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Congestion Management in Fourteen Bus System Using Thyristor Controlled Series Capacitor

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ABSTRACT

Aim: This paper proposes an effective approach for relieving congestion and improves power transfer capability of the power system transmission line. Flexible alternating current transmission system (FACTS) devices are said to be more effective tool in reducing congestion and improve power transfer capability of the system. Many number of FACTS devices are utilized for relieving congestion. In this paper Thyristor Controlled Series Compensator (TCSC) is preferred because of its ability to transfer more power

Modelling and simulation: The Indian fourteen bus test system is modelled and simulated using MATLAB simulink –software. The Work is of two fold. Firstly the Indian fourteen bus test system is modelled without TCSC and with TCSC for linear load. Secondly the Indian fourteen bus test system is modelled without TCSC and with TCSC for non- linear load.

Result: The true power and imaginary power of the Indian fourteen bus test system for cases without TCSC and with TCSC for linear load and non-linear load are obtained from simulation. The result comparisons are performed for all the cases and explained about the importance of using TCSC in power sytem Transmission line.

Conclusion: The simulation result shows that TCSC device is more effective in relieving congestion and improves the power transfer capability of Indian fourteen test system. This paper also presents the best location of TCSC in Indian fourteen test system to reduce congestion and improve power transfer capability of the test system. The future scope of the work can be extended to simulation of thirty bus test system for single TCSC and two TCSC devices.

Keywords: FACTS, Congestion Management, TCSC, power transfer capability, voltage stability, MATLAB.

1. INTRODUCTION

The need of electrical energy is increasing day by day due to the growth of industries and their increased demand. To meet the increased load demand, the power sector is widely expanded by restructuring. The power sector has been deregulated to increase the electrical energy to meet the industrial load demands. Deregulation of power sector led to the participation of private participants in the power sector industry. As the participation of private sector increased their generating capacity, the transmission line has to supply all the transactions by these private entities. This resulted in massive utilization of transmission system. The transmission line has to be operated very close to its physical and thermal limits. Due to the increased demand, there has been some undesired transactions that is violating the operating limits of transmission system which results in transmission congestion. Managing congestion and maintaining the transmission line with in the physical and thermal limits is very difficult in present scenario.

The Independent-system-operator (ISO) has to remove congestion and manage congestion as soon as possible to maintain the stability of the transmission system. Numerous techniques have been adapted in managing congestion generally called as congestion management.

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The research work carried out in this paper deals with improving the power transfer capability of an Indian fourteen bus test system with placement of TCSC with both linear load and non linear load thus relieving congestion that is improving the transmission capability of the Indian fourteen bus test system.

1.1. Literature review

The congestion in transmission lines is overloading of the transmission line which can be relieved by cost-free and non-cost free means. The cost-free means includes the re-modelling of structure of power system, by varying the tappings of transformers and by FACTS devices. Another approach of congestion management is rescheduling of generators and curtailing the loads suggested by Dutta S *et al.* (2008).

Various congestion management methods are followed in the deregulated power system to alleviate congestion management. The Independent system operator (ISO) alleviates congestion in transmission line by varying various control parameters of the power system. Another method of managing congestion is by rescheduling of the participating generators. Congestion alleviation by managing transactional agreements between seller and buyer is also widely followed.

Rescheduling of participating hydro and thermal generating stations using the control parameters of generators and based on the availability of water resources has been implemented to relieve congestion. The paper presented a new evolutionary programming including the renewable hydro power generator and thermal generator by Kanwardeep Singh *et al.* (2011).

Congestion management by most favourable scheduling of Distributed-generators (DG) based on the sensitivity of critical lines and also improving the voltage stability has been proposed as a multi objective function. The new favourable generation of the DG is calculated using Genetic Algorithm proposed by A.K.Singh et al. (2013).

The Real power of the participating-generators is rescheduled to relieve congestion by sensitivity of the generators to the congested line and congestion cost is reduced by different evolutionary algorithms. The paper presented a new algorithm called as bacterial foraging algorithm including Fuzzy. The optimal generators to be rescheduled are obtained sensitivity of the generators to the loaded line and they are rescheduled optimally by foraging algorithm to reduce the congestion cost suggested by Ch Venkaiah el at. (2011).

The Transient stability margin corresponding to the generation and demand is varied to manage congestion in deregulated power system. Using the exact stability margin of the system obtained by sensitivity method, the congestion is reduced and transient stability of the system is maintained after relieving congestion. This method based on transient stability to reduce congestion is proposed by Masoud Esmaili et at. (2010).

Flexible alternating current transmission system (FACTS) is another best alternative power electronics technology that can be adopted for transmission system in enhancing the available Transfer limit and managing congestion. A new method is proposed including FACTS and demand response of the system. Based on the bidding of participating generators the ISO decided the cost of electricity considering the welfare of people and a new re-dispatch of generators to reduce congestion is proposed by AYousefi el at. (2012).

FACTS devices are placed optimally in the transmission network for relieving congestion. Identifying the Correct location of FACTS devices by using various techniques to relieve congestion is proposed .The voltage stability, system losses and overload minimization are considered as the main objective for the operating the power system under reliable condition. These objectives are achieved by placement of TCSC and SVC by using brainstorm optimization algorithm by A. Rezaee jordehi et al. (2015).

The availability of the transfer capability of the transmission line to transfer the true power is improved by placing the facts devices at appropriate location in the power system. This method of improving the efficiency of the transmission line is suggested by Ying X et al. (2003).

A new FACTS operative method is introduced to relieve congestion and enhance the voltage stability of the power system by using series and parallel combinations of UPFC facts controller device proposed by Imran khan et al. (2015).

A single objective optimization and three objective optimization are proposed by placing two types of FACTS devices TCSC and SVC by using genetic algorithm and pareto evolutionary algorithm for relieving congestion, improve the voltage stability and reducing the system losses. This method is tested in IEEE thirty bus system by Vrushali Khatarkar et al. (2016).

A Multi-Objective evolutionary algorithm has been introduced to improve the voltage stability of the power system. The different control parameters of true power is varied to keep voltage within the limit and fuzzy based algorithm is proposed for best placement of FACTS device proposed by J.Preetha Roselyn et al. (2014).

The congestion operating cost, the voltage stability and transient stability are considered as three multi objectives and congestion problem is solved to satisfy the objectives using placement of FACTS devices at the best location of the corresponding system suggested by Masoud Esmaili et.al. (2014).

The TCSC is Placed in IEEE fifty seven bus test system to improve the power transfer capability of the test system by using sensitivity analysis method to find the most critical line that leads to congestion. The sensitivity analysis method is based on the complex power flow of the line and the most favourable tuning is made using firely algorithm by Venkateswara Rao Bathina et al. (2015).

The FACTS devices SVC and TCSC are incorporated in power system with different strategic techniques for reducing congestion and improve power transfer capability. SVC device is placed by identifying the weak node of the system by fuzzy techniques.TCSC is placed by controlling reactive power flows. The multi FACTS scheme is suggested by Biplab Bhattacharyya et al. (2014).

In this paper placement of TCSC in Indian fourteen bus test system has been proposed to enhance the load-ability limit of transmission system. The true power flow transfer is improved by using two TCSC circuit model by improved bus voltage.

The above literature does not deal with reduction of congestion in fourteen bus system using multiple TCSC. This work proposes two TCSCs model to reduce congestion.

1.2. Modelling of TCSC

FACTS devices are proving to be a good invention for improvement of performance of transmission system. FACTS devices are used to boost uo the loadability limit of transmission line, increasing the voltage limit and more real power transfer. One such FACTS device employed for improving performance of transmission system is TCSC.

A Fixed power-injection-model (PIM) of TCSC is shown in Figure 1 which is used for congestion management. The power injection model explains the true and-imaginary power injection by the facts devices.

A Simple illustration of transmission-line with bus-a and bus-b is presented in Figure 2.

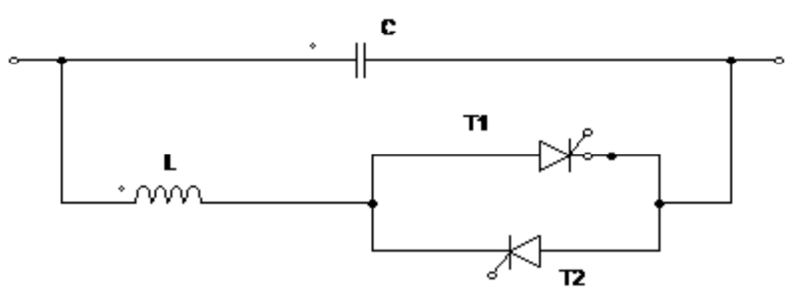

Figure 1: Circuit of TCSC

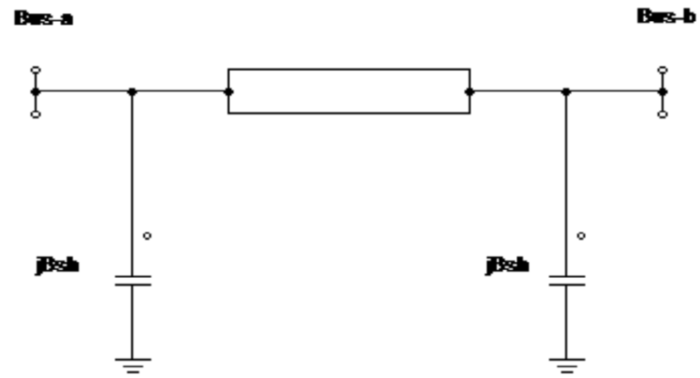

Figure 2: A Simple representation of transmission line

The true-and-imaginary power flow from bus-a to bus-b is given by

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

$$Q_{ab} = -V_a^2 (B_{ab} + B_{sh}) - V_a V_b [G_{ab} \sin\delta_{ab} + B_{ab} \cos\delta_{ab}]] \tag{2}$$

The true-and-imaginary power flow from bus-b to bus-a is given by

$$P_{ab} = V_b^2 G_{ab} - V_a V_b [G_{ab} \cos(\delta_{ab}) + B_{ab} \sin(\delta_{ab}) \tag{3}$$

$$Q_{ab} = -V_b^2 (B_{ab} + B_{sh}) + V_a V_b [G_{ab} \sin\delta_{ab} + B_{ab} \cos\delta_{ab}]] \tag{4}$$

Where,

$$G_{ab} = \frac{r_{ab}}{r_{ab}^2 + (x_{ab} + x_c)^2} \tag{5}$$

$$B_{ab} = \frac{-(x_{ab} - x_c)}{r_{ab}^2 + (x_{ab} + x_c)^2} \tag{6}$$

2. RESULTS AND DISCUSSION

The case studies on Indian fourteen bus test system with and without TCSCs with linear loads and non linear load are presented in this section. The wave forms for true power and imaginary at various buses are obtained by mat lab simulink software and the values are discussed below the wave forms. The result analysis is presented in discussion section.

2.1. Simulation Model of Fourteen Bus System without TCSC and Linear Load

The simulation-model of fourteen bus system with linear load is shown in Figure 3.Each line is modelled as series-impedance and Load is modelled as shunt impedance.

The true-and-imaginary Power at bus-3 are shown in Figure 4 .The current and voltage across bus 3 are shown in Figure 5.

The true power flowing at bus 3 is $3.5*10^5$ Watts and the imaginary power obtained is $10.2*10^5$ Var.This values are obtained by simulating the Indian fourteen bus test system using mat lab simulink software. Here the TCSC is not placed in any of the buses .If TCSC is placed in the best location in the system, the power transfer capability of the system can be boosted up hence utilizing the maximum of the power system.

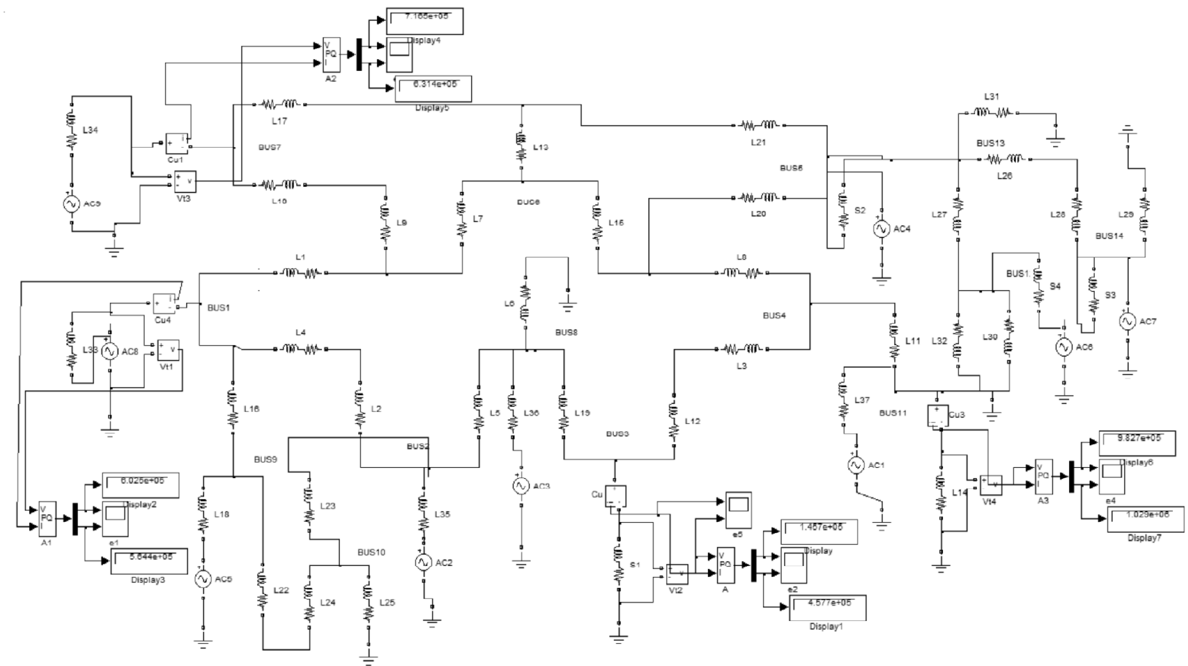

Figure 3: 14 bus system without TCSC and with linear loads

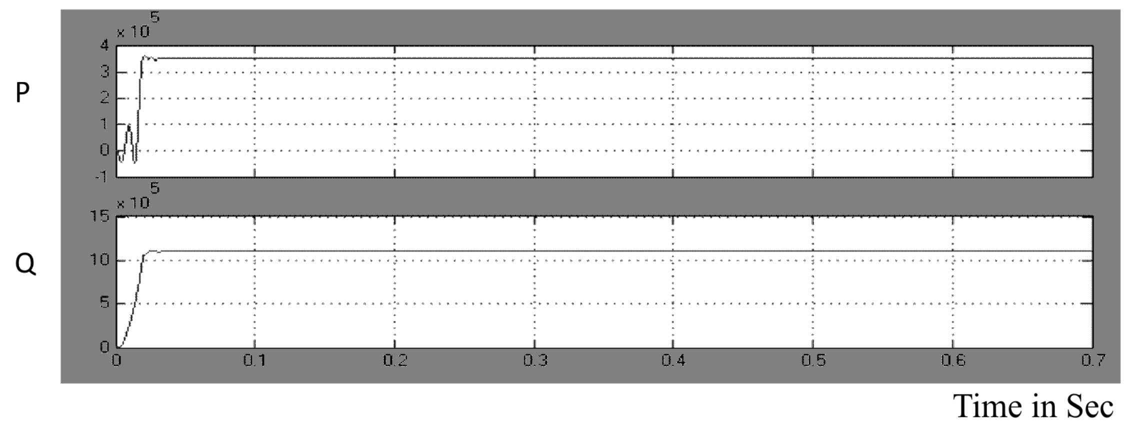

Figure 4: True and Imaginary Power at bus 3

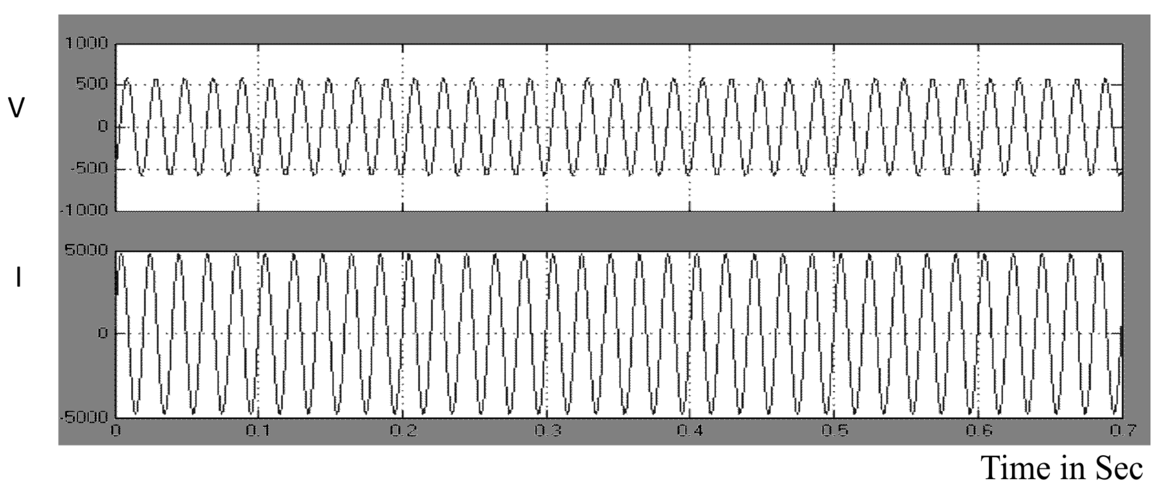

Figure 5: Voltage -and -Current at bus-3

2.2. Simulation Model of Fourteen Bus System employing Two TCSCs with Linear Load

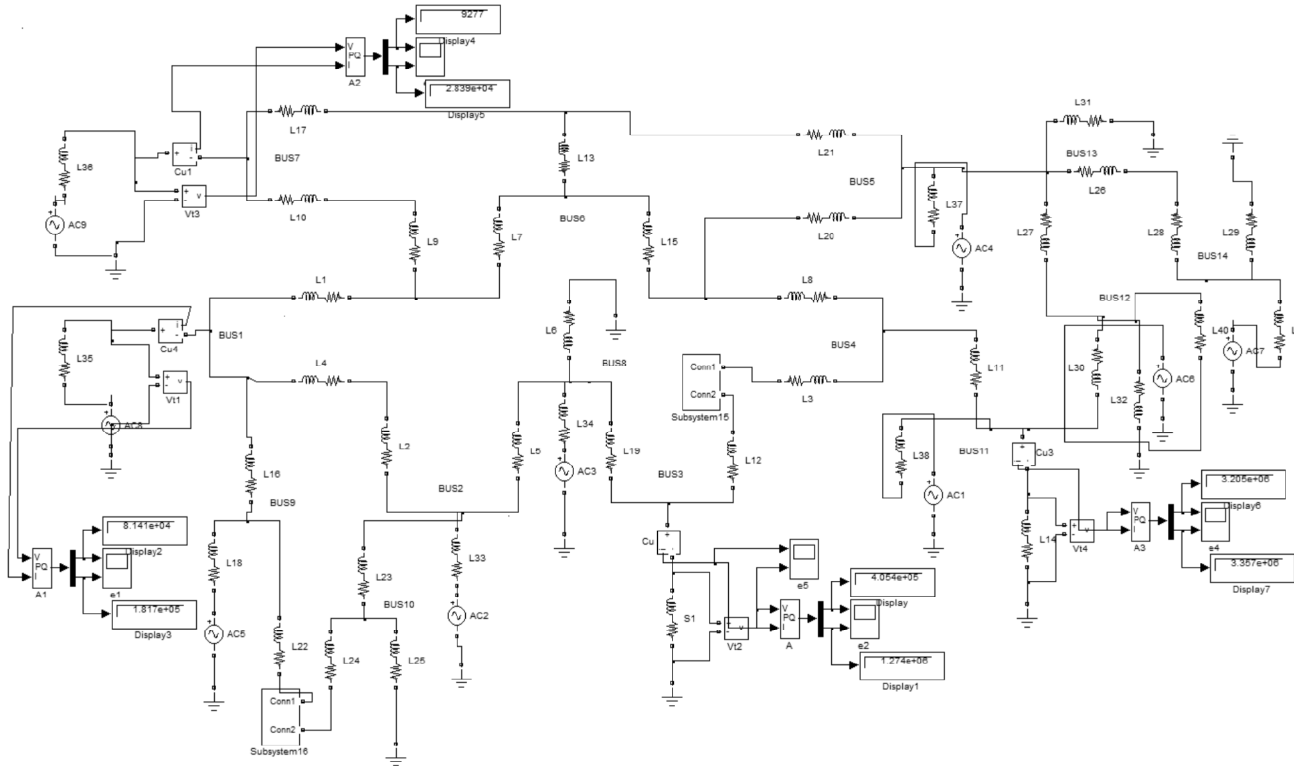

Figure 6: The TCSC model employed for the simulation is shown in the Figure 7

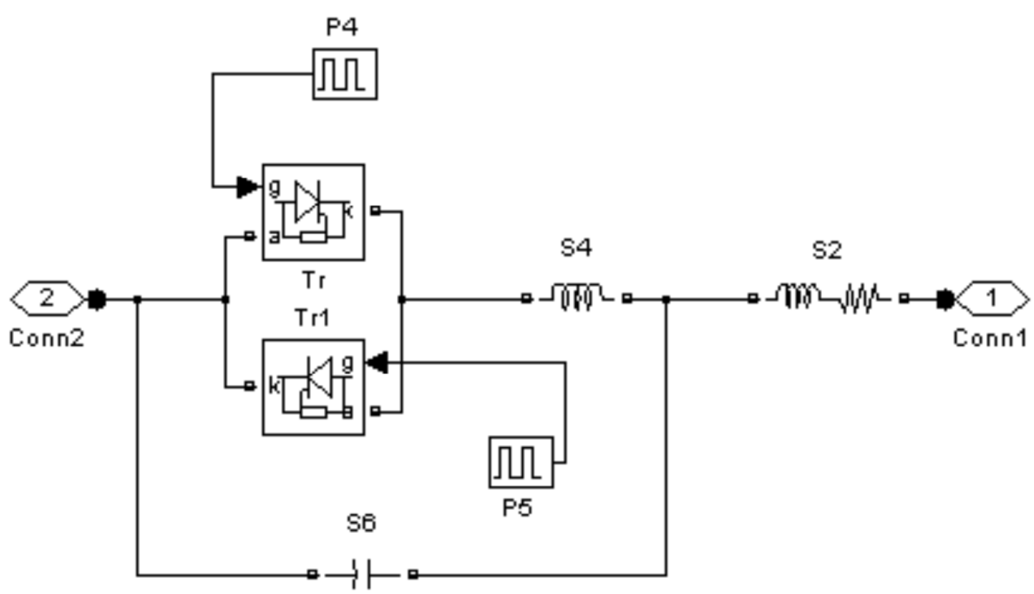

Figure 7: 14 bus system with two TCSC Circuit

The true-and-imaginary powers at bus 1 are shown in Figure 8. The true-and-imaginary powers at bus 3 are shown in Figure 9.The voltage and current at bus 3 are shown in Figure 10.The true-and-imaginary power at bus 7 are shown in Figure11.The true-and-imaginary power at bus 9 are shown in Figure12.The true-and-imaginary power at bus-11 are reported in Figure 13.

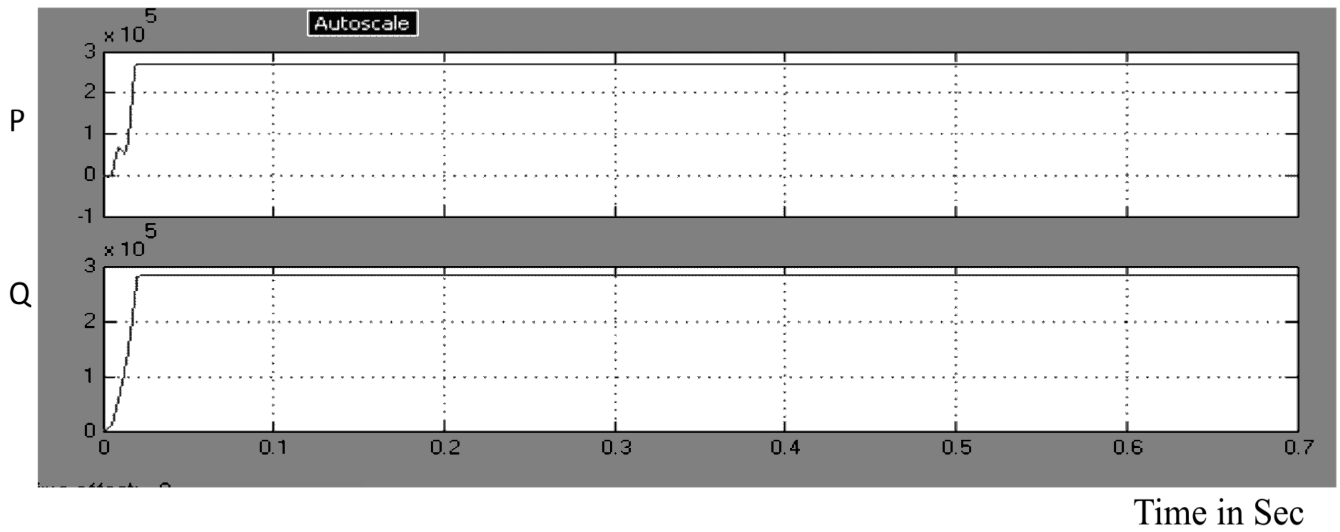

Figure 8: True-and-Imaginary Power at bus 1

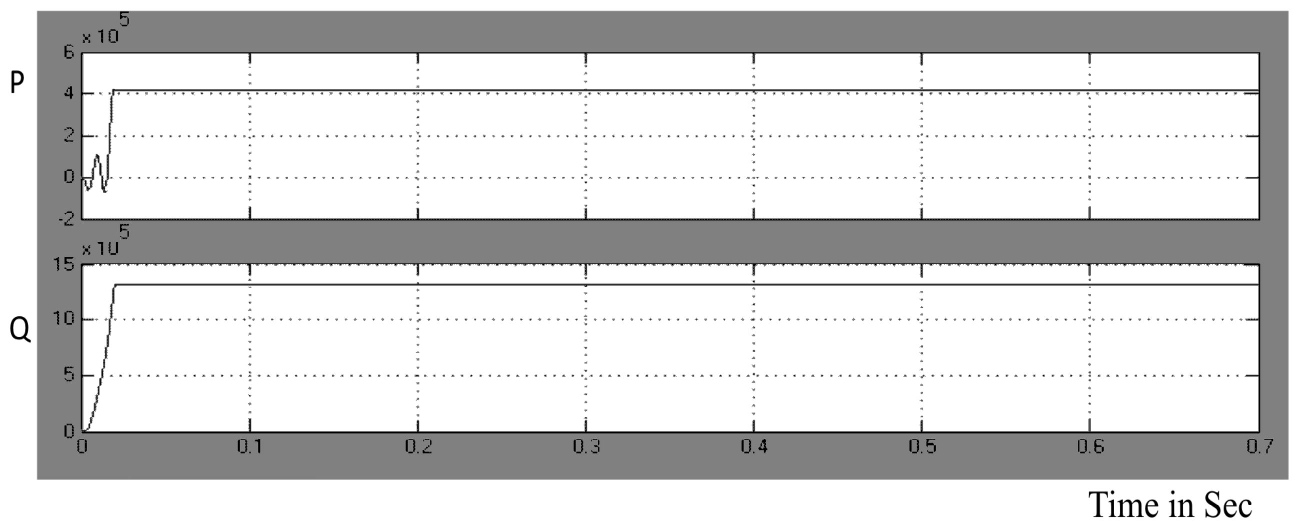

Figure 9: True-and-ImaginaryPower at bus 3

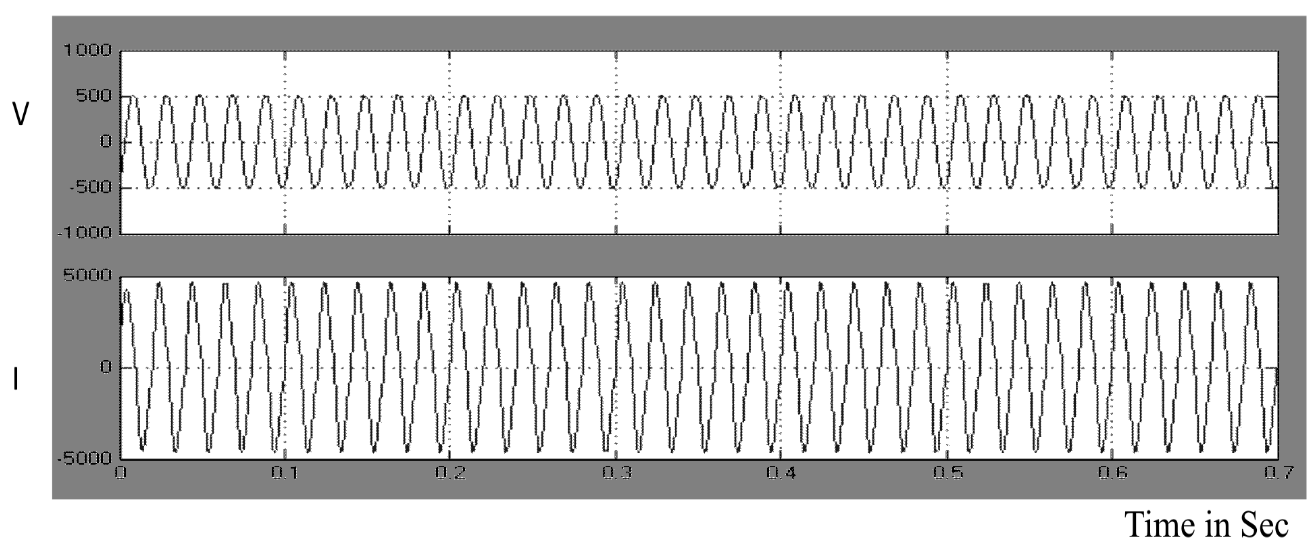

Figure 10: Voltage-and-Current at bus- 3

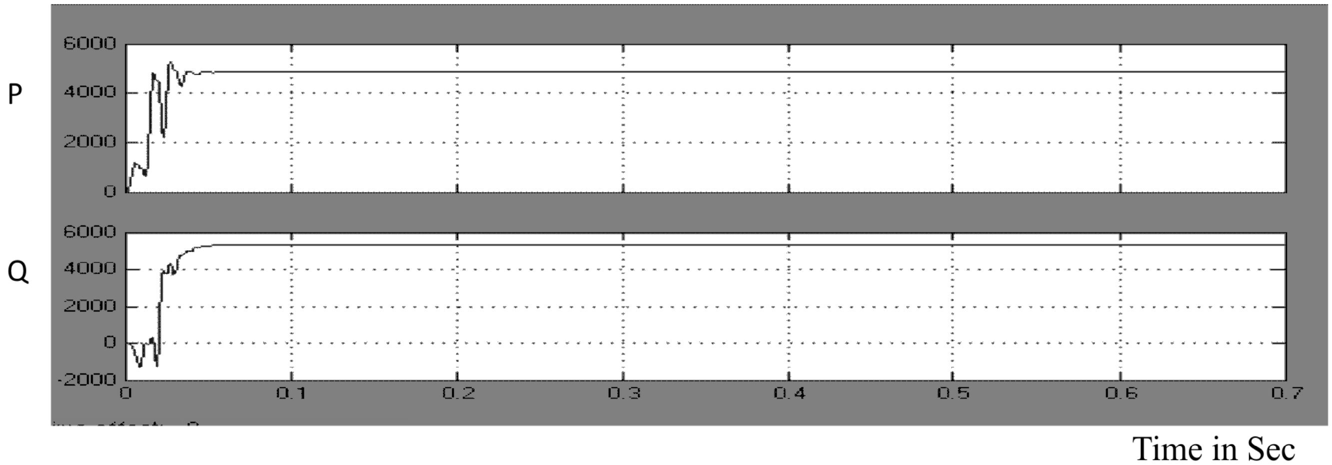

Figure 11: True-and-Imaginary Power at bus- 7

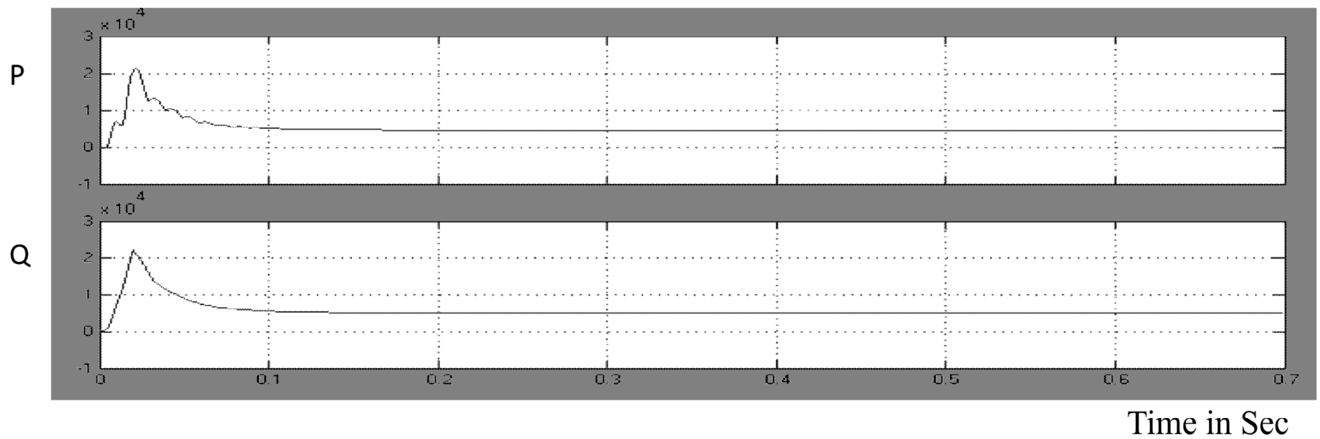

Figure 12: True-and-Imaginary power at bus- 9

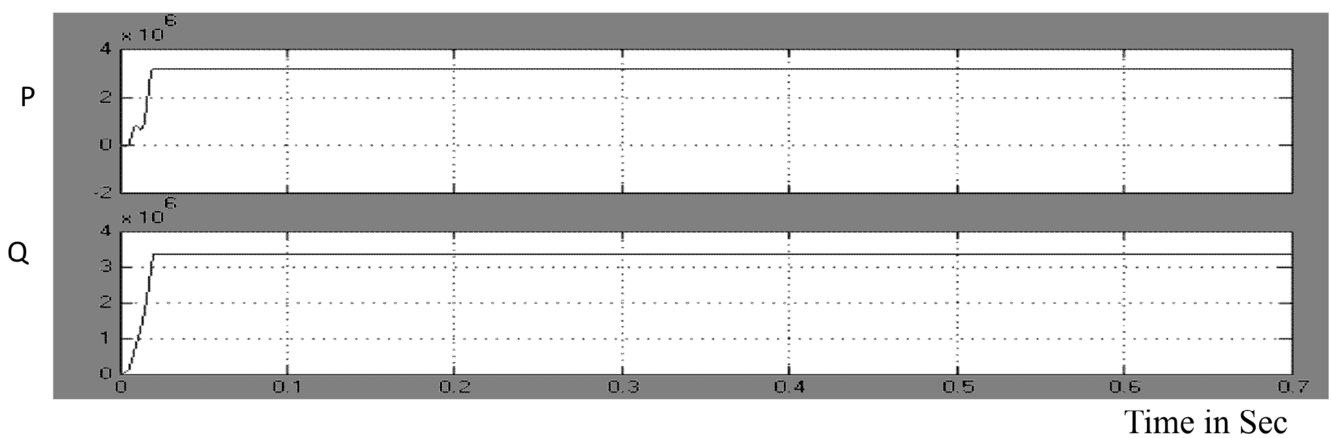

Figure 13: True-and-Imaginary Power at bus- 11

The above wave forms are obtained by simulating the fourteen bus system with two TCSCs circuit. When comparing the output results of simulation models of with and without TCSCs of figure 3 and 6,it is clear that the true and imaginary power flows are improved thus relieving the congestion of transmission line by utilizing the entire load ability limit of the transmission line. The result analysis is presented in discussion section.

Table 1
Summary of reactive powers

Bus No	*Reactive power (MVA) At Alpha (144 DEG)*	*Reactive power (MVA) At Alpha (153 DEG)*	*Reactive power (MVA) At Alpha (162 DEG)*
Bus 1	0.284	0.283	0.280
Bus 3	1.110	1.050	1.00
Bus 7	0.0531	0.034	0.012
Bus 9	0.5218	0.4351	0.412
Bus 11	3.357	3.350	3.30

The summaries of reactive power at various load buses for different firing angle alpha are shown in Table 1.

2.3. Simulation Model of Fourteen Bus System without TCSC for Nonlinear Load

The simulink model of fourteen bus system with nonlinear load is shown in Figure 4.1.In this circuit TCSC is not introduced.

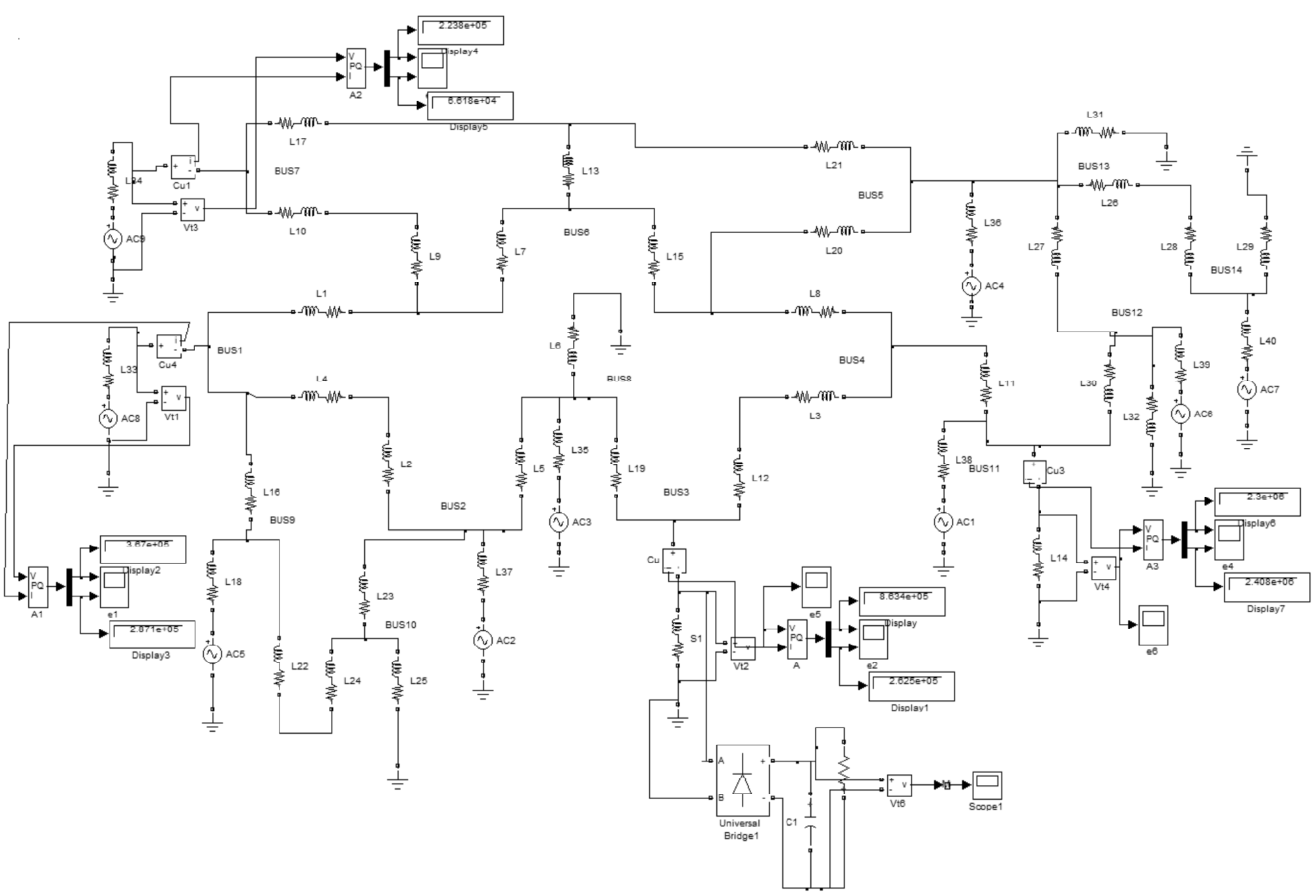

Figure 14: 14 bus system without TCSC & with non linear load

The voltage at bus 3 is shown in Figure 4.2.The true-power and imaginary power at bus 3 without-TCSC for the 14- bus system with non linear load is shown in Figure 4.3.

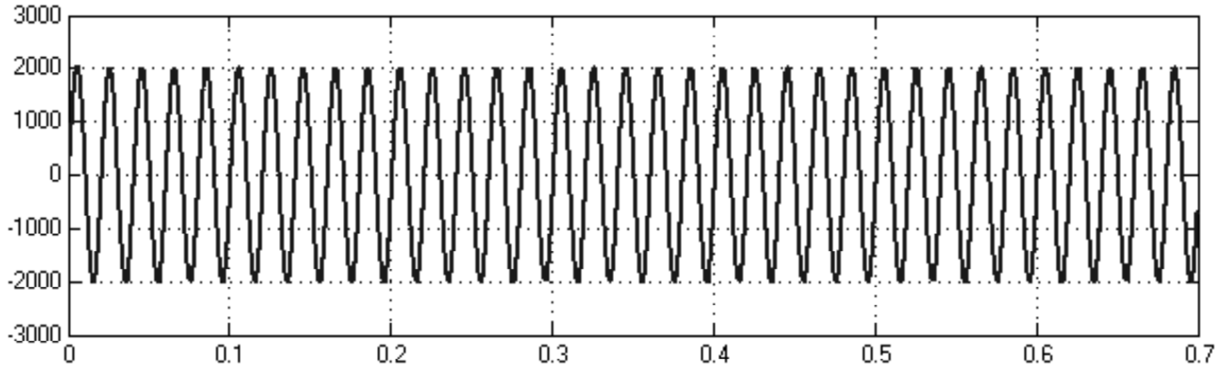

Figure 15: Voltage at bus 3

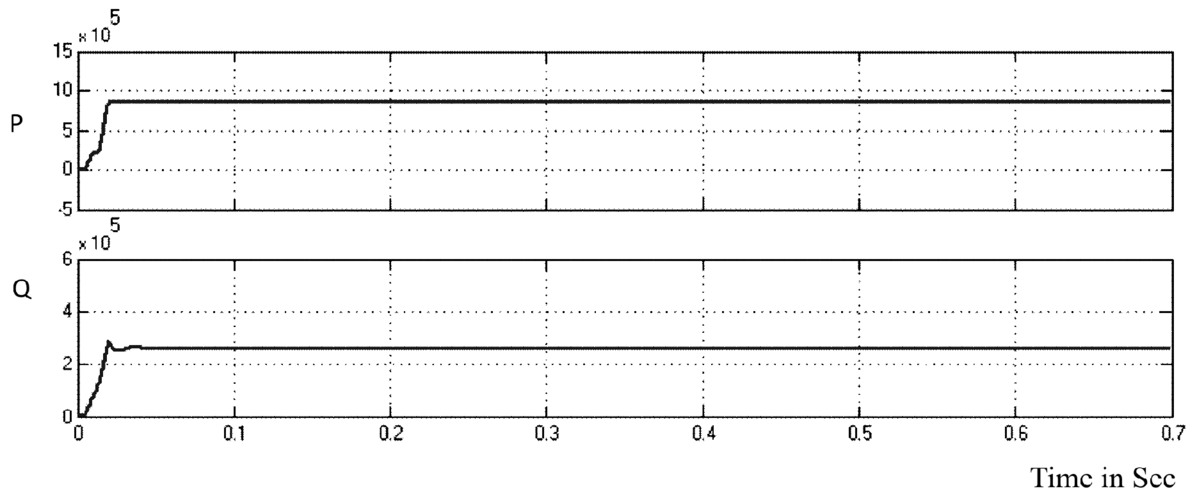

Figure 16: True-and imaginary-Power at bus-3

2.4. Simulation Model of Fourteen Bus System with Single TCSC and Nonlinear Load

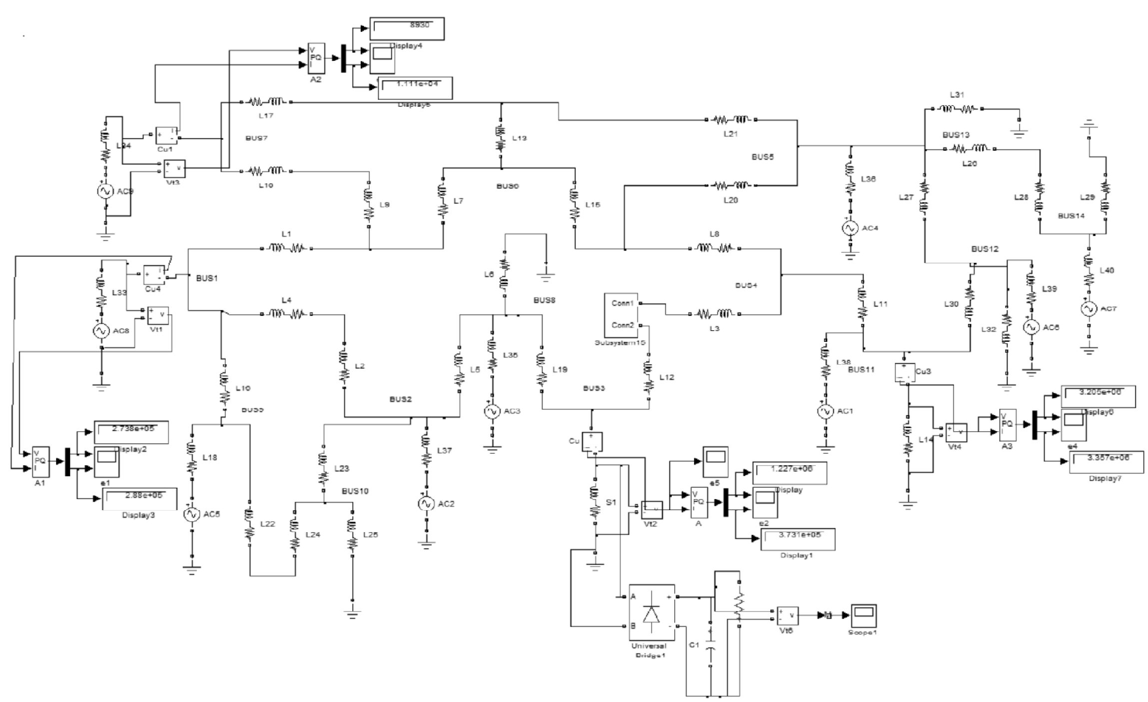

Figure 17: 14 bus system with Single TCSC & with non linear load

The simulink model of fourteen bus system with nonlinear load is shown in Figure 5.1.In this circuit single TCSC has been introduced between bus-3 and bus-4 and the voltage at bus-3 is shown in Figure 5.2 and the true-and imaginary-power at bus 3 is shown in Figure 5.3

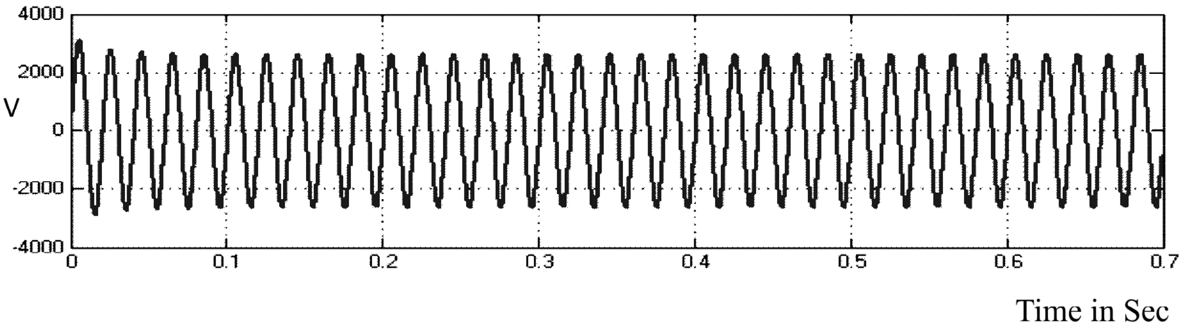

Figure 18: Voltage at bus 3

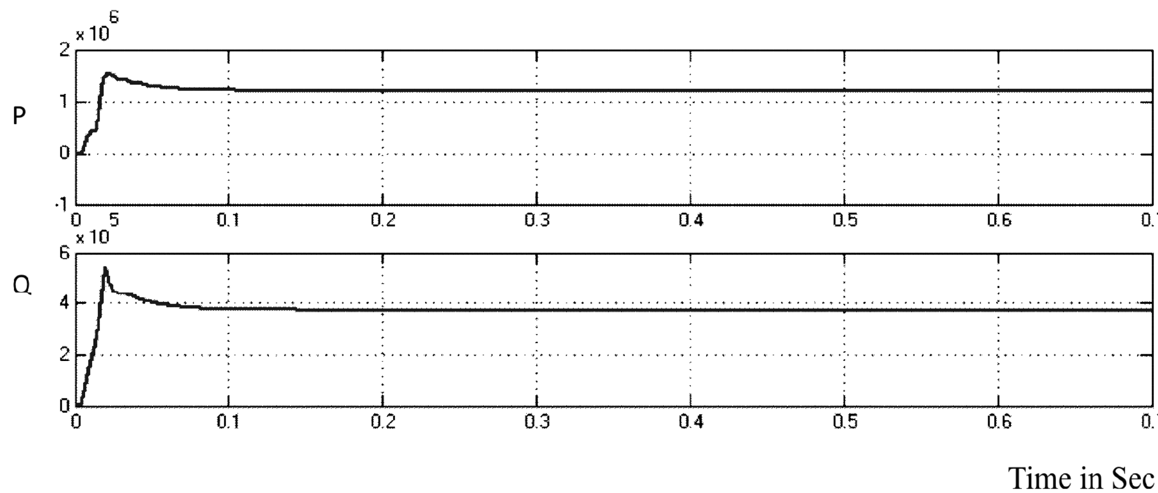

Figure 19: True-and imaginary-Power at bus-3

When the comparing the above simulated output results of simulation model of fourteen bus system without TCSC for nonlinear load as shown in Figure 14 and simulation model of fourteen bus system with single TCSC and nonlinear load as shown in Figure 17, it is observed that the voltage profile at bus 3 and the true and imaginary power flow at bus 3 are improved. The voltage and power flow can be further improved by adding another TCSC circuit and non linear load which is explained below. The result analysis is presented in discussion section.

2.5. Simulation Model of Fourteen Bus System with Two TCSC and Nonlinear Load

The simulink model of fourteen bus system with nonlinear load is shown in Figure 20.In this circuit two TCSCs are introduced .The first TCSC is connected between bus-1 and bus-8.The second TCSC is coupled between bus-3 and bus-4.

The voltage at bus-3 is shown in Figure 21 and the true and imaginary-power across bus 3 is represented in Figure 22.

3. DISCUSSION

The Indian bus fourteen bus test system is modelled and simulated without TCSC and linear load shown in figure 3 and the true and imaginary power obtained are tabulated below.

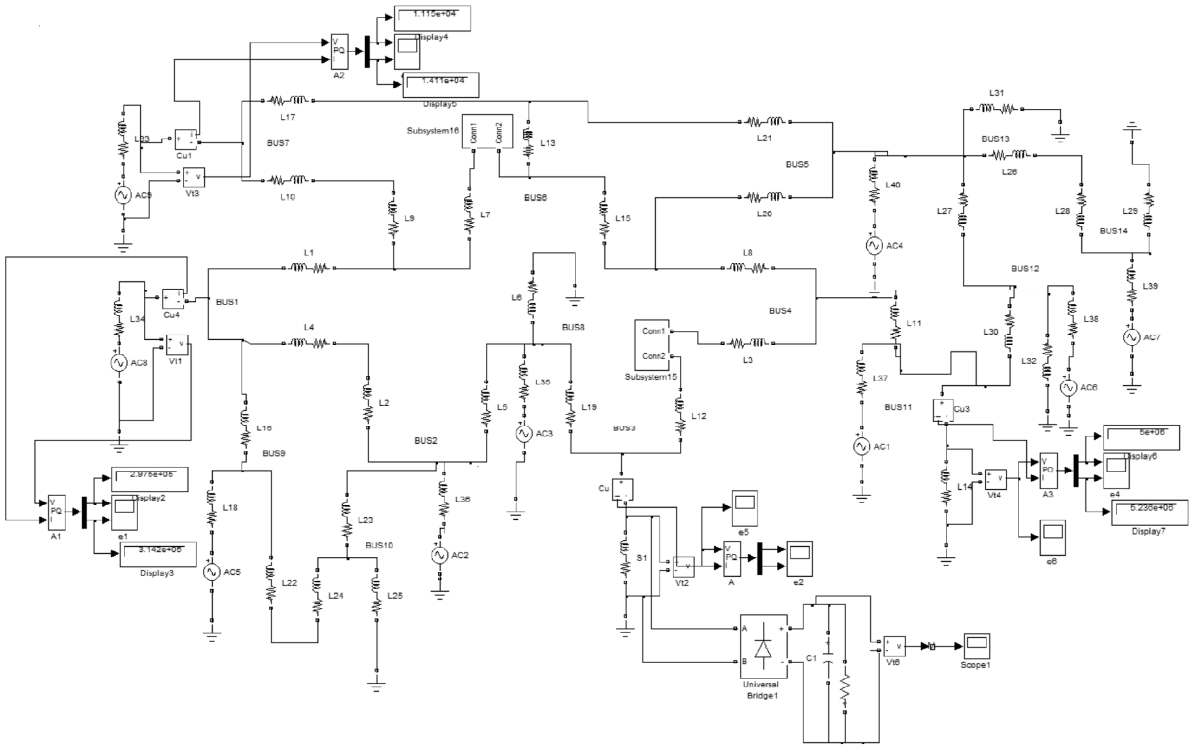

Figure 20: 14 bus system with Two TCSC & with non linear load

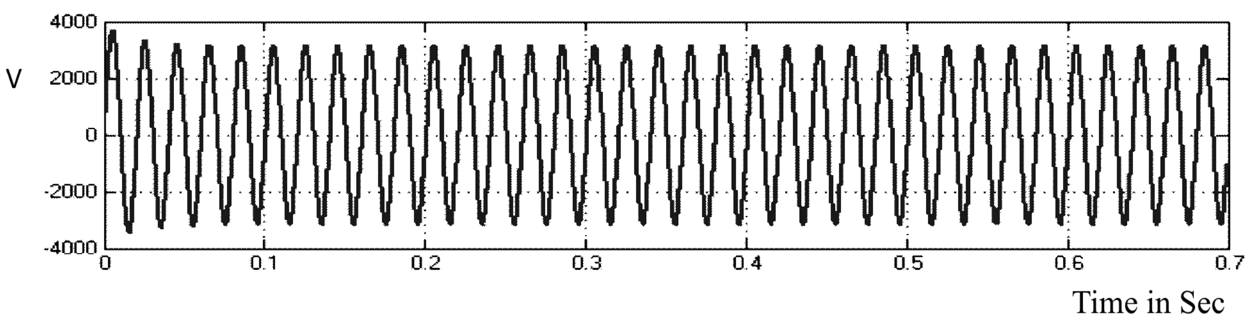

Figure 21: Voltage at bus 3

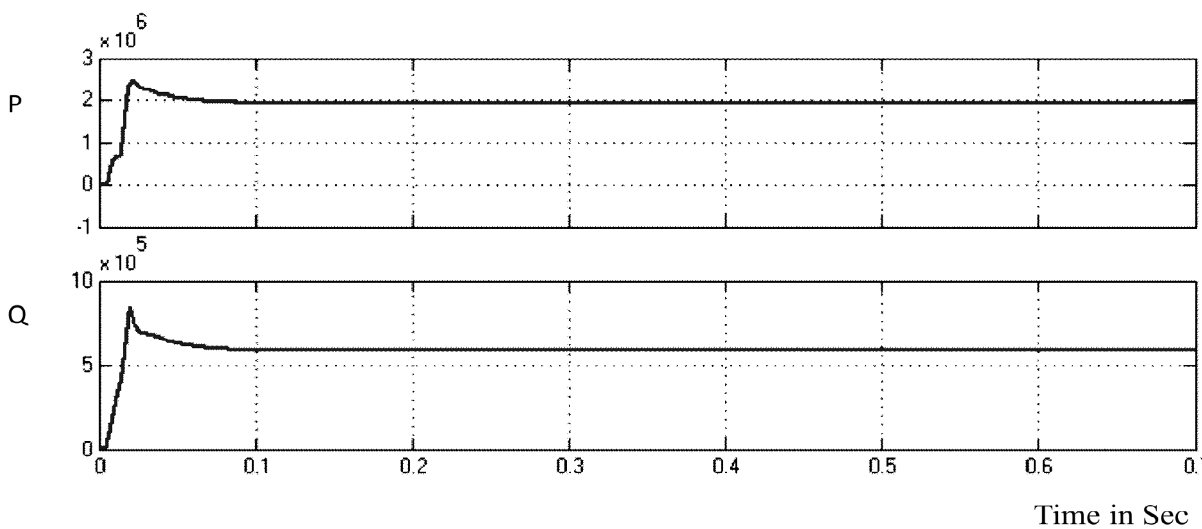

Figure 22: True- and- Imaginary Power at bus-3

Table 2
True and imaginary power obtained Without TCSC for linear load at bus 3

Bus number	*Without TCSC for Non linear load*	
	*True Power*10⁵WATTS*	*Imaginary Power*10⁵Var*
3	3.5	10.2

The Indian bus fourteen bus test system is modelled and simulated with two TCSC and linear load shown in figure 6 and the true and imaginary power obtained are tabulated below.

Table 3
True and imaginary power obtained With Two TCSC for linear load at bus 3

Bus number	*With TCSC for Non linear load*	
	*True Power*10⁵WATTS*	*Imaginary Power*10⁵Var*
3	4	14

From the above results it is observed that at bus 3 in the Indian bus fourteen bus test system the true power and imaginary power is boosted up from $3.5*10^5$ Watts to $4*10^5$ Watts. Similarly, the imaginary power is boosted up from $10.2*10^5$ Var to $14*10^5$ Var after placement of TCSC coupled between bus 3 and 4 and another TCSC coupled between bus 9 and bus 10.

Table 4
Comparison analysis of the above results

Bus number	*Without TCSC for Non linear load*		*With TCSC for Non linear load*	
	True Power $*10^5$ WATTS	*Imaginary Power $*10^5$ Var*	*True Power $*10^5$ WATTS*	*Imaginary Power $*10^5$ Var*
3	3.5	10.2	4	11

When the comparing the simulated output results of simulation model of fourteen bus system without TCSC for nonlinear load as shown in Figure 14, simulation model of fourteen bus system with single TCSC for nonlinear load as shown in Figure 17 and simulation model of fourteen bus system with two TCSC and nonlinear load as shown in Figure 20, it is observed that the voltage profile at bus 3 and the true and imaginary power flow at bus 3 are improved more in the circuit having two TCSC circuit. In this case the single TCSC is coupled between the bus 3 and bus 4 and two TCSC is coupled between 1 and bus 8 and between bus 3 and bus 4.The summary of the voltage and true power for various buses without TCSC, with single TCSC and with two TCSC for the fourteen bus system with non linear load are shown in table 4

Table 4
Summary of true power and voltage at various buses for non linear case

Bus No	*True power without TCSC (MW)*	*Voltage Without TCSC*	*True power with single TCSC (MW)*	*VoltageWith single TCSC*	*True l power With two TCSC (MW)*	*Voltage With two TCSC*
3	0.0851	2000	0.1154	2850	0.1721	3107
4	0.0923	2850	0.1258	2987	0.1786	3450
6	0.1058	3120	0.1254	3087	0.2481	3789
8	0.1178	3189	0.1725	3150	0.2498	4051
10	0.1250	3278	0.2389	3247	0.3597	4879
11	0.1375	3378	0.2851	3323	0.4210	5546

From the above table the results explain about the importance of placing TCSC in power system to improve the power transfer capability of the system and improving the dynamics of the power system. The result shows the comparison of true power flow with improved voltage level with single TCSC and two TCSC.The summaries of the imaginary power presented in table 1 for the simulation of fourteen bus system with two TCSC and linear load shows that the true power and imaginary power can be boosted by varying the firing angle of TCSC.

4. CONCLUSION

The fourteen bus system has been simulated with and without TCSC for both linear and non linear loads to observe its performance. It is clear that the real power transmitted with TCSC is higher than without TCSC. The real power flow with single TCSC increases due to the improved bus voltage. The enhancement of real-power flow in the fourteen-bus system is also much better with the introduction of two TCSC devices.

The FACTS device TCSC is implemented as it is cheaper than other FACTS devices such as UPFC and IPFC. It is observed that TCSC is more suitable to reduce transmission congestion and to control the power through the transmission lines. The disadvantage of TCSC is that it introduces current harmonics into the transmission line.

The scope of the present-work is to reduce the congestion in fourteen bus system. The congestion management in thirty bus system will be done in future and also can be expanded to determine the optimal placement of TCSC by suitable programming.

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