Line Loadability Improvement by using TCSC under Network Contingencies

D.Naga Krishna Sumanth, D.Ragaleela, Dr.Ch.Padmanabha Raju

Abstract: Hassled power system, either due to increase loading or due to severe contingencies, often leads to situation where system no longer remains in the secure operating region. Under these situations, it is primary objective of the operator to apply control action to bring the power system into the secure region. Any delay or unavailability of suitable control, the system may become unstable. FACTS devices can play very important role in power system security enhancement.
The Thyristor Controlled Series Capacitor (TCSC) is one of the most effective Flexible AC Transmission System (FACTS) devices. It offers smooth and flexible control of the line impedance with much faster response compared to the traditional control devices. It may be used to enhance system performance by controlling the power flows in the network and to alleviate /eliminate the overloads on the transmission lines under network contingencies. The Newton-Raphson ac power flow method was used to perform the above studies. The performance of the proposed algorithm has been tested for IEEE-14 bus system. Programming of the power flow studies is carried out by using MATLAB.

Index Terms: Contingency, FACTS, Newton-Raphson, Power Flow Control, TCSC.

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1 INTRODUCTION

In current day power system, there will be an increase in number of situations where power flow equations have either no real solution (unsolvable case) or solution with violating operating limits such as line limit (insecure case), particularly, in contingency analysis and planning applications. Since insecure cases often represent the most severe threats to secure system operation. Few papers have dealt with the power system insecurity and possible control to bring the system back to secure state [1]. The possibility of controlling power flow in an electric power system without generation rescheduling or topological changes can improve the performance considerably [2].

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The primary requirement of power system is to meet the demand that varies continuously. The dispatchers are required to operate the system closer to its thermal limits and increase its transit capacity of power. The control of the power system can be obtained through the implementation of devices based on power electronic with high-speed response, recently developed and called FACTS

[3]. The TCSC is one of the most promising components of FACTS. Thyristor Controlled Series Capacitor is one such device, which offers smooth and flexible control of the branch impedance with much faster response compared to the traditional control devices [4]-[6].

The electric power flow problem is the most studied and documented problem in power engineering. Load flow calculations provide power flows and voltages for a specified power system subject to the regulating capability of generators, tap changing transformers and as well as specified net interchange between individual operating systems. This information is essential for the continuous evaluation of the current performance of a power system and for analyzing the effectiveness of alternative plans for system expansion to meet increased load demand.

The power flow problem is formulated as a set of nonlinear equations. Many calculation methods have been proposed to solve this problem. Among them, Newton-Raphson method is a very successful method. The system conditions with large angles across lines (heavily loaded network) and with special control that strongly influence active and reactive power flows, Newton-Raphson method may be required [7].

Therefore, when the AC power flow calculation is needed in systems with FACTS devices, Newton-Raphson method is suitable for power flow calculation in the system with TCSC when high accuracy is required [8]-[9]. In case of a contingency, TCSC can be used effectively used in maintaining system security by eliminating or alleviating overloads along the selected network branches and the effects of the TCSC utilization under single line contingency are explored here [10]. In this paper, we concentrate on the enhancement of system static security against single contingencies via the use of TCSC.

2 MODELLING OF THYRISTOR CONTROLLED SERIES COMPENSATOR

Thyristor Controlled Series Capacitor (TCSC) allows rapid and continuous changes of transmission line impedance. Fig.1 shows the TCSC module connected in series with the transmission line [4].
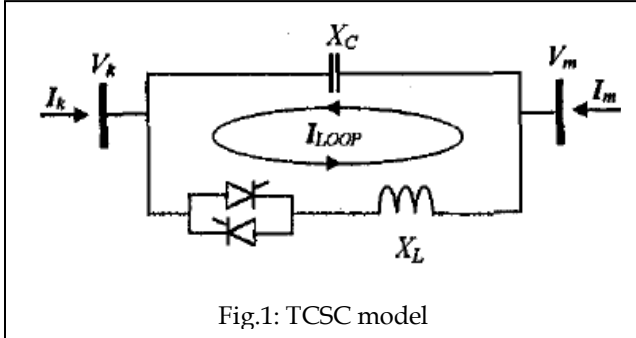

Fig.1: TCSC model

The TCSC is incorporated into the load flow calculations by setting the total line reactance to

$$X_{TOT} = X + X_{TCSC} \qquad (1)$$

The basic equation is,

$$Z_{TCSC(1)} = R_{TCSC(1)} + jX_{TCSC(1)} = \frac{V_{TCSC(1)}}{I_{line}} \qquad (2)$$

Where (bold type indicates complex quantities). $V_{TCSC(1)}$ is the fundamental frequency voltage across the TCSC module, I_{line} is the fundamental frequency line current and $Z_{TCSC(1)}$ is the TCSC impedance. The voltage $V_{TCSC(1)}$ is equal to the voltage across the TCSC and equation (2) can be written as,

$$Z_{TCSC(1)} = \frac{-jX_c I_{cap(1)}}{I_{line}} \qquad (3)$$

If the external power network is represented by an idealized current source, as seen from the TCSC terminals, this current source is equal to the sum of the currents flowing through the TCSC capacitor and inductor. The TCSC impedance can then be expressed as,

$$Z_{TCSC(1)} = \frac{-jX_C(I_{line} - I_{TCR(1)})}{I_{line}} \qquad (4)$$

In this paper, TCSC is represented by its fundamental frequency impedance module. TCSC power flow equations, with respect to firing angle, are incorporated into an existing Newton-Raphson algorithm. The fundamental TCSC equivalent reactance as a function of TCSC firing angle α [4], is given as

$$X_{TCSC(1)} = -jX_C + C_1\left(2(\pi-\alpha) + \sin(2(\pi-\alpha))\right) - C_2 \cos^2(\pi-\alpha)\left(\overline{\omega}\tan(\overline{\omega}(\pi-\alpha)) - \tan(\pi-\alpha)\right)$$

$$(5)$$

Where $\quad X_{LC} = \dfrac{X_C X_L}{X_C - X_L} \qquad (6)$

$$C_1 = \frac{X_C + X_{LC}}{\pi} \quad , \quad C_2 = \frac{4X^2_{LC}}{X_L \pi} \qquad (7)$$

The admittance matrix of the TCSC module shown in Fig .1 is

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} jB_{kk} & jB_{km} \\ jB_{mk} & jB_{mm} \end{bmatrix}\begin{bmatrix} V_k \\ V_m \end{bmatrix} \qquad (8)$$

$$B_{kk} = B_{mm} = B_{TCSC(1)} = -\frac{1}{X_{TCSC}} \qquad (9)$$

$$B_{km} = B_{mk} = B_{TCSC(1)} = -\frac{1}{X_{TCSC(1)}} \qquad (10)$$

When TCSC is used to control power flow in the line k-m, the set of power flow equations are given by

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_m \\ \Delta Q_m \\ \Delta P_{km} \end{bmatrix} = \begin{bmatrix} \frac{\partial p_k}{\partial \delta_k} & \frac{\partial p_k}{\partial |V_k|} & \frac{\partial p_k}{\partial \delta_m} & \frac{\partial p_k}{\partial |V_m|} & \frac{\partial p_k}{\partial X_{TCSC}} \\ \frac{\partial Q_k}{\partial \delta_k} & \frac{\partial Q_k}{\partial |V_k|} & \frac{\partial Q_k}{\partial \delta_m} & \frac{\partial Q_k}{\partial |V_m|} & \frac{\partial Q_k}{\partial X_{TCSC}} \\ \frac{\partial p_m}{\partial \delta_k} & \frac{\partial p_m}{\partial |V_k|} & \frac{\partial p_m}{\partial \delta_m} & \frac{\partial p_m}{\partial |V_m|} & \frac{\partial p_m}{\partial X_{TCSC}} \\ \frac{\partial Q_m}{\partial \delta_k} & \frac{\partial Q_m}{\partial |V_k|} & \frac{\partial Q_m}{\partial \delta_m} & \frac{\partial Q_m}{\partial |V_m|} & \frac{\partial Q_m}{\partial X_{TCSC}} \\ \frac{\partial p_{km}}{\partial \delta_k} & \frac{\partial p_{km}}{\partial |V_k|} & \frac{\partial p_{km}}{\partial \delta_m} & \frac{\partial p_{km}}{\partial |V_m|} & \frac{\partial p_{km}}{\partial X_{TCSC}} \end{bmatrix} \begin{bmatrix} \Delta\delta_k \\ \Delta|V_k| \\ \Delta\delta_m \\ \Delta|V_m| \\ \Delta X_{TCSC} \end{bmatrix}$$

$$(11)$$

Where, the elements of additional row and column of the modified Jacobean can be written as:

$$\frac{\partial P_{km}}{\partial \delta_k} = \frac{-|V_k V_m|}{X_{TCSC}} \cos(\delta_k - \delta_m) \qquad (12)$$

$$\frac{\partial P_{km}}{\partial X_{TCSC}} = \frac{|V_k V_m|}{X^2 X_{TCSC}} \sin(\delta_k - \delta_m) \qquad (13)$$

$$\frac{\partial P_{km}}{\partial \delta_m} = \frac{|V_k V_m|}{X_{TCSC}} \cos(\delta_k - \delta_m) \qquad (14)$$

$$\frac{\partial P_{km}}{\partial X_{TCSC}} = \frac{-|V_k V_m|}{X^2 X_{TCSC}} \sin(\delta_k - \delta_m) \qquad (15)$$

$$\frac{\partial P_{km}}{\partial |V_k|} = \frac{-|V_k|}{X_{TCSC}} \sin(\delta_k - \delta_m) \qquad (16)$$

$$\frac{\partial P_k}{\partial X_{TCSC}} = \frac{|V_k V_m|}{X^2 X_{TCSC}} \sin(\delta_k - \delta_m) \qquad (17)$$

$$\frac{\partial Q_k}{\partial X_{TCSC}} = \frac{-|V_k|^2}{X^2_{TCSC}} - \frac{|V_k V_m|}{X^2 X_{TCSC}} \cos(\delta_k - \delta_m) \qquad (18)$$

$$\frac{\partial Q_m}{\partial X_{TCSC}} = \frac{-|V_m|^2}{X^2_{TCSC}} - \frac{|V_k V_m|}{X^2 X_{TCSC}} \cos(\delta_k - \delta_m) \qquad (19)$$

The mismatch vector $\Delta P_{km} = P_{km(reg)} - P_{km(cal)}$ is the active power mismatch for the TCSC branch. $P_{km(reg)}$ is the required power flow in the TCSC branch. Now by using the mismatch it can be modified as $X_{TCSC}^{(p+1)} = X_{TCSC}^p + \Delta X_{TCSC}^p$ where ΔX_{TCSC}^p is the incremental change in TCSC reactance and P shows the Pth iteration.

3 COMPUTATIONAL PROCEDURE FOR PROPOSED POWER FLOW PROBLEM

Step 1: Consider each series FACTS device as a separate branch in the network.
Step 2: Initialize the unknown state variables to guessed values.
Step 3: Apply contingency analysis procedure to the bus network.
Step 4: Find the security violated lines.
Step 5: Place the TCSC in the security violated line and then solve the load flow problem with TCSC.
Step 6: If convergence is reached then go to next step otherwise go to step 3.
Step 7: Stop

4 NUMERICAL RESULTS

The effectiveness of the proposed method is tested on IEEE 14-bus system. The 14-bus test system consists of five generator buses at buses 1, 2, 3, 4, 5. Buses 6, 7, 8, 9, 10, 11, 12, 13, 14 are load buses. The system has got 20 transmission lines. In the study the power handling ability of a line is limited by its thermal loading limit. This limit is used to check for any violation in the line limits. The important contingencies, which are actually causing problems to system security, are considered in the study. The power flow solutions in each of these contingencies are computed in MATLAB. For the intended work, the mathematical model of TCSC is incorporated in MATLAB. The results are presented in the paper to demonstrate the effectiveness of the proposed method.

In this system, three typical load patterns have been taken into account, which are referred as Case1, Case2 and Single line contingency as shown in the Table-1.The power flow of the transmission lines which are violated their load limits are mentioned in the tables of different cases, others which are not represented in these tables are within the load limits.

TABLE-1: TYPICAL LOAD PATTERNS

Case-1	Case-2	Case-3
Load pattern-1	Load pattern-2	Single line contingency

Case 1: Load Pattern -1

The objective of the approach is to alleviate the overloads on the transmission lines by minimizing the apparent value of power by incorporating the TCSC. In this case, the load on the power system is 259.1 MW. The power flow in the branch 7-5 is 33.72 MVA (without TCSC) and the line limit is 32 MVA.

TABLE-2: COMPARISON OF POWER FLOWS WITH BASE LOAD

BRANCHES		LINE FLOW LIMIT (MVA)	LINE FLOWS(MVA) [without TCSC]	LINE FLOWS(MVA) [With TCSC]
FROM NODE	TO NODE			
7	5	32	33.72	25.7

Fig.2: With Base load
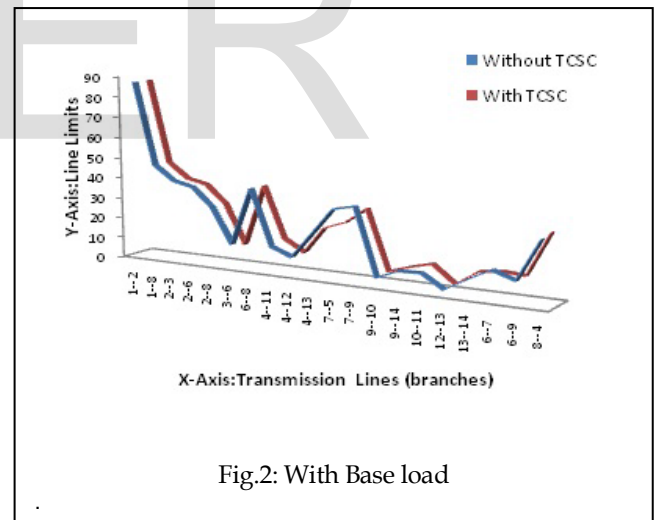
From the Table-2, we observe that the line 7-5 gets overloaded and the power flow in that branch is 33.72 MVA. So by placing TCSC in line 7-5 we can decrease the power flow to 25.7 MVA without crossing the line limits. The Fig.3 shows the line flow limits on Y-axis in MVA and the X-axis represents transmission lines of the network. The equivalent reactance of the TCSC required for reducing the overload in line 7-5 is 0.2469 (p.u). In Fig.2 the red line indicates the line flows when the TCSC is placed in the network and the blue line indicates the line flows when the TCSC is not present in the network, From the Fig.2 we can

observe that the power flow is reduced and it is within the acceptable limits for the 7-5 line by incorporating TCSC.

Case 2: Load Pattern -2

In this case load on the power system is 285.01 which represent 10% increment on base load. The power flow in the branch 7-5 is 34.39 MVA (without TCSC) and the line limit is 32 MVA. Thus, the system needs controlling of power in the line 7-5 i.e., well below their thermal rating. So, we place the TCSC in the line 7-5 for reducing the overload. After placing the TCSC in the line 7-5, the overloaded line carries the power flow well below their power rating shown in Table-3. In the Fig.3 on the X-axis, the numbers 1-2, 1-8, 2-3, 2-6, 2-8, 3-6, 6-8, 4-11, 4-12, 4-13, 7-5, 7-9, 9-10, 9-14, 10-11, 12-13, 13-14, 6-7, 6-9, 8-4 are the branches and the Y-axis indicates line limits. From the Fig.3 it is observed that the line limit at transmission line 7-5 violates its specified maximum limit of 32 MVA. With proper setting of TCSC, the overloads are eliminated / alleviated. The equivalent reactance of the TCSC required for reducing the power flow in 7-5 is 0.30 p.u.

TABLE-3: COMPARISON OF POWER FLOWS WITH INCREMENT LOAD

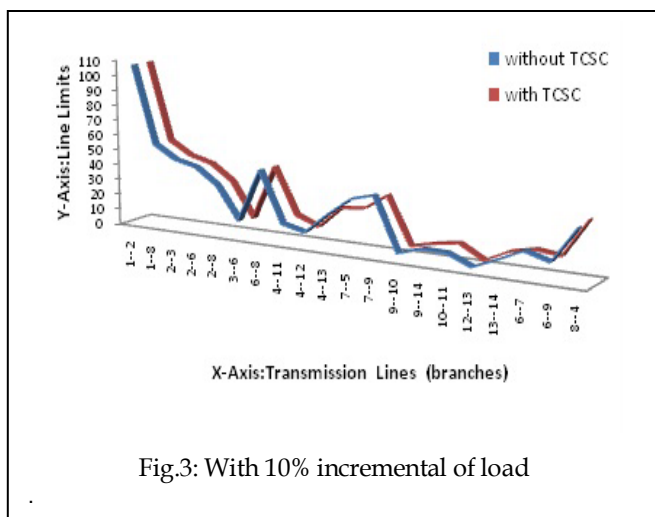| BRANCHES		LINE FLOW LIMIT (MVA)	LINE FLOWS(MVA) [without TCSC]	LINE FLOWS(MVA) [With TCSC]
FROM NODE	TO NODE			
7	5	32	34.39	25.37

Fig.3: With 10% incremental of load

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Case 3: Single line Contingency

In this case, the transmission line 4-13 is removed from the network and the load on the power system is 259.1 MW. The power flow in all the branches are within the acceptable limits except the 7-5 branch i.e. 35.02 MVA

(without TCSC) and the line limit is 32 MVA. The power flows are represented in Table-5. By placing the TCSC in the 7-5 branch and setting of TCSC parameters the power flow was controlled to 28.56 MVA and the load is transferred to other lines without violating the line limits. The TCSC parameters are mentioned in the table-4.

TABLE-4: LOCATION AND PARAMETER SETTING OF THE TCSC

BRANCHES	Initial TCSC Parameter value (p.u)	TCSC reactance (p.u.)
7-5	-0.015	0.2181

TABLE-5: COMPARISON OF POWER FLOWS WITH SINGLE LINE CONTINGENCY

BRANCHES		LINE FLOW LIMIT (MVA)	LINE FLOW(MVA) [without TCSC]	LINE FLOW(MVA) [With TCSC]
FROM NODE	TO NODE			
7	5	32	35.02	28.56

In Fig.4 the Y-axis indicates the line limits and the X-axis represents the branches of transmission lines. From the Fig.5 we observe that in the line 7-5 power flow violates the limits and the power is reduced after placing of the TCSC.
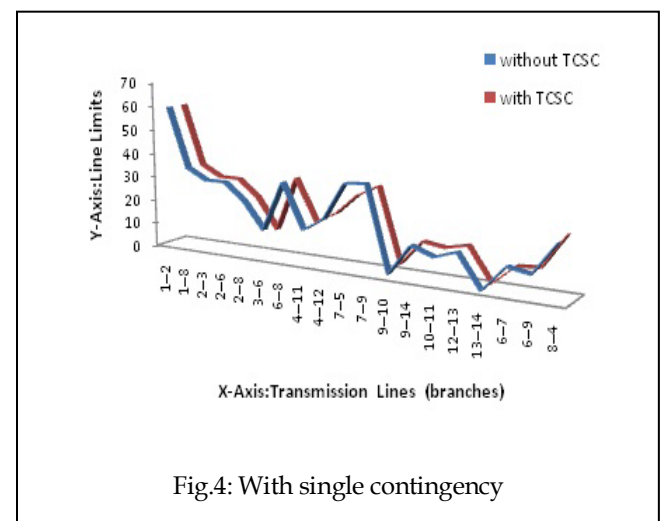

Fig.4: With single contingency

5 CONCLUSION

This paper has presented a Newton-Raphson load flow method to solve power flow problems in power system with placement of the TCSC. It is simple, efficient and reliable method for solving power flow problem with increase in network load and under occurrence of contingencies. The proposed method is tested on IEEE-14 bus system and the simulation results are reported.

It was observed that the proposed algorithm is also suitable for large systems with better range of power control. The results show the effectiveness and robustness of proposed method over a wide range of power flow variations in the transmission system.

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