paper first describes the control of power systems with illustration of controllability of power systems. The examples of conventional equipment and FACTS controllers for improving the power flow control. The advantages of control of power system are discussed. The paper describes the important five phases of power system analysis for installation of FACTS devices in the transmission system. The paper also presents an overview of FACTS controller circuits.

Abdel-Moamen M. A. et.al in [11] proposed the power flow control and transmission minimization model using Newton optimization technique with TCSC in practical power networks. The objective of this model is to minimize the total system real power losses and also to control the real power flow in transmission line. The proposed model is tested on IEEE 30 bus systems with single and multiple TCSC devices. In problem formulation the TCSC power flow model and optimal power flow with TCSC is explained. Graph is shown between TCSC equivalent impedance and equivalent impedance as function of firing angle. The author suggests that the proposed model is useful and appropriate for reliable extent of power control.

In [12] the author discussed the application, advantages and installations of FACTS devices in transmission system. The paper briefly discusses the history of development of FACTS technology. The paper presented the application of FACTS devices in deregulated market of power system. TCSC installation across the world is tabulated based on year of installation. Different types of FACTS controllers are also described in the paper. The application of TCSC is proposed under the classification based on three states of power system that is steady state, transient state and post transient steady state. The paper presented some selected case studies also. The paper presented a comparison of cost between conventional equipment’s and FACTS controllers.

In reference [13] author M. O. Hassan et.al proposed a steady state model for SVC and TCSC for power flow studies where a firing angle model for SVC and TCSC is proposed to control the voltage and real power flow in transmission line respectively. The paper presented a Newton-Raphson algorithm to solve the power flow equations. To show the performance of the proposed model it is tested on 9 bus system. First the power flow equations are drawn and then the modelling of SVC and TCSC is explained. For simulation and result four cases are considered to reach the maximum convergence characteristics.

In [14] author proposed a power flow analysis using firing angle model with TCSC to calculate the power transferred, node voltages and node angles. The paper also presented a comparison between variable impedance model and firing angle model. The model is tested on IEEE 30 bus and IEEE 118 bus systems. The paper presents an introduction of TCSC FACTS device. The model provides a firing angle based nodal admittance matrix to use with power flow algorithm. Based on the result of case study the author suggest that with TCSC connected in transmission line the real power flow is increased and thus by placing the TCSC at specified line the real power flow can be improved to the required level.

In reference [15] a study is carried out on the reactive power control and transmission loss reduction with static models of SVC and TCSC. The proposed algorithm is tested on 9 bus and IEEE 14 bus test system. The paper presents an introduction to power flow control and Newton-Raphson technique. The paper explains the modelling of SVC and TCSC with a Flow chart. The simulation and result is described for with and without SVC and with and without TCSC. The voltage magnitude and phase angle is tabulated for both test bus systems. The comparison of result is also show between Matlab Programming and Power World Simulator for power loss and reactive power. Thus the paper presents an approach with SVC and TCSC in power system to reduce the total loss in active power.

P Paul Clee et.al in [16] proposed a model for the enhancement of power flow using TCSC FACTS controller. The proposed model is using MATLAB-SIMULINK simulation to show the effect of variation in parameters of TCSC over the performance of the system. The paper presents a study of basic module of TCSC and its analysis. The change in TCSC inductance with change in TCSC capacitance is shown. The paper presents a SIMULINK block representation in single integral model of TCSC. The simulation results are described in form of waveform drawn for voltage across TCSC, effect of TCSC in three-phase line, voltage at other end of line, three-phase voltage across the TCSC in three- phase transmission line.

In [17] the author proposed a case study on modelling and analysis of SVC, TCSC, and TCPAR in power flow analysis. The paper presents the application of different FACTS devices in power system to improve the power transfer capabilities of transmission system. The paper carries out an investigation for power flow problems using steady state model of FACTS devices namely SVC, TCSC, and TCPAR. The proposed algorithm is validated on IEEE 5 bus test system and IEEE 30 bus test system. The paper describes the basic concept and problem formulation using N-R method. The modeling of FACTS devices is explained in various stages. The results of different models are tabulated for voltages, angles, power flow and line losses with and without FACTS devices connected in the line.

In reference [18] the author discussed the power flow analysis and voltage stability enhancement using TCSC for voltage control of Nigerian 330 kV grid system where voltage drop are noticed at specified buses. The basic structure of TCSC is described and case study is carried out by forming the power flow equations and is solved using Newton-Raphson iterative method. The paper presented a simulation of power flow solution with and without TCSC. Thus the voltage is regulated at given buses and the result is represented in bar chart showing the variation in voltage profile without TCSC and with TCSC. Many other researchers such as [19], [20], [21], and [22] have performed researches in the same field to show the application of TCSC in Power flow analysis to reduce the losses and improve the power flow in transmission system.

In reference [23] author proposed the model for power flow control and power flow studies with series FACTS devices like TCSC, Static Synchronous series Compensator (SSSC) and Thyristor Controlled Phase Shifter (TCPS). The paper presents the modelling of series FACTS devices. The nonlinear equations of the models are solved using Newton-Raphson method and the power flow study is carried out with MATLAB programming. A convergence test is performed on IEEE 30 bus system to show the effectiveness of the proposed system. The result showing the variation in line flow with TCSC, SSSC and TCPS is drawn in graph for line power flow and number of iteration required for convergence.

III. CONCLUSION

The above case study is carried out on the role of Thyristor Controlled Series Compensator (TCSC) in the improvement of power system analysis. The paper presented an introduction to power flow analysis and FACTS Technology. The paper presented the research made for improvement in real power flow in transmission line with application of TCSC in transmission network. Newton-Raphson power flow algorithm is basically carried out in most of the case papers used for the analysis and the algorithm is tested on various standard IEEE bus test systems. And the result of different researches suggested that the improvement in real power flow is observed when TCSC connected in the specified transmission line. Thus the various case studies clearly suggest the advantages of including the TCSC in the transmission network.

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