Congestion Management in Power Transmission Network under line interruption condition Using TCSC

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Abstract—**The Modern Power System faces new problems and challenges due to restructuring of power systems. Congestion and voltage stability issues are major impact on the present modernized electric power system network. In the modern electric power system network, utilization of Transmission lines are maximized close to or beyond their thermal limits to satisfy the increased power consumption and trades due to unexpected power transactions. If such unplanned power exchanges were not controlled, the power flow on some transmission lines may become overloaded. This phenomenon is called as congestion. Congestion also occurs due to failure or outage of transmission lines in power system. One of the most challenging problems to operate power system in stable condition is overloading of transmission lines by the private entities. The establishment of Flexible-Alternating-Current-Transmission-System (FACTS) devices is more encouraging in relieving congestion, regulates the power flow and upholds the stableness of the electric power system network. Thyristor Controlled Series Compensation (TCSC) device is utilized to relieve congestion and regulate voltage stability of the system. In this research paper alleviation of overloading of transmission lines is carried out in a newly developed fourteen bus test system by interrupting a transmission line. The fourteen bus test system is modeled and simulated using Matlab-Simulink software. The simulation process is carried out under testing condition of fourteen bus system with one line interrupted and improved the performance of system with TCSC.**

Index Terms—FACTS- (TCSC), Line-termination, congestion, Real power flow, Reactive power flow, Voltage stability.

I. INTRODUCTION

The design of power system is becoming more challenging for power system engineers in the present trend as the industrial needs and the technology is growing at a faster rate. The stability constraints like maintaining voltage of the system, reliability and stableness of the system are more essential factors considered while designing the power system.

The industrial growth and modern development in technology resulted in more exploitation of transmission line, due to competitive power system. In the modern power world, performing the transmission network to operate within the transfer limit is a demanding task for power system engineers. The transmission line limits are violated in the multilateral transactions between the sellers and buyers. This overloading of transmission lines beyond the stability limits is referred to congestion. Restructuring of power systems becomes more complex as numerous problems arise due to the rapid increase of modern technology. Hence the restructured power system requires a precise architecture of new components for the stable operation and supervised power flow manipulations in transmission network. The demand for electricity is extremely increasing due to increase of industries. So the need to upgrade the existing power system and to erect new power system to supply increasing demand is necessary. Numerous techniques have been employed for solving congestion problem. One such technique which is gaining more interest in solving congestion problem is flexible-alternative-current-transmission-system.

Managing congestion includes the power system voltage limits and the transient steadfastness limits. Hence congestion problem is modeled as a multi objective problem [1].Solving the congestion problem including the stability constraints has been proposed in [2].The author has explored the possibility of transient-stability complications after removing congestion and introduced a dynamic technique to relieve congestion which maintains the stableness of the transmission system within the operating limit. An Extensive and diagnostic literature study has been reported in [3] about the conventional methods and the recent evolutionary programming methods used for solving congestion. The author also explains the methods followed for relieving congestion in various countries. A new technique including the consequences of electrical parameters with load paradigm has been developed in [4].The Author solves the congestion problem using integrated pattern of power system network. Flexible –alternative- current transmission-system is placed in a prime location for relieving congestion and also improves the system stability [5].Voltage instability is considered to be an important problem by the electrical engineers in recent times. Alleviating the voltage-instability complications by optimally placing the FACTS devices with fuzzy-based approach has been addressed in [6].Optimally identifying the location of FACTS devices to be placed in the power system network using fuzzy rules has been examined in [7].Thyristor controlled-series-capacitor is placed in a suitable place in the overloaded lines by adopting fuzzy rules to relieve congestion. Reducing the voltage instability in power system by using TCSC by appropriate placement and correct setting of TCSC by using an evolutionary method has been proposed in [8]. Multi FACTS devices have been introduced in fourteen bus test system at an optimal place for reducing congestion and enhancing the voltage stability of power system by genetic and fuzzy hybrid optimal approach method in [9].A different fuzzy logic approach has been proposed in [10] for controlling the various parameters of a voltage controlled induction motor drive. Also the author has presented and compared the results of induction motor drive using fuzzy rules with conventional PI controller output parameters. A new closed loop feedback controller design using PI controller for variable speed induction motor has been proposed in [11]. The transmission congestion problem is a global issue in transmission network systems due to the deficit of governance between Genco and Transco participants. New congestion management schemes are adapted to relieve congestion to maintain power system in secure state.[12-15]. A new method to relieve congestion by rescheduling the real power of generators by using PSO technique with time- varying -acceleration concept is introduced in [16].FACTS devices are recently explored on utilization of managing demand side to control congestion in transmission lines[17].The influence of TCSC in congestion management has been analyzed to view the performance of TCSC with maximum loading condition minimum loading condition under various bilateral conditions[18].Genetic Algorithm and Differential algorithm techniques are used in reducing transmission losses and in reducing the running cost of power system using FACTS devices[19].A detailed study has been discussed to optimally locate the FACTS device in the transmission lines to protect the security of the system [20].

In this paper a new technique for optimally locating the Flexible- Alternating-Current-Transmission devices for removing congestion is examined. In this paper, designing and modeling of Thyristor Controlled Series Capacitor (TCSC) is carried out in the following section. A new concept of optimally identifying the location of TCSC to relive the congestion is developed in section 3. The simulation results with neat wave forms of output voltage, real & reactive power and RMS voltage at congested bus are presented in section 4.Section 5 concludes with the closure of the paper.

II. THYRISTOR CONTROLLED SERIES CAPACITOR(TCSC)

The simplified representation of elementary Thyristor-Controlled-Series-Capacitor is presented in figure 1. A ripple less adjustable series-capacitive reactance is obtained by paralleling series compensating capacitor with Thyristor-controlled Reactor which forms the basic construction of TCSC. Thyristor Controlled Reactor (TCR) is bridged opposite to a series capacitor. In a practical TCSC circuit, primitive compensators may be connected in series to fetch the required voltage rating and operating characteristics. The inductive-reactance of the transmission line is compensated by optimally locating TCSC, thus reducing the exchange- reactance between the overloaded buses of the transmission system. to improve the power transfer capability of the power transmission system.

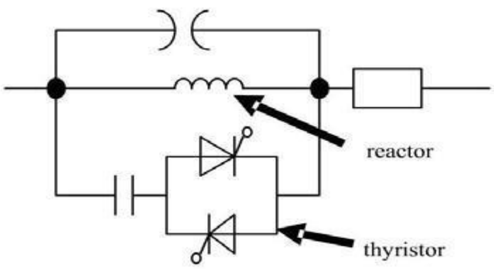

Figure 1. Equivalent circuit of TCSC

In this paper FACTS device is utilized to reduce congestion and improve the power flow capacity of the system

A. Modelling of Tcsc

Various types of FACTS devices are employed to solve congested condition in transmission line and to enhance the voltage stableness of power system. In this paper Thyristor-Controlled-Series-Compensator is introduced for enhancing the voltage stability of the system. An elementary representation of transmission line is shown in figure1.It consist of two buses represented by the notation, bus-a and bus-b.The voltages-of two-buses are represented as $V_a \angle \delta_a$ and $V_b \angle \delta_b$ .The real power flow between the two buses are mathematically represented as

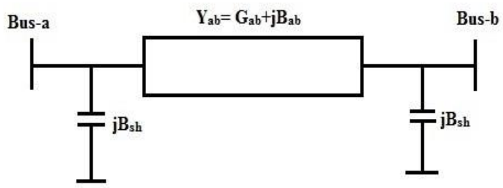

Figure 2. Elementary model of transmission line

$$P_{ab} = V_a^2 G_{ab} - V_a V_b [G_{ab} \cos(\delta_{ab}) + B_{ab} Sin(\delta_{ab})] \quad (1)$$

Where $\delta_{ab} = \delta_a - \delta_b$.

Similarly the true power flow from bus-a to bus-b (P_{ba}) is

$$P_{ba} = V_b^2 G_{ab} - V_a V_b [G_{ab} \cos(\delta_{ab}) + B_{ab} Sin(\delta_{ab})] \quad (2)$$

The elementary representation of transmission line with incorporating TCSC between two buses bus-a and bus-b is shown in figure 2.

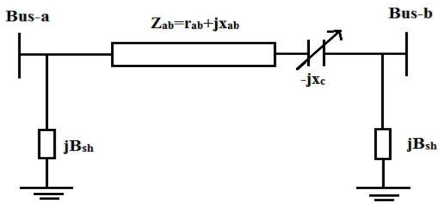

Figure 3. Model of TCSC

At stable condition of the power system network, the TCSC is considered as fixed reactance $-jx_c$ .The real power flow from bus-a to bus-b (P_{ab}^k) and from bus-b to bus-a (P_{ba}^k) of the transmission line with series impedance $Z_{ab} = r_{ab} + jx_{ab}$ and series reactance $-jx_c$ are represented as

$$P_{ab}^K = V_a^2 G'_{ab} - V_a V_b [G'_{ab} \cos(\delta_{ab}) + B'_{ab} Sin(\delta_{ab})] \quad (3)$$

$$P_{ba}^K = V_b^2 G'_{ab} - V_a V_b [G'_{ab} \cos(\delta_{ab}) + B'_{ab} Sin(\delta_{ab})] \quad (4)$$

Where, $$\frac{r_{ab}}{r_{ab}^2 + (x_{ab} - x_c)^2} \quad (5)$$

and

$$B'_{ab} = \frac{-(x_{ab} - x_c)}{r_{ab}^2 + (x_{ab} - x_c)^2} \quad (6)$$

The abnormal power flow conditions in the transmission line due the presence of series capacitance effect can be compensated by infusing more (complex) power to the transmission line at sending end (S_{ac}) and receiving end (S_{bc}) without series capacitance. It is designed as power injection model of TCSC as shown in figure 3.The power flows mathematical notations are represented as

$$P_{ac} = P_{ab} - P_{ab}^c = V_a^2 \Delta G_{ab} - V_a V_b [\Delta G_{ab} Cos\delta_{ab} + \Delta B_{ab} Sin\delta_{ab}] \quad (7)$$

$$P_{bc} = P_{ba} - P_{ba}^c = V_b^2 \Delta G_{ab} - V_a V_b [\Delta G_{ab} Cos\delta_{ab} + \Delta B_{ab} Sin\delta_{ab}] \quad (8)$$

Where

$$\Delta G_{ab} = \frac{x_c r_{ab}(x_c - 2x_{ab})}{(r_{ab}^2 + x_{ab}^2)(r_{ab}^2 + (x_{ab} - x_c)^2)} \quad (9)$$

and

$$\Delta B_{ab} = \frac{-x_c(r_{ab}^2 - x_{ab}^2 + x_c x_{ab})}{(r_{ab}^2 + x_{ab}^2)(r_{ab}^2 + (x_{ab} - x_c)^2)} \quad (10)$$

III. CRITERIA FOR OPTIMAL PLACEMENT FOR TCSC

The location of Thyristor Controlled Series Compensation (TCSC) at a better place in the test system considered is a prime factor in removing congestion to improve the voltage stability of the system. Optimal location of TCSC helps in better usage of the present functioning transmission lines. The FACTS-device TCSC should be optimally located on the most sensitivity bus or line. In this paper TCSC is located in the line having fewer losses compared to the other lines as it is overloaded.

IV. SIMULATION RESULTS

In this study a new fourteen bus test system has been modeled and introduced for managing congestion by the optimal location of FACTS device TCSC using MATLAB-SIMULINK software. The new fourteen bus test system consists of eight generators, six load buses and twenty lines. The fourteen bus test system is constructed using MATLAB-SIMULINK and the simulation is carried out. The congestion is created by removing a line connected in the midst of bus 3 and bus 4.The fourteen test system without any line interruption under stable condition is-represented in figure 4.

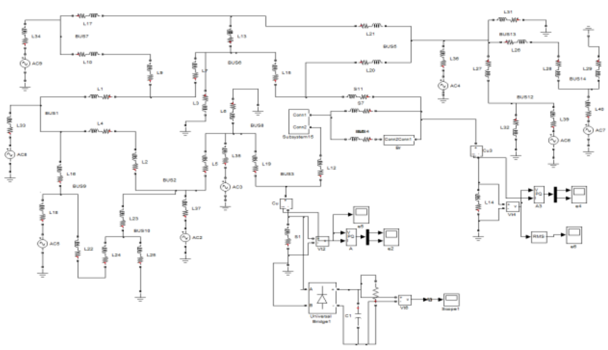

Figure 4. Fourteen Bus Test System Under Normal Condition

Under normal condition without any line interruption the system remains stable with no voltage fluctuations and power problems. The voltage wave form at bus 3 is represented in figure 5.The peak value of the voltage wave form is 6000 V.The RMS output voltage wave form at bus three is presented in figure 6.The real and reactive power at bus 3 is shown in figure 7.The real-power and reactive-power are explained in the table 1.

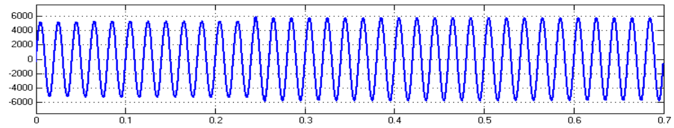

Figure 5.Output voltage at bus 3

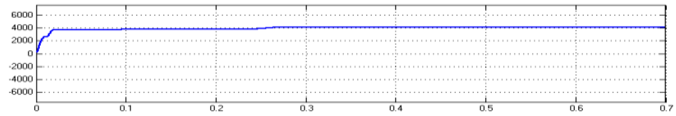

Figure 6.RMS output voltage at bus 3

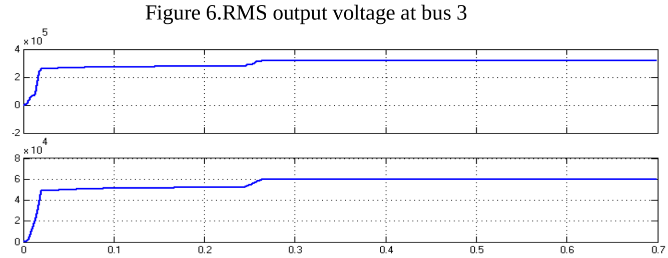

Figure 7.Real & Reactive Power

Table 1.Parameters at bus 3 during normal condition

14 Bus System	RMS Voltage (KV)	Real Power (MW)	Reactive Power (MVA)
Normal Condition	4.12	0.318	0.059

During stable condition of the system without any congested condition, the output voltage of the system remains stable and the power flow remains at normal condition of the rated value. During the faultless condition of the line the RMS voltage of the system is 4.12 KV.The real and reactive powers of the system are 0.318MW and 0.059 MVA respectively.

A. OPTIMAL PLACEMENT OF TCSC

Congestion is created randomly by introducing a new concept called as line interruption method. A transmission line connected in the midst of bus 3 and bus 4 is disconnected from the system to introduce congestion problem. Due to the interruption of transmission line another line connected between bus 3 and bus 4 gets congested. The congestion in the particular line is to be relieved as soon as possible to maintain the stableness of the power system. In this paper the optimal location of TCSC is analyzed by identifying the losses at each bus of the system. The transmission lines connected to the buses with lower losses are identified to be the congested line with power flow exceeding the limit of that particular line. The simulation circuit for identifying the optimal location of TCSC is shown in figure 8.

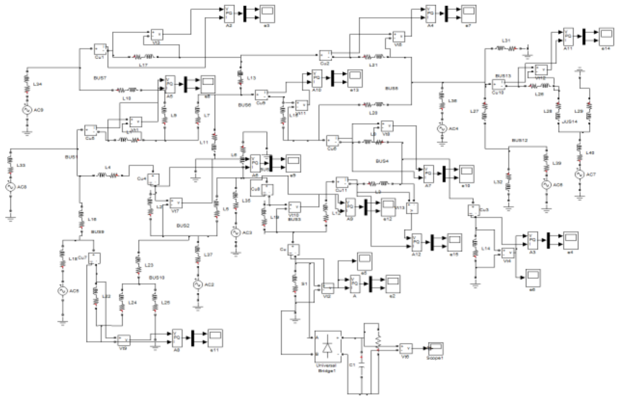

Figure 8.Simualtion circuit of fourteen bus system to identify the optimal placement of TCSC

The true power losses and imaginary power losses of the system after line interruption in the fourteen bus test system is discussed below.

Table 2.Real & Reactive Power losses after line interruption

14-Bus System	Real power Losses after line interruption	Reactive power Losses after line interruption
Bus-1	0.156	0.071
Bus -2	0.143	0.064
Bus -3	0.117	0.069
Bus -4	0.081	0.038
Bus -5	0.163	0.046
Bus -6	0.159	0.049
Bus -7	0.161	0.057
Bus -8	0.157	0.041
Bus -9	0.146	0.063
Bus -10	0.139	0.072
Bus -11	0.178	0.086
Bus -12	0.167	0.053
Bus -13	0.163	0.067
Bus -14	0.158	0.045

The simulation result of real-power losses and reactive-power losses of the fourteen bus test system from the above table reveals that the real power loss at bus 4 is very low. Thus the facts device TCSC can be placed in the midst of bus 3 and bus 4 to remove congestion occurred in line connected to bus 3 and bus 4.

B. SIMULATION OF FOURTEEN BUS TEST SYSTEM WITH TCSC OFF CONDITION & WITH LINE INTERRUPTION.

Fourteen bus system at line S6 interrupted with breaker switch and the better optimized location of TCSC in the midst of bus 3 and bus 4 in off condition is modeled and simulated shown in figure 9.

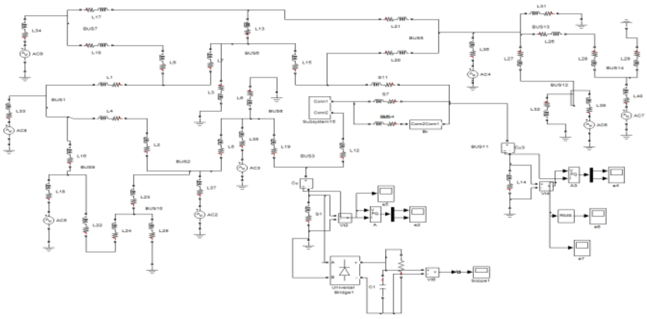

Figure 9.Line S6 Open & TCSC off Condition

During this condition the corresponding parameters are measured. The voltage wave form and RMS voltage wave form at bus three is represented in figure 10 and figure 11 respectively. When comparing the output voltage with line interruption to the output voltage during the normal condition the voltage has been marginally dropped at bus 3.This voltage is dropped in the system due to the interruption of line S6 and overloaded line S7.Similarly the real power and reactive power flow is affected at bus 3. The true power and imaginary power wave forms are shown in figure 12.

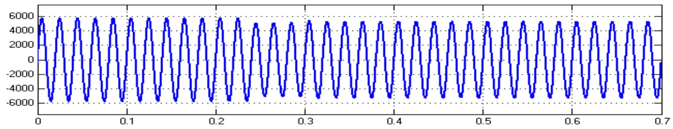

Figure 10.Output voltage at bus 3 with line interruption & TCSC off condition

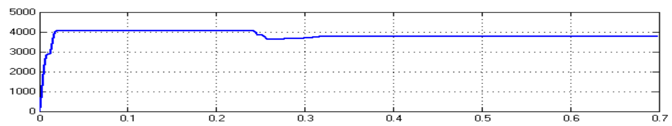

Figure 11.RMS output voltage at bus 3 with line interruption & TCSC off condition

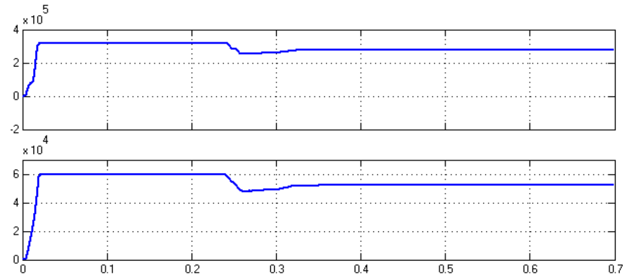

Figure 12.Real & Reactive Power at bus 3 with line Interruption & TCSC off condition

Table 3.Parameters at bus 3 with line interruption & TCSC off condition

14 Bus System	RMS Voltage (KV)	Real Power (MW)	Reactive Power (MVA)
Line S6 open & TCSC off Condition	3.72	0.275	0.050

C. Simulation of Fourteen Bus Test System with TCSC on Condition & With Line Interruption.

Fourteen bus system at line S6 interrupted with breaker switch and better placement of TCSC in the midst of bus 3 and bus 4 in on condition is modeled and simulated shown in figure 13.

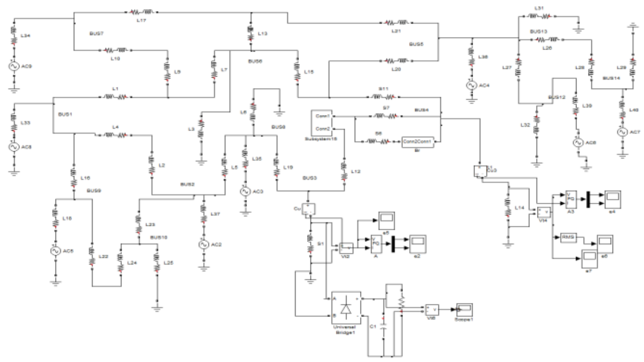

Figure 13.Line S6 Open & TCSC on Condition

The output voltage at bus 3 is shown in figure 14.When compared the output voltage during the line interruption, it is clear that by using TCSC the voltage has been boosted up to the corresponding voltage during normal condition. The RMS voltage wave form at bus three is represented in figure 15.By the placement of FACTS device TCSC in the midst of bus 3 and bus 4, the RMS voltage wave form at bus 3 is retained to the system normal voltage. The true and imaginary powers at bus 3 are shown in figure 16.

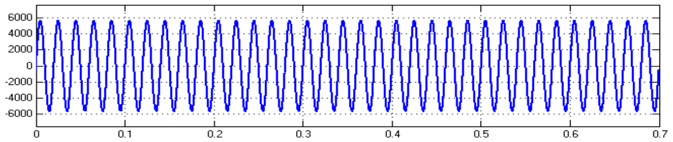

Figure 14.Output voltage at bus 3 with line interruption & TCSC on condition

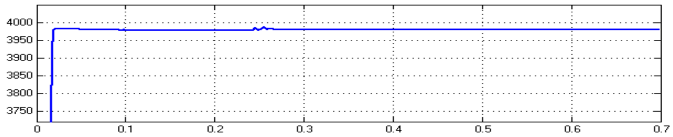

Figure 15.RMS output voltage at bus 3 with line interruption & TCSC on condition

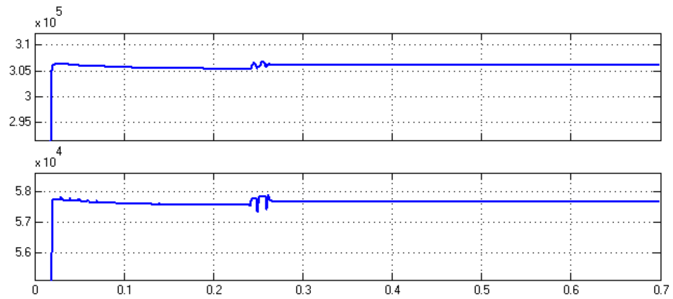

Figure 16.Real & Reactive Power at bus 3 with line interruption & TCSC on condition

Table 4. Comparison of Parameters at bus 3 with TCSC off condition & TCSC on condition

14 Bus System	RMS Voltage (KV)	Real Power (MW)	Reactive Power (MVA)
Normal condition	4.12	0.318	0.059
Line S6 open & TCSC off Condition	3.72	0.275	0.050
Line S6 open & TCSC off Condition	3.98	0.306	0.057

The comparison of all parameters at bus 3 during normal condition, line interruption with TCSC off condition and line interruption with TCSC on condition is discussed in table 4.From the above discussion, it can be seen that by using FACTS device TCSC, the overloaded condition occurred in the midst of bus 3 and 4 is removed by enhancing the voltage stableness of power system and recovering the power flow of the transmission line. By analyzing the output voltage wave forms of figure 10 and figure 14, the peak voltage of the system during the line interruption condition and with TCSC on condition is improved from 3.72 KV to 3.98 KV which is almost very nearer to the system voltage of 4.12 KV at stable condition. From the simulation results it can be suggested that the power flow of the fourteen system is enhanced by optimal location of TCSC in the midst of bus 3 and bus 4 observed from figure 16.During the removal of line S6, the true power at bus 3 is reduced from the normal rated value of 0.318 MW to 0.275 MW.By placing optimally the FACTS device TCSC in the midst of bus 3 and bus 4 the real power flow has been enhanced from 0.275 MW to 0.306 MW very close to the stable condition.

The comparisons of real- power and Reactive -power flow of fourteen bus test system with and without -TCSC during congestion problem is shown below.

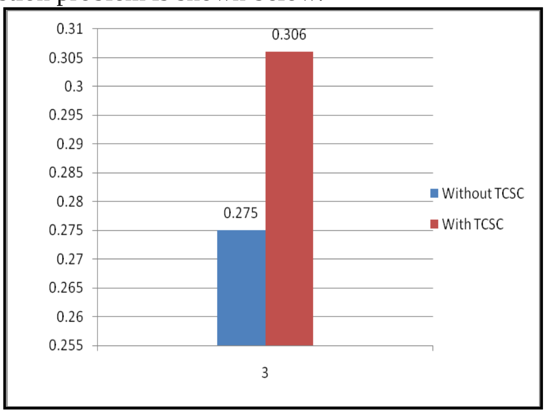

Figure 17. Comparison of real-power (MW).

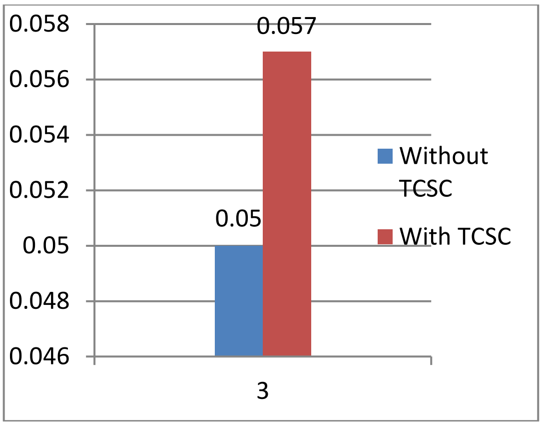

Figure 18. Comparison of reactive-power (MW).

V. CONCLUSION

This paper introduces a new concept of congestion management by line interruption method. Development of FACTS devices has enabled the power engineers to improve the performance of power system. This paper presents the application of facts device TCSC to relieve congestion in fourteen bus test system. A new fourteen bus test system is modeled and simulated without TCSC and with TCSC by interrupting a transmission line. The results obtained in this paper are more encouraging. It shows the utilization of facts device TCSC under optimal location relives the overloading of transmission line efficiently, improves the power transfer capability and voltage stability of the system. The present work can be extended to modeling and simulation of thirty bus system with the utilization of FACTS device TCSC to relieve congestion.

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