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Enhancement of Power Transfer Capability of Transmission Line Using Thyristor Controlled Series Capacitor (TCSC)

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***Abstract:** Electricity demand is increasing with the increase in urbanization and industrialization. And to meet this increasing demand, the power generation system has been rapidly increased. But along with increase in generation capacity, transmission capacity also needs to be increased simultaneously. For this, either new transmission line needs to be added in the network or power transfer capability of the existing transmission line needs to be enlarged. Latter is the more preferred choice as it involves less cost and time than to erect the new transmission lines. Power transfer capability of a transmission line can be improved by the adjustment of various parameters of a power system network such as voltage phase angles of the buses connected by the lines, impedance of the lines, etc. For this several power electronics-based FACTS devices have been developed, which are most effective in manipulating these parameters to control the power flow through the lines. In this paper, the use of thyristor-controlled series capacitor (TCSC) is highlighted. In this paper, TCSC is implemented in series with line, connecting two buses, to reduce line series impedance. From the results, it is seen that TCSC implementation increases power transfer capability and stability limit, while improving voltage regulation.*

***Keywords:** FACTS, MATLAB/Simulink, Power Quality, TCSC.*

1. INTRODUCTION

Demand for electricity has pointedly increased globally, however power generation and transmission capacities have not increased correspondingly with this increasing need. To fulfil the load demand, either electrical system network has to be upgraded or the transmission line power transfer capability is needed to be boosted. But from economic point

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of view, alteration of electrical network is an expensive option. Also, preserving the stability and reliability of the interconnected power system will become challenging task for the power system operators. To solve these ramifications, the capacity for available power transfer of a transmission network should be improved. Researchers from all across the world have used flexible AC transmission system (FACTS) devices to overcome this issue. “FACTS are defined as power electronics-based system and other static equipment which has the ability to enhance controllability and increase power transfer capability” (IEEE). ‘Thyristor controlled series capacitor (TCSC)’ is one of the series compensating Flexible Alternating Current Transmission System (FACTS) devices. It consists of a series compensating capacitor shunted by a Thyristor Controlled Reactor (TCR). Thus, to solve these problems, instead of installing new transmission lines, TCSC can be used in existing transmission lines in the interconnected power system. This allows the optimum utilization of the existing transmission lines. The term used for the improvement of power quality along with the increase in transmission line loadability is called ‘power flow enhancement’.

Several studies have been conducted on the use of TCSC to enhance power transfer capability. For example, a study by X. Zeng et al. (2017) proposed a new control strategy for TCSC based on a combination of power flow control and voltage stability enhancement. The proposed strategy was able to improve the power transfer capability of the transmission line by up to 15%. Another study by Y. Li et al. (2019) investigated the use of TCSC to enhance the power transfer capability of a transmission line under different operating conditions. The study found that TCSC was able to effectively boost the line power transfer capability by up to 25% under normal operating conditions and by up to 50% under emergency conditions. Additionally, a study by A. Raza et al. (2018) proposed a new control strategy for TCSC based on artificial intelligence (AI) techniques. The proposed strategy was able to improve the power transfer capability of the transmission line by up to 20%.

2. MATERIALS AND METHODS

2.1 Matlab

MATLAB SIMULINK is a simulation and model-based design platform developed by MathWorks. It allows users to design, simulate, and analyze dynamic systems using block diagrams and chains nonlinear and linear systems, modeled in continuous time, sampled time, or a hybrid of the two. It can be used to model and simulate a wide range of systems, including mechanical, electrical, electronic, and biological systems, as well as control systems, signal processing, and communications systems. It also provides a wide range of tools for analyzing and visualizing simulation results and can be integrated with other MATLAB functions and toolboxes.

2.2 Two-Bus System Parameters

The model of the two-bus electrical system with TCSC device was prepared and simulated in Simulink of MATLAB R2019a [10]. The parameters of the model are as follows:

Ideal 3-phase voltage source

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The line-to-line voltage VLL = 11 kV
Frequency f = 60 Hz

3-phase parallel RL load
Configuration Y = Grounded

3-phase line
Line resistance R =6.0852Ω
Line inductance L=0.4323H.

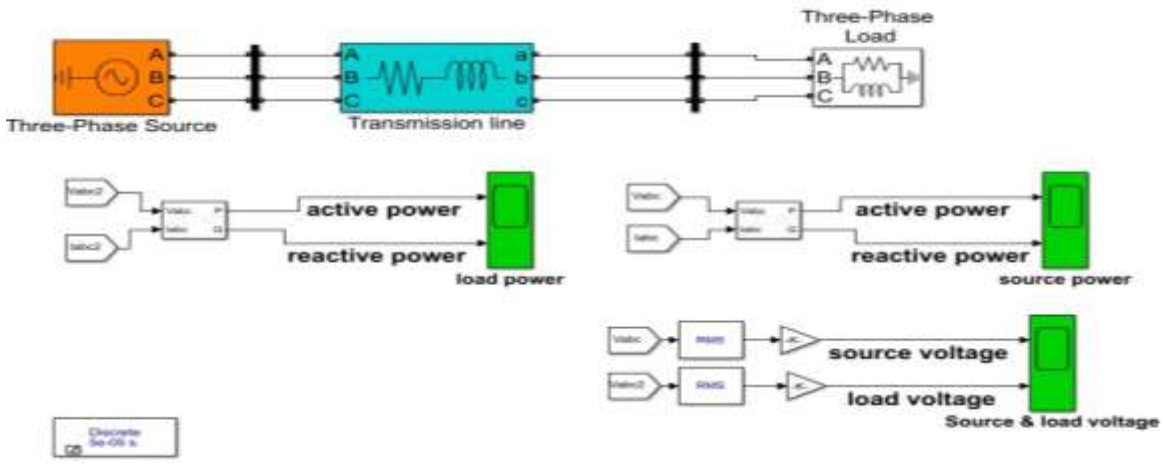

Figure 1. Two-bus system

2.3 Two Bus System with TCSC

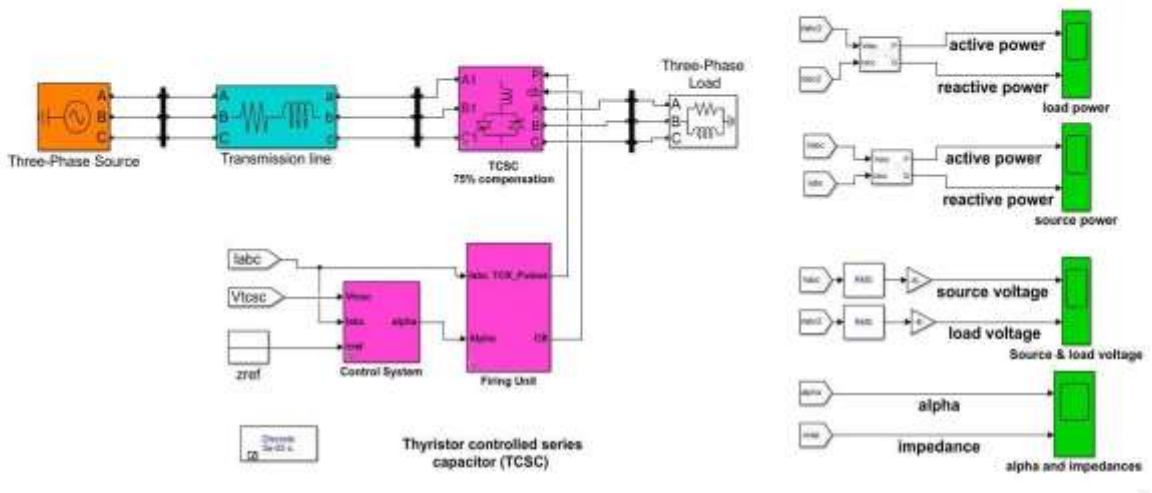

Figure 2. Two-bus system with TCSC

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Here, the blocks in pink color constitute the complete TCSC system, consisting of the TCSC block and its control system and firing unit as shown above. The value of the impedance of the series compensator (TCSC) corresponding to the desired value of the degree of compensation is given to the control system as reference impedance and the control system consists of a PI controller which continuously adjusts the firing of thyristor by providing appropriate firing instants of the thyristors, based on error signal obtained by linking reference with the measured impedance of TCSC, to the firing unit. This, in turn, ultimately adjusts the impedance of TCSC to approach the reference impedance corresponding to the desired degree of compensation of the transmission line. The Simulink model of the control system is shown below:

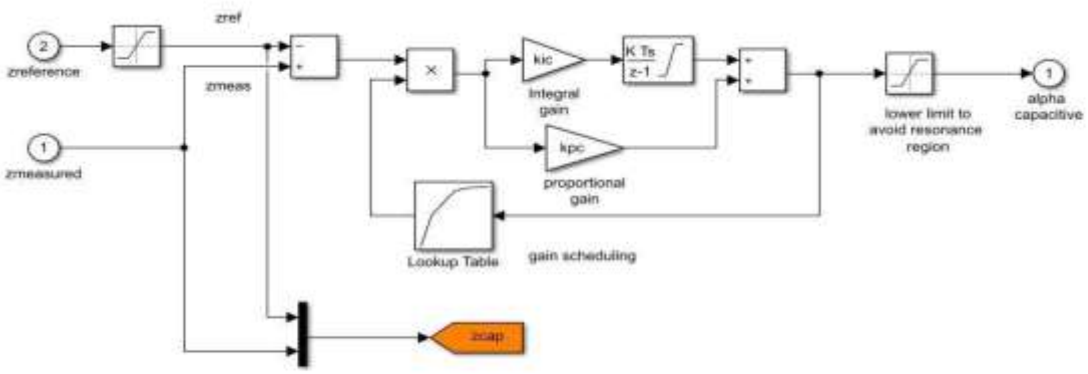

Figure 3. Control system

To avoid resonance regions, a saturation block is used. It restricts the value of ‘α’ to lie within the capacitive reactance region. Also, a 2-d lookup table is used for the gain scheduling of the amplifier(multiplier) used for amplifying the error signal obtained after subtracting reference impedance from the measured impedance. For measuring impedance, the RMS value of TCSC voltage is divided by the value of line current. Also, the firing unit is as shown below:

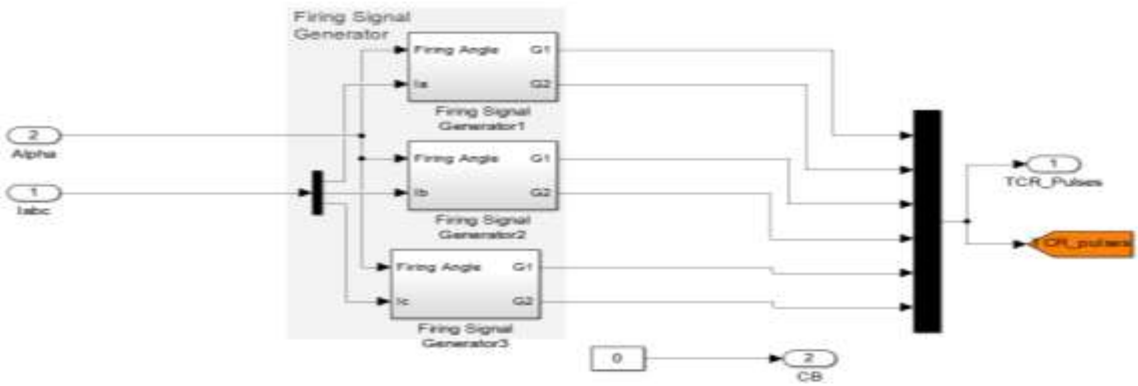

Figure 4. Firing unit

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After obtaining the value of ‘α’ from the control system, the firing unit triggers the thyristors when the line current advances by the angle equal to the value of ‘α’ obtained from the control system. For this, it delays the conduction of the firing signal to the thyristors until the line current advances by the angle equal in value to ‘α’ It consists of separate firing units for each of the phases. And firing unit of each phase controls the firing of the anti-parallel thyristors of the respective phase of the TCSC block.

2.4 Calculation of TCSC Parameter

For the range of 0o to 90o of α, XL(α) starts to change from actual reactance XL to infinity. This controlled reactor is coupled across the series capacitor so that the variable capacitive reactance is possible across the TCSC to alter the impedance of transmission line.
The delay angle α is measured from the line current zero crossing. We have performed a simulation of TCSC in Simulink on a 2-bus system. For this, we have calculated parameters of TCSC for example fixed capacitance and inductance of inductor of shunted TCR. Which is as described below:

- In the above model, the inductive reactance of the transmission line is 162.973Ω.
- For determining the value of fixed capacitance, we have taken the degree of compensation (k) =75% so the value of XC comes out to be 122.23Ω and the corresponding value of the capacitor is 21.77µF.
- To avoid resonance between parallel inductive and capacitive reactance, a factor ‘ω’ is advised to be kept between 1 & 3. From this value of Xl comes out to be 30.56Ω, and the corresponding value of the inductor is 0.081H.
- The resonance characteristics of TCSC greatly depend upon the value of ‘ω’. And hence upon the values of L & C.
- If the value is greater than ‘3’, then the characteristics will have two resonance regions, which ultimately reduces the operating range of TCSC.

From below tabulated value, it can be observed that the impedance is positive for the value of ‘α’ form 0o to 45o, which means that the TCSC offers inductive reactance. And from 50o to 90o, it offers negative impedance i.e., it behaves as a variable capacitor offering variable capacitive reactance, and this capacitive reactance is used for the series compensation of the line.

Table 1. TCSC impedance table

Alpha (in radian)	**Alpha (in degree)**	**TCSC impedance (in ohm)**
0	0	203.8372607
0.0873	5	238.3158591
0.1745	10	288.5334349
0.2618	15	333.4000015
0.3491	20	388.4473338

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0.4363	25	469.8685298
0.5236	30	469.8685298
0.6108	35	584.3456365
0.6981	40	3408.929653
0.7854	45	15561.98387
0.8726	50	-5360.027287
0.9599	55	-2163.99555
1.0472	60	-1305.758214
1.1344	65	-124.3330572
1.2217	70	-105.5050193
1.3090	75	-62.71757366
1.3962	80	-42.10962985

Also, it can be observed that the impedance of TCSC, either positive or negative, has very high value for the range of 25o to 60o. This high value of impedance is due to parallel resonance between the fixed capacitor and inductance of TCR, and so this region is known as 'resonance region', which needs to be avoided by the control circuit of TCSC.

3. RESULT AND DISCUSSION

3.1 Result without TCSC

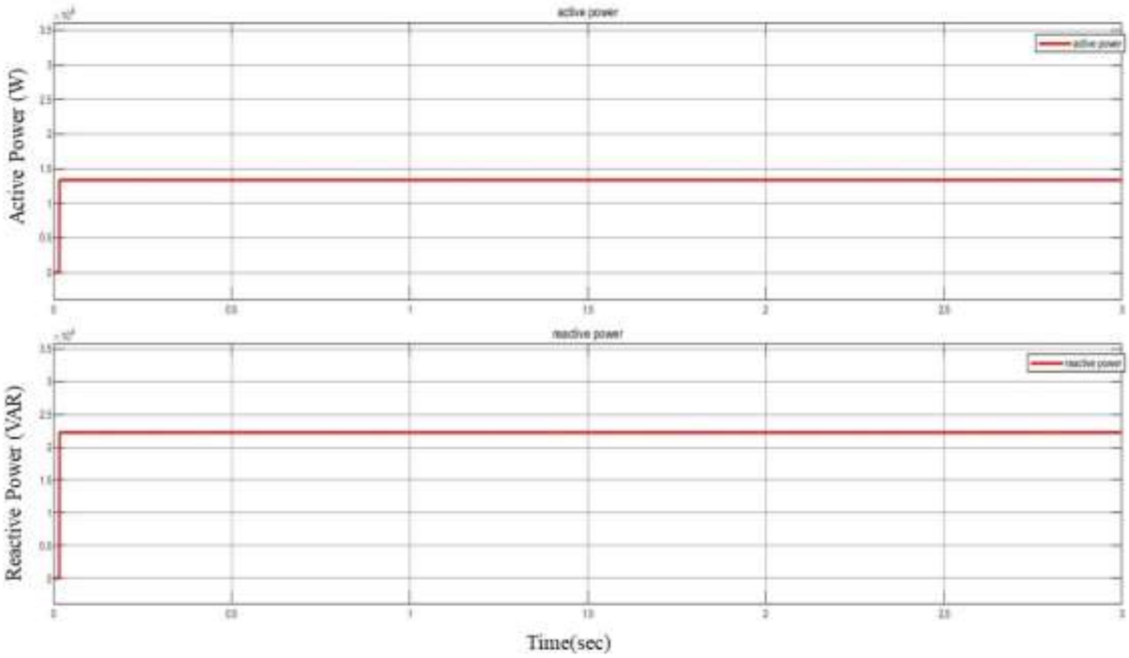

Figure 4. Load active and reactive power

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Figure 5 indicates that the value of load active and reactive power without TCSC is 139.65 KW and 22.5 KVAR respectively, which is less than the actual demand of the load and hence it can be concluded that the power demand of load exceeds the power transfer capability of the line due to voltage drop exceeding the allowable limit of 5%.

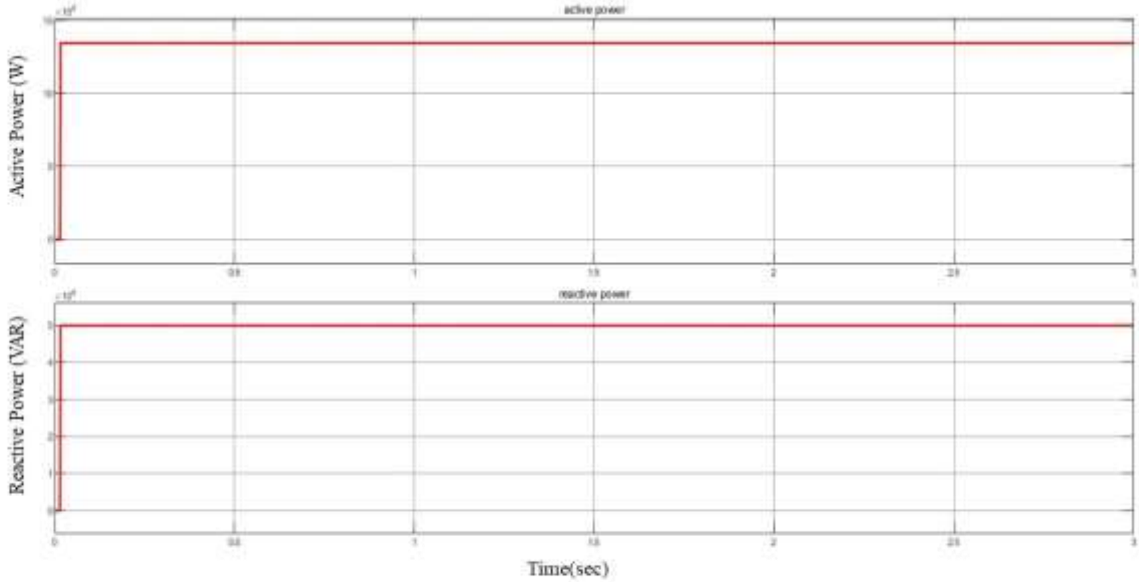

Figure 6. Source active and reactive power

Figure 6 shows that the source active and reactive power without TCSC is 140 KW and 50 KVAR respectively. There is huge difference of (50-22.5 =) 27.5 KVAR in reactive power supplied from the source and the reactive power reaching the load. This amount of reactive power is consumed by the transmission line, as line acts as sink of reactive power, due to its high value of inductive reactance.

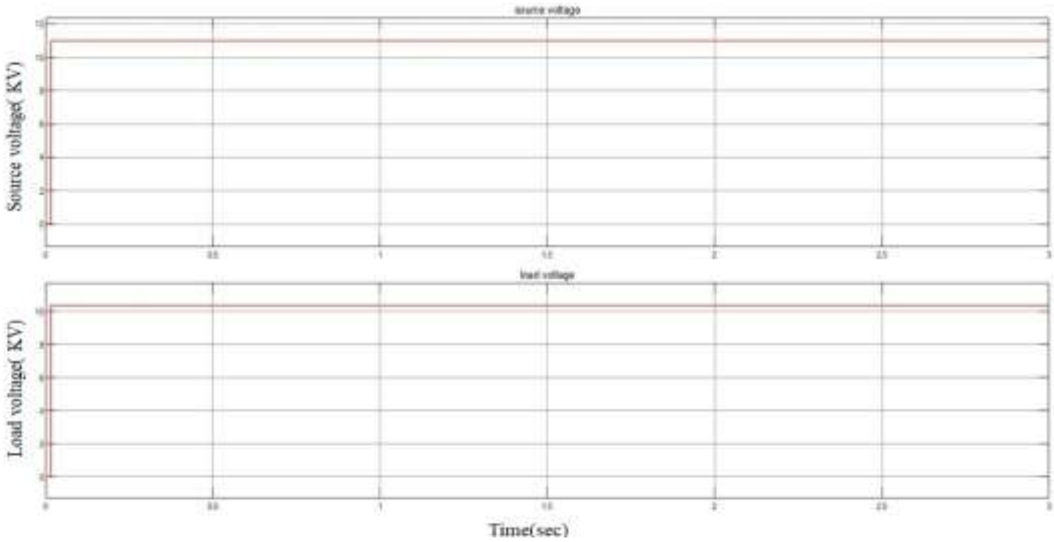

Figure 5. Source and load voltage

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Figure 7 demonstrates that the source and load voltage without TCSC is 11KV and 10.25KV respectively. So, the voltage drop in the line is more than the acceptable limit of 5%, which means the line is violating the voltage regulation limit.

3.2 Result with TCSC

The simulation of two bus system with TCSC, and the same value of load as above, is done and results is obtained as shown below:

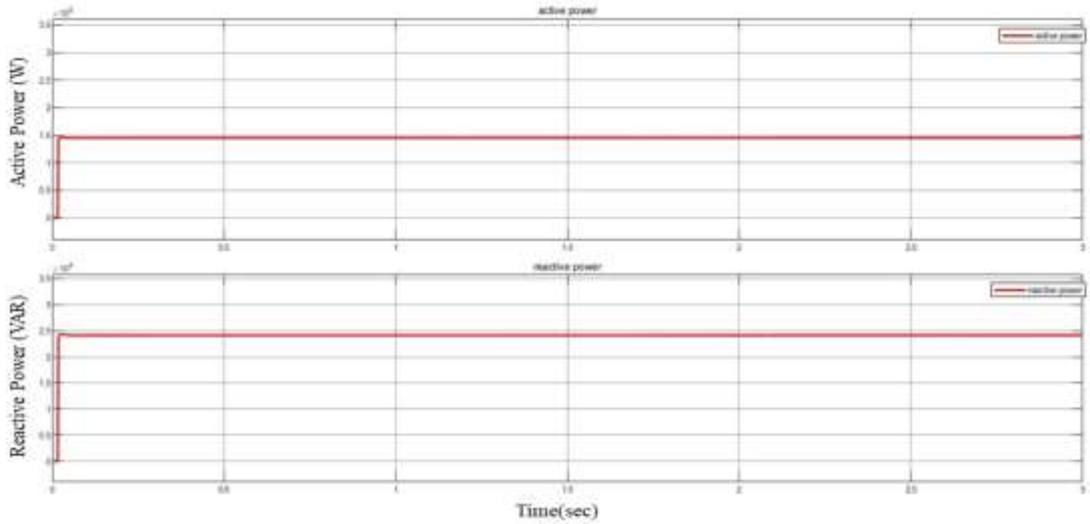

Figure 6. Load active and reactive power

Figure 8 shows that the load active and reactive power with TCSC is 148.23KW and 24 KVAR respectively, which is very close to the actual power demand of the load. So, the line is now capable of supplying the power demand of the load.

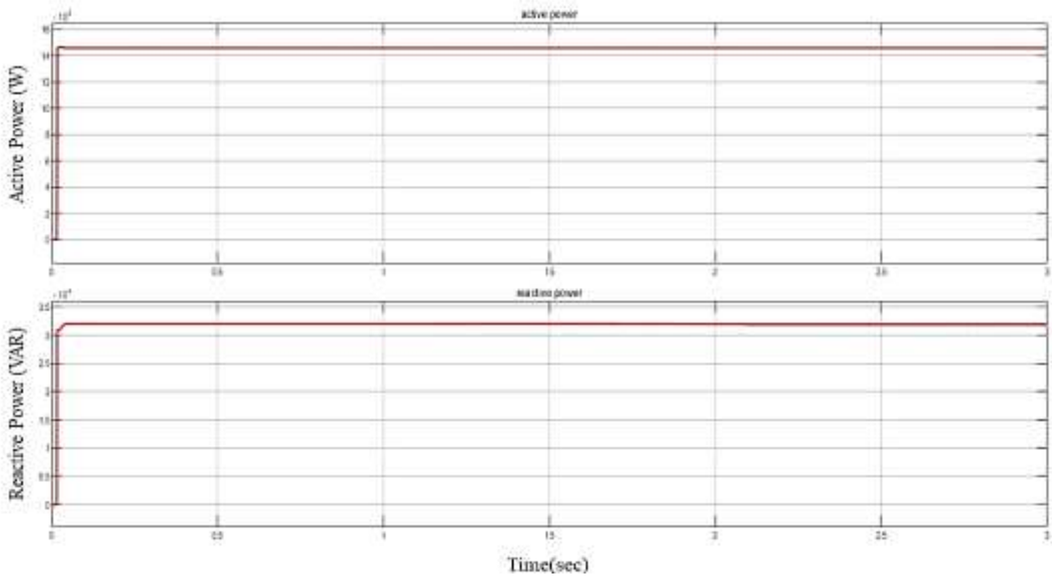

Figure 9. Source active and reactive power

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Figure 9 illustrates that the source active and reactive power in this case with TCSC is 148.79 KW and 32.5 KVAR respectively. In this case, the difference in reactive power supplied from the source and the reactive power reaching the load is reduced to value of only (32.5 – 24 =) 8.5 KVAR. This implies that with the reduction in series impedance of the line by TCSC, reactive power consumed by the line is also reduced.

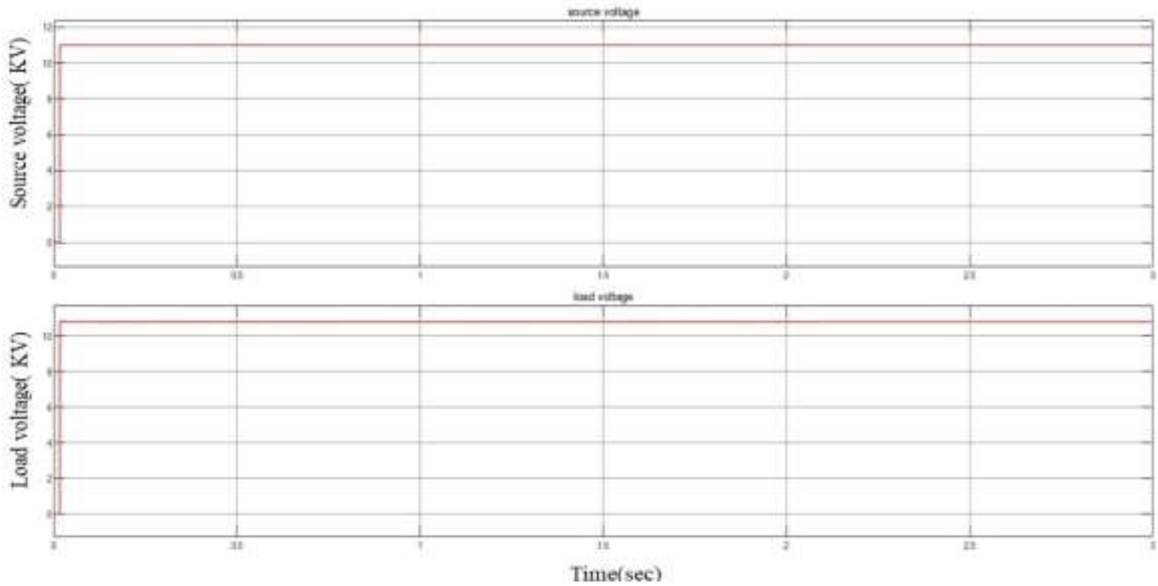

Figure 7. Source and load voltage

Figure 10 depicts that the source and load voltage with TCSC is 11KV and 10.65KV respectively. This is also represented in the form of bar graph as shown below:

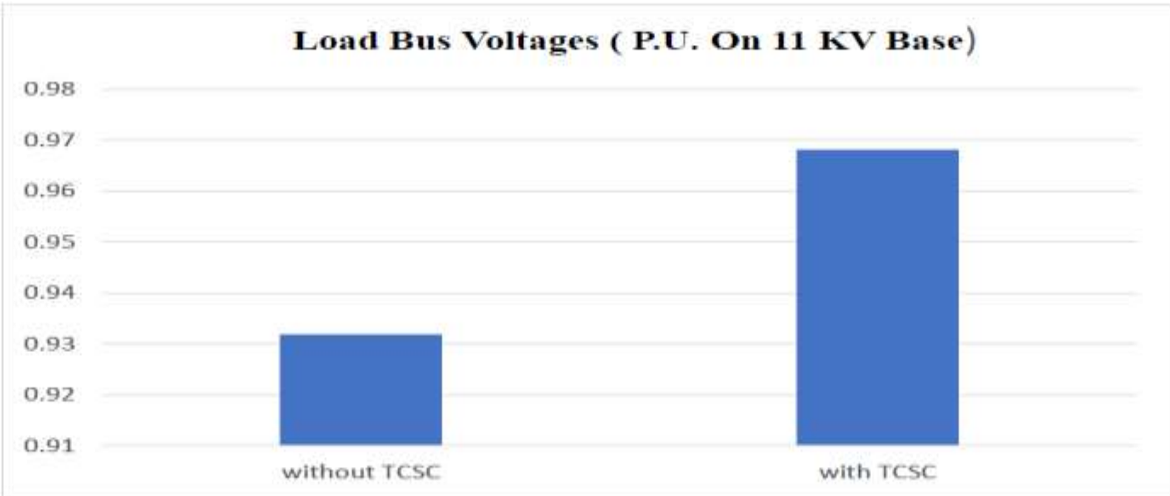

Figure 8. Bar graph for load bus voltage

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So, there is decrement in the voltage drop in the line due to reduced impedance of line by the series compensation of TCSC. So, with the implementation of TCSC, voltage regulation limit is not violated, which suggests that the power transfer capability of the line is increased and the power demand for the load can be supplied through the transmission line. Also, with the implementation of TCSC there is increment in the stability limit of the line as shown below:

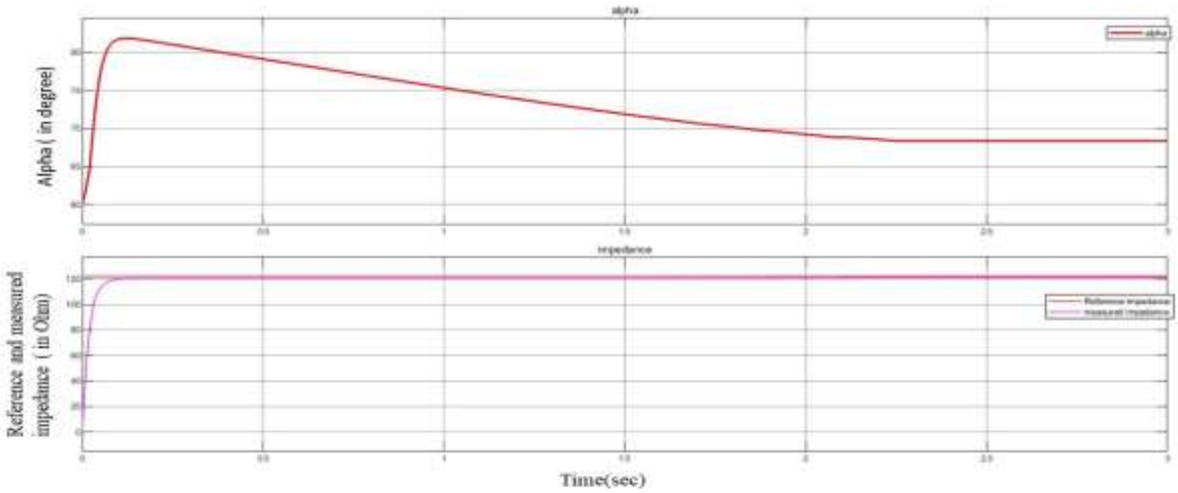

Figure 9. Power angle curve with and without TCSC

It is known that the maximum power transfer through the line is obtained for value of δ= 90o , which gives the steady state stability of the line. But, for the sake of transient stability the value of δ is kept between the values of 30o - 45o. and the from the above graph, it can be observed that the stability limit for the line, considering the maximum value of δ for transient stability to be 45o, is 498.74 KW (without TCSC) and 1983.89 KW (with TCSC implemented in the series with the line). Thus, stability limit is also increased with the implementation of TCSC in series with the line.

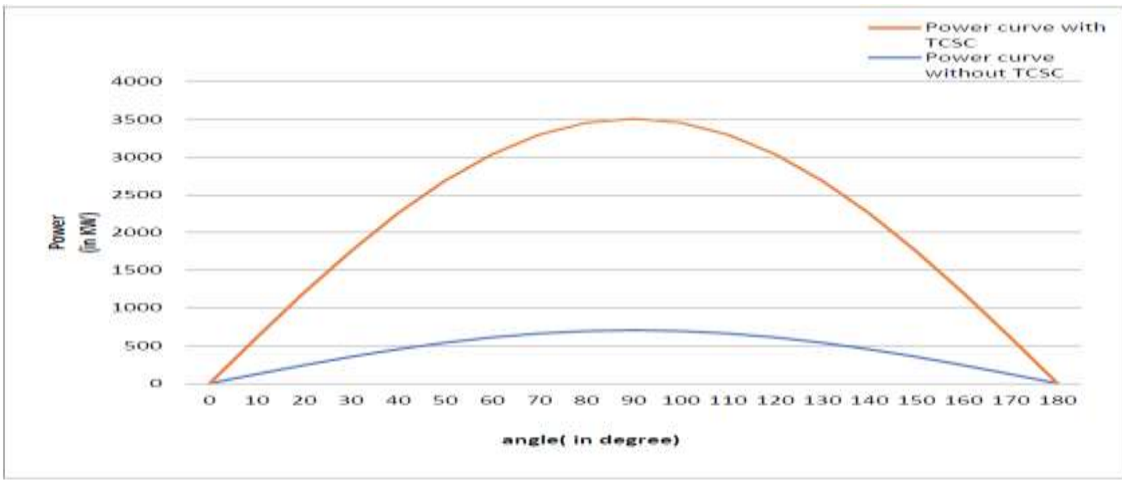

Figure 10. Firing angle and impedance

Figure 13 demonstrates the adjustment of the value of 'α' with time (in sec) by the control system so as to track the reference impedance. And the second figure shows the variation of impedance of TCSC with respect to time, so as to track the reference impedance, due to the continuous adjustment of the value of 'α'. From the above figure, it is clear that the control system is able to track the reference impedance and the settling time is around 2.25 sec. The final value of 'α'is 68o. The reference impedance and steady state value of TCSC impedances are 122Ω and 120.5Ω respectively.

4. CONCLUSIONS

Hence, modelling of TCSC has been done in Simulink which provide variable series compensation in the line. This reduces the net impedance of the line so that the voltage drop in the line will decrease and thereby allowing increased power to be transferred through the line. Also, the stability limit is increased. Thus, the use of TCSC increases the power transfer capability of the transmission line such that the line will be able to transfer power upto its thermal limit, ensuring the optimum utilization of the line.

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