Sindh Univ. Res. Jour. (Sci. Ser.) Vol. 48(2) 257-260 (2016)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Using Series Capacitors for the Improvement and Evaluation of Transmission Line Utilization

I. HASSAN[++], A. ALI*, F. KHAN**, S. KHAN**, S. RAHIM***, S. U. HAQ****, T. JAN[++]*****, M. ASIF****

Department of Electrical Engineering, Staffordshire University, United Kingdom

Received 5[th] March 2015 and Revised 19[th] January 2016

Abstract: The increase of power demand in recent years have developed a number of challenges for power system engineers for increasing the power transfer capability of the already installed transmission system without the expansion of the existing transmission network. This is where FACTS (Flexible ac Transmission System) devices are very useful because of its low initial cost as compared to setting up a completely new transmission network. The FACTS technology makes use of the already installed generating and transmission systems with minimum line losses and maximum use of the existing system. This paper analyzes the importance of Series Capacitance for the improvement of transmission line utilization. The circuit for a generic grid system was designed using Simulink software. The system was tested for different load configurations. Calculation for bus voltages, currents and other parameters were performed before and after series compensation using Matlab software. It was found out that the Power transfer capability (PTC) of the circuit improved after using FACTS devices.

Keywords*:* FACTS, Series Capacitors, Power, Power Transfer Capability, Simulink.

1. INTRODUCTION

During the evolution of the electric power industry it has faced many changes. The generation capacity of the electric power has not increased in proportion to the demand of the consumer. This increase in consumer demand can be overcome by setting up new transmission lines and building new generation stations. However there are many factors that hinder the process of establishing new transmission system, such as environmental issues, high cost and limited space in residential areas. Hence there is more focus to increase the power transfer capability of the existing transmission system instead of building a new one. For this reason a big interconnected system has been established known as FACTS (Manikandan, 2011) (Zellagui, 2011)

FACTS devices are very useful in increasing the security of the system and also enhancing the power transfer capability of the transmission network without its expansion. FACTS devices are also increasingly used for providing control facilities for power flow control, both in steady state and also for dynamic stability control. FACTS controllers are used for both active and reactive power controls. One of the most important applications of FACTS controller is Series Compensation, which is achieved using Series Capacitors.

Series capacitors are used for the overall reduction of the inductive reactance of a transmission line. Series capacitors improve the stability margins in a transmission line, they are also useful for improved load divisions on parallel path, reduction of line losses and reduce voltage drop during disturbances in system (Mohanty, 2012) (Xiao, 2003) (Joshi, 2014).

Series capacitors are normally used for transmission line greater than 200 miles. However in some cases they can also be used for shorter lines if the shorter line is a part of another longer transmission system. Series capacitors are typically used for the compensation of 25% - 75% of inductive reactance of a line. Usually it is not economically viable to design series capacitors to withstand over voltages because of the additional devices required for the protection of the capacitor (Zhou, 2005) (Bhavithira, 2014) (Pateriya, 2013).

2. DESCRIPTION OF THE SYSTEM

For the simulation, study and modeling of the system a commercial tool Matlab Simulink is used. It has many sets of block library and it has a graphical based block diagram having programming tool. The modelling and designing of transmission line is mostly based on Matlab Simulink.

In the figure a generic grid station is shown which consist of three transmission lines. The diagram also

[++]Corresponding author: I. HASSAN. Tariqullah Jan: tariqullahjan@uetpeshawar.edu.pk
*Department of Electrical Engineering, Sarhad, University of Science and Information Technology, KPK, Pakistan
**Balochistan University of IT, Engineering & Management Sciences, Quetta, Pakistan
***Department of CS/IT, Sarhad, University of Science and Information Technology, KPK, Pakistan
****Department of Electronics, University of Peshawar, Pakistan
*****Department of Electrical Engineering, University of Engineering & Technology Peshawar, Pakistan

shows the limits of transmission line. The data for each transmission line is also given in **(Table 1 and 2)**. The base voltage is 275KV and the base power is 100MVA. At a bus bar feeding transmission line 1&2 the fault level is 50p.u. The system is analyzed on thermal limits of a transmission line, that is to determine which line is deviating the thermal limits and which one is over loaded. The given Grid station is analyzed on practical situation in which we consider the three configurations of load as shown in **(Table 3)**.

With the help of digital display the voltage and the current at the sending end side and the receiving side is noted by the digital display also the real and reactive power at the receiving is calculated by applying a digital signal called the active and reactive power measurement and it is noted. The single line diagram and data are given below.

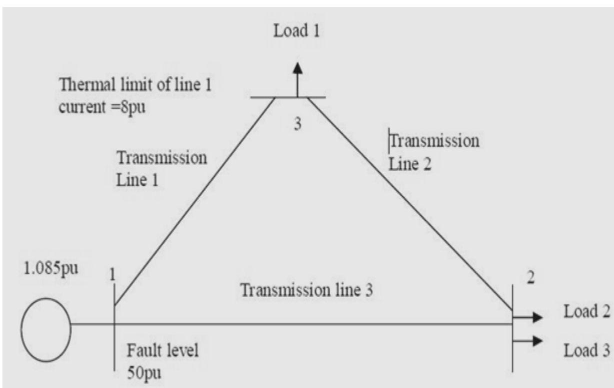

Fig: 1 Generic Grid Transmission System
(Base kV=275, Base MVA =100)

Thermal limit of transmission line 1 = 8pu
Thermal limit of transmission line 2 = 5pu
Thermal limit of transmission line 3 = 5pu

Table 1: Specification of the 275kV line.

LLine	R (Ω/km)	L (mH/km)	C (nF/km)	Length (km)
1	**0.022**	**1.067**	**1.402**	**60**
222	**0.036**	**1.052**	**1.499**	**40**
33	**0.035**	**1.046**	**1.513**	**70**

Table 2: Generic grid station load data

Description	MVA	P.F
L 1	**6.00**	**0.92**
L 2	**6.00**	**0.95**
L 3	**3.0**	**0.97**

Where L1, L2 & L3 are load one, load two and load three respectively

Table 3: Load combinations

	Configuration 1	Configuration 2	Configuration 3
L1	**1**	**1**	**1**
L2	**1**	**0**	**1**
L3	**1**	**1**	**0**

Where 1 & 0 represents the on & off state respectively.

Calculation of Line Parameters

Line 1:
R1 = 0.022 Ω/km, L1 = 1.067 MH/km,
C1 =1.402 nF/km, length = 60 km
Total resistance is R1 = 0.022 *60 = 1.32 **Ω**
Total inductance is L1 = 1.067 *60 = 64.02 MH
Total capacitance is C1 = 1.402 *60 = 84.12nf
Total inductive reactance XL1 = 2pifL1
XL1 =2*pi*50*1.034*70 = 24.72Ω

Total capacitive reactance XC1 = $\frac{1}{2\pi f C1}$

XC1 = $\frac{1}{2*\pi*50*84nf}$ = 37.89 kΩ

Line 2:
R2 = 0.036 **Ω**/ km, L2 = 1.052 MH/km,
C2 = 1.499 nF/km, length = 40 km
Total resistance is R2 = 0.036 *40 = 1.44 **Ω**
Total inductance is L2 = 1.052* 40 = 42.08 MH
Total capacitance is C2 = 1.499*40 = 59.96 nf
Total inductive reactance XL2 = 2pifL2
XL2 =2*pi*50*1.052*40 = 13.21 **Ω**

Total capacitive reactance XC2 = $\frac{1}{2\pi f C2}$

XC2 = $\frac{1}{2*\pi*50*59.96nf}$ = 53.11 kΩ

Line 3:
R3 = 0.035Ω/ km, L3 =1.046 MH/km,
C3 = 1.513 nF/km, length = 70 km
Total resistance is R3 = 0.035*70 = 2.45 **Ω**
Total inductance is L3 = 1.046*70 = 73.22 MH
Total capacitance is C3 = 1.513*70 = 105.91nf
Total inductive reactance XL3 = 2pifL3
XL3 = 2*pi*50*1.046*70= 22.99 **Ω**

Total capacitive reactance XC3 = $\frac{1}{2\pi f C3}$

XC3 = $\frac{1}{2*\pi*50*105.91nf}$ = 30.07 K Ω

Table 4: Total Inductance and Capacitance

LLine	TTotal resistance (Ω)	Total inductance (MH)	Total capacitance (nF)
11	**1.32**	**64.02**	**84.12**
2	**1.44**	**42.08**	**59.96**
3	**2.45**	**73.22**	**105.91**

Table 5: Inductive and capacitive reactance

Line	XL(Ω)	Xc (kΩ)
1	**24.72**	**37.89**
2	**13.21**	**53.11**
3	**22.99**	**30.07**

Calculation of Load Parameters

The load parameters for all the three lines are calculated such as P.F, active power and reactive power.

For Load 1:
MVA in p.u = 6.00, power factor $\cos\Phi = 0.92$
$\Phi = \cos\text{-}1(0.92) = 23.07$
Active power = $VI\cos\Phi$ = (MVA) $\cos\Phi$
= 6.00 * 0.92 =5.52 MW
Reactive power = $VI \sin\Phi$ = (MVA) $\sin\Phi$
= 6.00 * sin (23.07) = 2.34 MVAr

For Load 2:
MVA in p.u = 6.00, power factor $\cos\Phi = 0.95$
$\Phi = \cos\text{-}1(0.95) = 18.19$
Active power = $VI \cos \Phi$ = (MVA) $\cos\Phi$
= 6.00 * 0.95 = 5.7 MW
Reactive power = $VI \sin\Phi$ = (MVA) $\sin\Phi$
= 6.00 * sin(18.19) = 1.872 MVAr

For Load 3:
MVA in p.u = 3.0, power factor $\cos\Phi = 0.97$
$\Phi = \cos\text{-}1(0.97) = 14.06$
Active power = $VI \cos\Phi$ = (MVA) $\cos\Phi$
= 3.0 * 0.97 = 2.91MW
Reactive power = $VI \sin\Phi$ = (MVA) $\sin\Phi$
= 3.0 * sin(14.06) = 0.72 MVAr

Table 6: Active and Reactive Power of Lines

Line	Real Power	Reactive Power
1	5.52	2.34
2	5.7	1.872
3	2.91	0.72

Study of Power Flows without Compensation

The circuit was designed for different load configurations without the installation of series compensation. The values of currents and voltages were observed and tabulated.

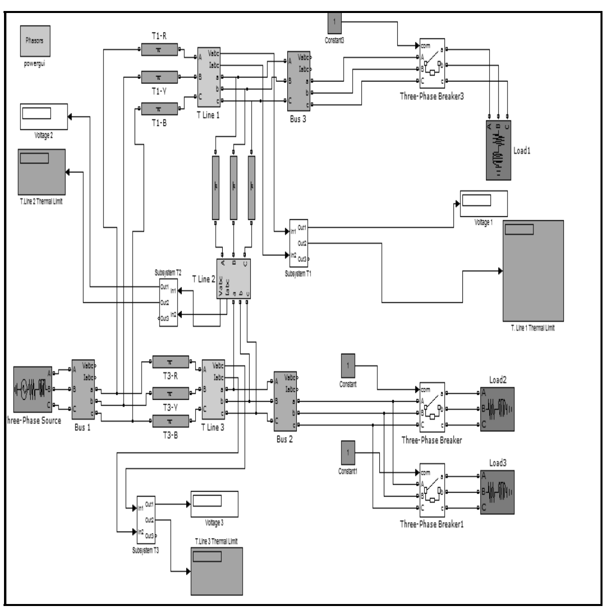

Fig: 2 Simulation Without Compensation

Table 7: All Loads are in ON:

	bus 1	bus 2	bus 3
Voltage (pu)	0.8787	0.874	0.874
Current (pu)	6.124	0.8815	6.986

Table 8: Loads 1,3 are ON and Load 2 OFF:

	bus 1	bus 2	bus 3
Voltage (pu)	0.9195	0.933	0.933
Current (pu)	4.593	0.9319	3.682

Table 9: Loads 1,2 are ON and Load 3 OFF:

	bus 1	bus 2	bus 3
Voltage (pu)	0.8787	0.8741	0.8741
Current (pu)	6.124	0.8815	6.986

Study of Power Flows with Series Compensation

The circuit was simulated with Series Compensation in place for different load configurations and the values of currents and voltages were observed.

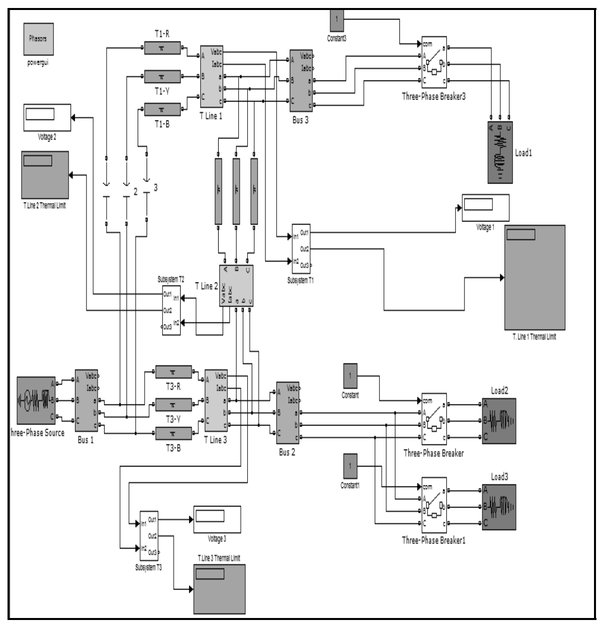

Fig: 3 Simulation With compensation.

Table 10: All Loads are in ON:

	bus 1	bus 2	bus 3
Voltage (pu)	0.8777	0.8605	0.8605
Current (pu)	7.98	2.792	4.949

Table 11: Loads 1,3 are ON and Load 2 OFF:

	bus 1	bus 2	bus 3
Voltage (pu)	0.9599	0.9633	0.9633
Current (pu)	5.943	0.3515	2.635

Table 12: Loads 1, 2 are ON and Load 3 OFF:

	bus 1	bus 2	bus 3
Voltage (pu)	0.9154	0.9067	0.9067
Current (pu)	7.023	1.59	3.853

3. RESULT AND DISCUSSION

Improving the power transfer capability of the power system using FACTS devices was the main objective of this work. In this case series capacitors were used for the improvement of the power transfer capability of the system. The circuit was simulated for different load conditions. The circuit was first investigated without series compensation. The values of current and bus voltages were observed from simulation by connecting load parameters like active power and reactive power and rms values for a better understanding of the circuit. The results for current values and bus voltages were tabulated for all load conditions and comparison of the values were done to the given thermal limit. The results showed that the thermal limit of line 3 exceeded to 6.986. The circuit was then simulated with series compensation in place for the same load conditions. The current values and bus bar voltages were observed and again compared to the thermal limit. The tabulation shows that after series compensation the thermal limit of line 3 returned to the normal range which is below 5.

4. CONCLUSION

The circuit for the generic grid was constructed using Matlab Simulink software and the difference in the power transfer capability of the power system with and without FACTS devices were observed. It was observed that without the series compensation the power transmitting capability of the circuit was low. Hence series compensation was put in place in the transmission line and output of the system was observed and compared with the output of the system without series compensation. It was observed that the power transfer between the transmission lines increased where the current value was more than the given thermal limit of the line. Also it was noted that by the implementation of the series compensation, the stability of the system increased and there was more reliability of the power flow.

5. ACKNOWLEDGMENT

The lab facilities and help provided by the faculty of Electrical Engineering at Staffordshire University is gratefully acknowledged.

REFERENCES:

Bhavithira, V., and A. Amudha (2014). "Enhancement of Available Transfer Capability Using FACTS Controller". Applied Mechanics and Materials, Vol. 573, 340-345.

Joshi, M., and N. H. Kothari (2014). A Reiview on Series Compensation of Transmission Line and Its Impact on Performance of Transmission Line. International Journal of Engineering Development and Research 1(1), 72-76.

Li, G., M. Zhou, Y. Gao, (2005). "Determination of Total Transfer Capability Incorporating FACTS Devices in Power Markets," in Proc. of IEEE PEDS Conf., 1327-1332.

Manikandan, B. V., S. Charles Raja, and P. Venkatesh (2011). Available Transfer Capability Enhancement with FACTS Devices in the Deregulated Electricity Market. Journal of Electrical Engineering and Technology. 6 (1), 14-24

Mohanty, A. K., and A. K. Barik (2012). Power System Stability Improvement using FACTS Devices. International Journal of Modern Engineering Research. 1 (2), 666-672

Pateriya, A., and N. Saxena (2013). Transfer Capability Enhancement of Transmission Line Using Static VAR Compenstator. International Journal of Electrical, Electronics and Computer Engineering. 2 (1), 1-6.

Xiao, Y., Y. H. Song, C. C. Liu, Y. Z. Sun (2003). Available Transfer Capability Enhancement using FACTS Devices . IEEE Transactions on Power Systems. 18 (1), 305-312.

Zellagui, M., and A. Chaghi. (2011). Impact of Series Compensation Insertion in Double HV Transmission Line on the Settings of Distance Protection. International Journal of Scientific and Engineering Research. 2 (8), 1-7.