Statistical Analysis of Power System on Enhancement of Available Transfer Capability-Applying FACTS

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***Abstract*—The paper aims to conduct Statistical Analysis of the Performance Characteristics of Power System subjected to tests for Enhancement of Power Transfer Capability by using TCSC-FACTS Device. The 30Bus Test system has been considered for the study. The objective is reduction of losses by applying TCSC and thereby enhances Available Transfer Capability. The parameters studied are Voltage profile, Losses, Power Flow on Lines. The Statistical Analysis tool, Standard Deviation is applied on the results. Statistical Analysis conducted on the results obtained has shown good positive results in improvement of the parameters after application of TCSC.**

***Keywords*—**Available Transfer Capability, Statistical Analysis, FACTS, TCSC and Standard Deviation

I. INTRODUCTION

In the present day scenario of Electric Power System the world over two aspects are of prime importance for Power Engineers. The first, in the context of deregulation and competitive market [1] determination of the Available Transfer Capability at any instant of time. The second, in the context of optimum usage of existing resources and demand for quality power, study and implementation of means and methods to satisfy the requirement. This aspect is made true and feasible by the developments in Power Electronics – FACTS [2], [3] devices. FACTS device like thyristor controlled series compensator (TCSC) can be employed to reduce the flows in heavily loaded lines, resulting in a low system loss and improved stability of network.

In a restructured electricity market [4], [5], the market participants share a common transmission network for wheeling power from the point of generation to the point of consumption. All the participants, in the open access environment, may try to maximize their profit and procure the electrical energy from the cheapest source, which may, sometimes lead to congestion of certain transmission system at various points. This may undermine the system security and reliability. Therefore, the Available Transfer Capability (ATC) [6], [7] of the transmission system needs to be determined at regular intervals to ensure that the system security is maintained while serving a wide range of transactions. The ATC of a transmission network [8], [9] refers to its unutilized transfer capability available for further transactions, over and above already committed usage, without violating system security constraints. The constraints required to determine ATC include static constraints such as line thermal limits, voltage limits and maximum loadability limits as well as stability constraints.

The rest of the paper is organized as follows: Section II – Available Transfer Capability Section III – FACTS Devices, Section IV – Statistical Analysis In Section V – Proposed Algorithm and Case Study. In Section VI – Results and Discussion, Section VII – Conclusion.

II. AVAILABLE TRANSFER CAPABILITY

According to the report of NERC (1995), transfer capability refers to the ability of transmission systems to reliably transfer power from one area to another over all transmission paths between those areas under given system conditions. The mathematical definition of ATC given in the report of NERC (1996) [10] is '*the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments and the Capacity Benefit Margin (CBM)*'. This equation is diagrammatically depicted in Fig. 1.

1). Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre**-** and post**-**contingency system conditions (OR) TTC is the largest value of electric power that can be transferred over the interconnected transmission network in a reliable manner without violation of specified constraints. Total transfer capability (TTC) is the key component for calculating Available Transfer Capability (ATC).

2). Transmission Reliability Margin (TRM) is defined as that amount of transmission transfer capability necessary to ensure that interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.

3). Capacity Benefit Margin (CBM) is defined as that amount of transmission transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements. Several methods for TTC computation have been suggested in the [13] literature. Initially proposed techniques were based on DC load flows [14], Power Transfer Distribution Factor (PTDF) [15]. But due to the approximations involved in DC power flows, AC power flow methods have gained importance. Methods based on AC power flows for computing TTC can be divided into four types**:**

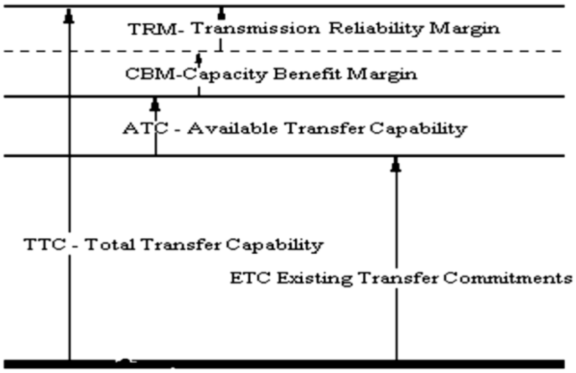

Fig. 1. Transfer Capability Concept

i). Security Constrained Optimal Power Flow (SCOPF) method: This method can be implemented by many optimization approaches such as interior point approach, neural network[16] and two-level optimization approach.

ii). Continuation Power Flow (CPF) method: The implementation of this mathematically complicated method involves predictor, parameterization, corrector and step-size control [17], [18].

iii). Repeated Power Flow (RPF) method: This method repeatedly solves power flow equations at a succession of points along the specified load generation increment [19], [20].

iv). Probabilistic Approach method: TTC is calculated using probabilistic approaches such as nonsequential Monte Carlo [21] and stochastic programming [22]. In these studies, sometimes maximization of power transaction between areas is only emphasized and sometimes commercial aspects.

One of the most common approaches for transfer capability calculations is the continuation power flow (CPF) [11], [12].

In principle, CPF increases the loading factor in discrete steps and solves the resulting power flow problem at each step. CPF yields solutions at voltage collapse points. However, since CPF ignores the optimal distribution of the generation and the loading together with the system reactive power, it can give conservative transfer capability results.

III. FACTS

Flexible Alternating Current Transmission Devices (FACTS) are Power Electronics devices. Several FACTS controllers have been developed which are capable of controlling the network condition in a very fast and efficient manner. FACTS solutions are particularly justifiable in applications requiring rapid dynamic response, ability for frequent variations in output, and/or smoothly adjustable output. Under such conditions, FACTS is a highly useful option for enabling or increasing the utilization of transmission and distribution grids avoiding the need to construct new transmission lines.

The paper aims to study the implementation of TCSC FACTS device [23] in reduction of losses and enhancement of ATC.

A. Modeling of TCSC

Transmission lines are represented by lumped π equivalent parameters. The series compensator TCSC is simply a static capacitor/reactor with impedance jX_c. Fig. 2 shows a transmission line incorporating TCSC.

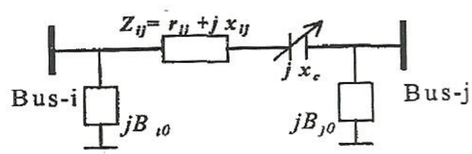

Fig. 2: Equivalent circuit of a line with TCSC

Where X_{ij} is the reactance of the line, R_{ij} *is* the resistance of the line, B_{io} and B_{jo} are the half-line charging susceptance of the line at bus-i and bus-j.

IV. STATISTICAL ANALYSIS

Statistical analysis refers to a collection of methods used to process large amounts of data and report overall trends. Statistical analysis is particularly useful when dealing with noisy data. Statistical analysis provides ways to objectively report on how unusual an event is based on historical data. It provides methods and indices to compare the trends of two or more data sets and compare their relative performance. The various tools are mean, median, mode, variance and standard deviation. In this study standard deviation tool has been used to compare the performance results of the different cases study results. Statistical moments are used to provide some sort of measure for a probability distribution of ATC. The most important and useful moment is the center of a distribution of X. This center is called the mean and is denoted as $\bar{x}$. The variance is a measure of the spread of the distribution. The square root of variance is called standard deviation and is denoted as σ.

B. Standard Deviation

Standard deviation is a widely used measurement of variability or diversity used in statistics and probability theory. It shows how much variation or ' dispersion' there is from the 'average' (mean value). A small standard deviation indicates the scores are close together and a large standard deviation indicates that the scores are more spread out.

The standard deviation is the square root of the variance, which is based on the distance of each score from the mean. It is appropriate when the data represent an interval or ratio scale. It is the most stable measure of variability and takes into account each and every score. Steps for calculating the standard deviation are: 1) Find out N, the number of subjects, 2) Calculate the sum of the scores, 3) square each score, 4) Add all the squares, to get the sum of squares of the scores, 5) Square the sum of the scores and divide by the number of scores (we have a measure of variability called variance), 6) Subtract the variance from the sum of the squares of scores to get the sum of the squares (SS), and 7) divide the SS by N-1.

V. PROPOSED ALGORITHM AND CASE STUDY

The aim of the paper is to study the enhancement of Available Transfer Capability of 30 Bus Test System with TCSC FACTS device and evaluate the performance results of different cases. The four cases studied are:

i) 30 Bus Base Case

ii) 30 Bus with TCSC

iii) 30 Bus Maximum Load

iv) 30 Bus with TCSC and Maximum Load

The 30 Bus System consists of 30 Buses, 6 Generators and 20 Loads spread in 3 Areas. Each Area consists of 2 Generators each.

1). 30 Bus Base Case: The power flow study also known as load-flow study or base case is an important tool involving numerical analysis applied to a power system. It analyzes the power systems in normal steady-state conditions. The study is important for future expansion planning of the power system as well as determining the optimum operating condition of the existing system. The principal information obtained from the power flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line

This paper features an OPF-based procedure for calculating the total transfer capability (TTC) and Available Transfer Capability (ATC). This is based on full AC power flow solution which accurately determines reactive power flow, and voltage limits as well as the line flow effect. The objective function is to maximize total generation supplied and load demand at specific buses taking into consideration reduction of losses.

2). 30 Bus with TCSC: The objective of placing TCSC is to reduce losses and improve the Voltage profile and enhance Transfer Capability of the Power System.

The criteria for placement of TCSC are lines with maximum losses [23]. Hence, the lines identified were between buses 1-3, 2-4, 2-6, 24-25, 25-27. TCSC was placed in these lines.

3). 30 Bus with Maximum Load: The method adopted was an iterative method of running OPF. First the Loads in Area 1 are increased linearly until a contingency is encountered. Then Loads in Area 2 are increased and then in Area 3.Finally the Loads in the 3 Areas are increased finely for tuning the Maximum Lodable Condition, until a Contingency is encountered on running OPF.

4). 30 Bus with TCSC and Maximum Load: This is a combination of Case B and C. This case enables us to determine the enhancement in the performance of the system with TCSC and under Maximum Load conditions.

The results of the four cases are tabulated in Table I, Table II and Table III and graphs in Fig. 3, Fig. 4 and Fig. 5.

VI. RESULTS AND DISCUSSION

The results of the four cases depicted in the Tables I, Table II and Table III give the numerical comparison of the performance of the 30 Bus system subjected to the four conditions. The graphs show the comparison of Real Power and Reactive Power Flow on the lines and the Voltage of the two cases A and B i.e., Base Case and TCSC. The standard deviation (SD) results in Table I of the Voltage Magnitude and Angle shows there is an improvement in the SD with TCSC over Base Case. The results obtained show the reduction of losses, convergence time and enhancement of ATC with TCSC.

VII. CONCLUSIONS

FACTS devices have proved an effective method for Loss reduction .The effectiveness of TCSC is demonstrated on 30 – Bus IEEE Power Systems. The main conclusions of the paper are: i) The time of convergence is less, ii) The placement of Facts devices enhances system ATC and mitigates real power loss, iii) The simple and direct method of placing TCSC in the lines having maximum power loss has shown effective results in loss reduction and enhancing ATC, and iv) Standard Deviation has proved to be a good tool for comparison.

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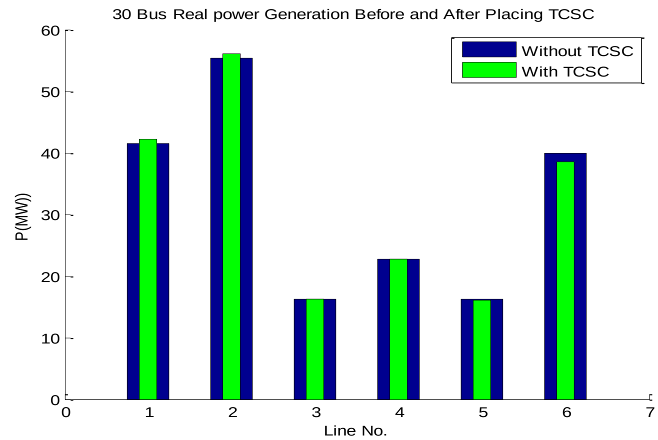

Fig. 3: Real Power Flow With and Without TCSC

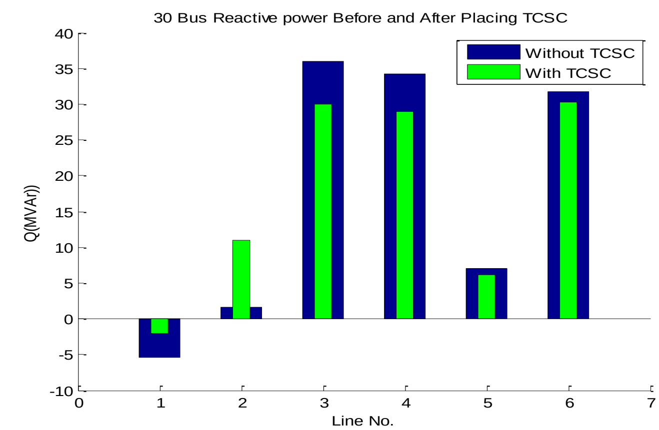

Fig. 3: Reactive Power Flow With and Without TCSC

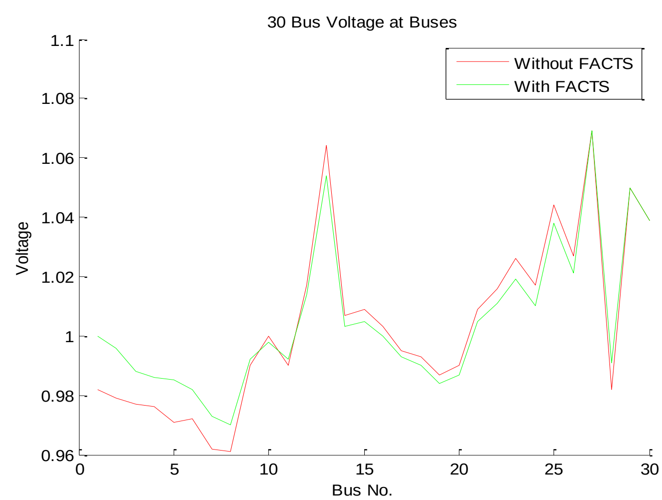

Fig. 5: Voltage Magnitude With and Without TCSC

Table I: Standard Deviation of Voltage Magnitude and Angle at Buses

Parameter	Base Case	TCSC in Base Case	Base Case Max.Load	System with TCSC+Max.Load
Voltage Magnitude	0.029	0.024	0.3	0.32
Angle	1.47	1.68	1.44	2.01

Table II: 30 Bus Test System Comparative Results

ATC (MW)	Base Case	System with TCSC Maximum Loaded
Area 1 To 2	91.7	105.8
Area 3 To 2	66.5	67.3

Table III: Available Transfer Capability

Parameter	Base Case	With TCSC	System Maximum Loaded	System with TCSC Maximum Loaded
Generation	192.1MW	191.8MW	266.0MW	305.2MW
Load	189.2MW	189.2MW	262.5MW	300
Losses	2.86MW	2.59MW	4.76MW	5.73MW
Converging Time (sec)	0.17	0.14	0.14	0.16
Objective Function Value ($/hr)	576.89	575.58	857.42	1053.85