International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 5, Number 6 (2012), pp. 769-781

http://www.irphouse.com

Multibus System using Thyristor Controlled Series capacitor and Combined operation of UPQC with photovoltaic Array

P. Annapandi[1] and Dr. M. Rajaram[2]

[1]Ph. D Scholar/Asst. Prof/ Electrical and Electronics Engg
Dr. Sivanthi Aditanar College of Engineering, Tiruchendur, Tamilnadu, India.
annapandime@yahoo. com
Mobile:+91-9884850976, Fax: +91 -04639 – 243188
Prof/ Electrical and Electronics Engg
Government College of Technology, Coimbatore,Tamilnadu, India
rajaramgct@rediffmail.com

Abstract

In this paper the design of combined operation of UPQC and PV array is proposed. The proposed system is composed of series and shunt inverters, PV array connected to DC link by boost converter which is able to compensate the voltage sag and swell and voltage interruption, harmonics and reactive power. Thyristor controlled series capacitor has a fixed capacitor in parallel with a thyristor controlled reactor. Net reactance can be varied by varying the firing angle of Thyristor controlled reactor. The power transferred from the sending end to the receiving end can be controlled by varying the firing angle. Eight bus system and Fourteen bus system without and with Thyristor controlled series capacitor and unified power quality conditioner with photovoltaic array is modeled and simulated using MATLAB SIMULINK and the results are presented.

Keyword: Unified power quality conditioner (UPQC), Photovoltaic array (PV), Power Quality, Active filter, Harmonics.

1. INTRODUCTION

Thyristor Controlled Series Compensator (TCSC) is one of the important members of FACTS family that is increasingly applied with long transmission lines by the utilities in modern power systems. It can have various roles in the operation and control of power systems, such as scheduling power flow, decreasing unsymmetrical components, reducing net loss, providing voltage support limiting short-circuit currents, mitigating subsynchronous resonance (SSR), damping the power oscillation, and enhancing transient stability [1]-[4]. The problem of FACTS controller parameter tuning is a complex exercise as uncoordinated local control of FACTS controller may cause destabilizing interactions. The power electronic- based switches in the functional blocks of FACTS can usually be operated repeatedly and the switching time is a portion of a periodic cycle, which is much shorter than the conventional mechanical switches. The advance of semiconductor increases the switching frequency and voltage-ampere ratings of the solid switches and facilitates the applications.

Power electronic based power processing offers higher efficiency, compact Size and better controllability. But on the flip side, due to switching actions, these systems behave as non-linear loads. Therefore, whenever, these systems are connected to the Utility, they draw non-sinusoidal or lagging current from the source. As a result these systems pose themselves as loads having poor displacement as well as distortion factors. Hence they draw considerable reactive volt-amperes from the utility and inject harmonics in the power networks. As more sensitive loads, such as computers, automation equipments, and communication equipments, have come into wide use, power quality is a big issue in both customer and utility company. Since these equipments are very sensitive for the input voltage disturbances, the inadequate operation or the fault of these loads brings about huge losses [5]-[7]. The elimination or mitigation of disturbances propagated from the source side and the other loads interconnected is critical for improving the operational reliability of these critical loads. PV-UPQC has been widely studied to eliminate the disturbances propagated from the source side and the other loads interconnected [8]-[10]. PV-UPQC has two voltage-source inverters of three-phase four-wire or three-phase three-wire configuration. The UPQC, just as in a UPFC, employs two voltage source inverters (VSIs) having a common DC energy storage capacitor. One of these two VSIs is connected in shunt with the AC system while the other is in series with AC line. This paper proposes a new configuration of PV- UPQC that consists of the DC/DC converter and the capacitors for compensating the voltage interruption. The operation of proposed system was verified through simulation

2. CONFIGURATION OF UPQC

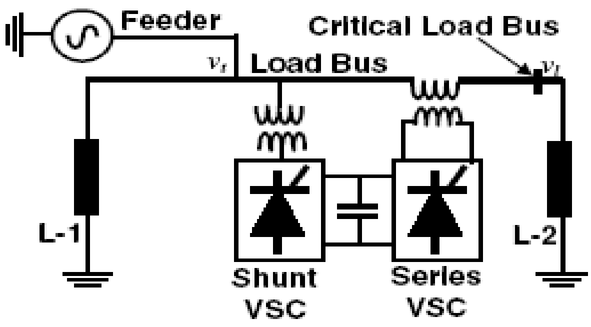

Fig. 1 Single-line diagram of a UPQC compensated distribution system

With respect to the circuit of Fig 1, load L-3 is a critical load that requires a balance voltage of specified magnitude . The load L-1 can be unbalanced and may draw harmonic current. The main purpose of the UPQC is to regulate the critical load bus voltage v_l. This is achieved through the series VSC. The primary goal of the shunt VSC is to supply real power to the dc capacitor. Additionally, the shunt VSC also eliminates the unbalance and harmonics from the bus voltage on the left-hand side of the UPQC. This voltage is denoted by v_t and will be termed as the terminal voltage. The operation of UPQC that combines the operations a Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Restorer (DVR) [11]. The series component of the UPQC inserts voltage so as to maintain the voltage at the load terminals balanced and free of distortion. Simultaneously, the shunt component of UPQC injects current into the AC system such that the currents entering the bus to which the UPQC is connected are balanced sinusoids. Both these objectives must be met irrespective of unbalance in either source or load sides.

3. POWER STABILITY STUDIES

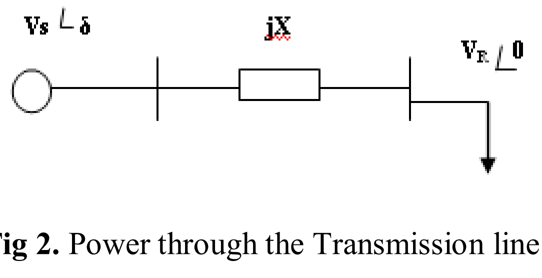

Fig 2. Power through the Transmission line

Real power through the line connecting the buses 1 and 2 is,
$P = (V_1V_2/X). \sin\delta$

Reactive power through the line connecting the buses 1 and 2 is,
$Q = (V_2 / X).\ (V_1 - V_2)$

The real power transferred to the receiving end is proportional to Sinδ, while the reactive power is proportional to the magnitude of the voltage drop across the line. The real power received is maximum for $\delta=90^0$. Maximum real power transferred for a given line can be increased by raising its voltage level. It is from this consideration that voltage levels are being progressively pushed up to transmit larger chunks of power over longer distances warranted by large size generating stations. For very long lines voltage level cannot be raised beyond the limits placed by present day high voltage technology. To increase the power transmitted in such cases, the only choice is to reduce the line reactance. This is accomplished by adding series capacitors in the line. Series capacitors increase the severity of line over voltages under switching conditions. When the line reactance(x) decreases, the real power (P) and the reactive power (Q) can be increased. Thus the steady state stability limit can be increased. So the system stability will be improved. As a result the real power flows from the higher angle to lower angle and the reactive power flows from a bus with higher potential to a bus with lower potential. Power system stability is primarily concerned with variation in speeds, rotor positions and generated loads. If the transmission lines are of sufficiently high reactance, the stability limit can be raised by using two parallel lines which incidentally also increases the reliability of the system. Series capacitors are employed in lines to get better voltage regulation and to raise the stability limit by decreasing the line reactance. Higher excitation voltages and quick excitation system are also employed to improve the stability.

4. THYRISTOR CONTROLLED SERIES CAPACITOR

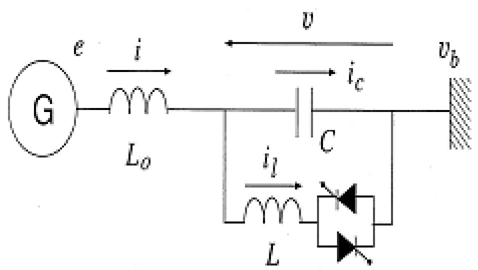

Fig 3. Transmission system with TCSC

A. Design of TCSC:
Capacitance=50 Micro Farad, Inductance=10mH

Thyristor1:
Resistance =0. 001Ω, Forward voltage=0. 8, Snubber resistance=500,
Snubber capacitance=250e^{-9}

Thyristor2:
Resistance =0. 001Ω, Forward voltage=0. 8 v, Snubber resistance=500 Ω
Snubber capacitance=250e^{-9}

Generator :
Amplitude=3300v, Frequency=50Hz

Load :
Resistance=8Ω, Inductance=390mH

The basic TCSC module shown in Fig 3, comprises a series capacitor C in parallel with a thyristor-controlled reactor. If the TCSC valves are required to operate in the fully "on" mode for prolonged durations, the conduction losses are minimized by installing an ultra high speed contact across the valve. This metallic contact offers a virtually lossless feature similar to that of circuit breakers and is capable of handling many switching operations. The metallic contact is closed shortly after the thyristor valve is turned on and it is opened shortly before the valve is turned off. During a sudden overload of the valve, and also during fault conditions, the metallic contact is closed to alleviate the stress on the valve.

B. Operation of the TCSC

A TCSC is a series-controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. From the system viewpoint, the principle of variable-series compensation is simply to increase the fundamental-frequency voltage across an fixed capacitor (FC) in a series compensated line through appropriate variation of the firing angle α. This enhanced voltage changes the effective value of the series – capacitive reactance. A simple understanding of TCSC functioning can be obtained by analyzing the behavior of a variable inductor connected in parallel with an FC . The equivalent impedance Z_{eq}, of this LC combination is expressed as,

$$Z_{eq} = (j\,(1/\omega c)) \,||\, (j\omega L) = -j\,(1/(\,\omega c - (1/\,\omega L))) \quad (1)$$

If $\omega c - (1/\omega L) > 0$, the reactance of the FC is less than that of the parallel-connected variable reactor and that this combination provides a variable – capacitive reactance are both implied. Moreover, this inductor increases the equivalent – capacitive reactance of the LC combination above that of the FC. If $\omega c - (1/\omega L) = 0$, a resonance develops that results in an infinite- capacitive impedance an obviously unacceptable condition. If $\omega c - (1/\omega L) < 0$, the LC combination provides inductance above the value of the fixed inductor. This situation corresponds to the inductive-vernier mode of the TCSC operation.

5. UNIFIED POWER QUALITY CONDITIONER WITH PV ARRAY

One of the comparative structures of the electric power is back to back converter. In respect to controlling structure, these converters may have various operations in compensation. For example, they can operate as series or shunt active filters for synchronous compensating the load current harmonics and voltage oscillation. This is called unified power quality conditioner. It is a basic device to control power quality[11]. The duty of UPQC is reducing perturbations which effect on the operation of sensitive loads. UPQC has two shunt and series voltage source inverters which are 3-phase 3-wire or 3-phase 4-wire. Shunt inverter is connected to point of common coupling by shunt transformer and series inverter stands between source and coupling point by series transformer. Shunt inverter operates as current source and series inverter operate as voltage source. UPQC is able to compensate current harmonics, to compensate reactive power, voltage distortions and control load flow but cannot compensate voltage interruption because of not having any source[13]. In this study, a new structure is proposed for UPQC, where, PV is connected to DC link in UPQC as energy source. In this case, UPQC finds ability of injecting power using PV to sensitive load during source voltage interruption.

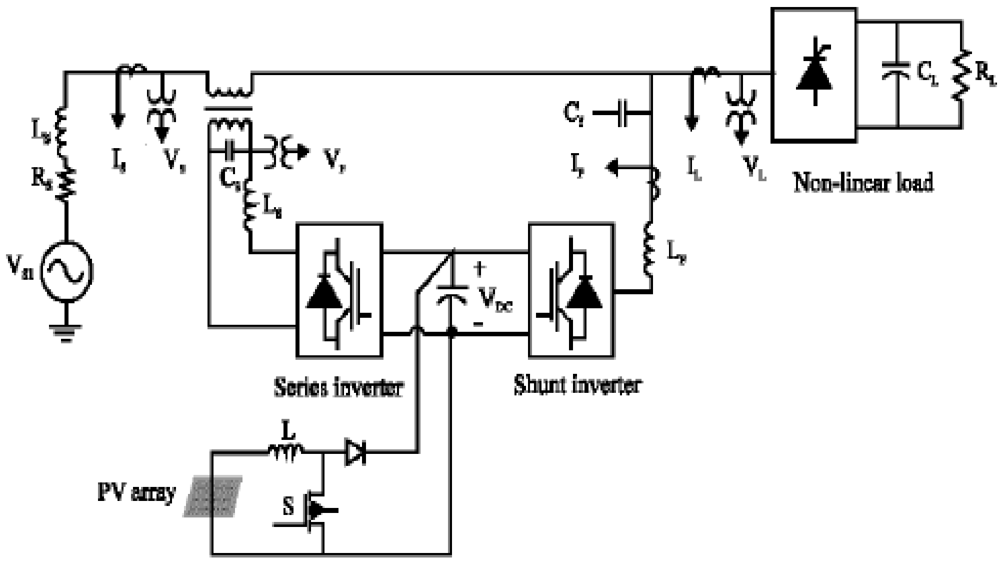

Fig4. Configuration of proposed UPQC with PV

When current flows through the source, there will a current drop IZ. DC voltage which is produced from the photo voltaic cell is boosted and is converted into ac using an inverter. The ac voltage of the inverter is injected into transmission line through the step up transformer. The injecting line voltage v_i cancels the drop (iz) means, the receiving end voltage will be equal to the sending end voltage.

$$V_R = V_S - (IZ) \tag{2}$$

Photo voltaic system

Photo voltaic system is based on the ability of certain matrials to convert the radiant energy of the sun into electrical energy. The total amount of solar energy that lights a given area is known as irradiance. Photo voltaic array is a linked collection of phpto voltaic modules which are inturn made up of multiple interconnected solar cells. The cell convert solar energy into direct current electricity. The power that one module can produce is seldom enough to meet the requirements of a home or a business, so the modules are linked together to form an array. Most PV array use an inverter to convert the DC power produced by the modules into alternating current that can plug into existing infrastructure to power lights, motors and other loads. The modules in a PV array are first connected in series to obtain the desired voltage, the indivival strings are then connected in parallel to allow the system to produce more current.

6. SIMULATION RESULTS

In order to inspect different variables, analysis will be carried out of different parameters in two steps. Real and reactive power across bus-3 for eight bus system without TCSC is shown in Fig 5 . Current and volatge across bus-3 for eight bus system without TCSC is shown in. Fig 6. Real and reactive power across bus-3 for eight bus system with TCSC is shown in Fig 7 . Current and volatge across bus-3 for eight bus system with TCSC is shown in Fig 8. Reactive power without and with TCSC of eight bus system is shown in Table 1.

EIGHT BUS SYSTEM WITHOUT TCSC

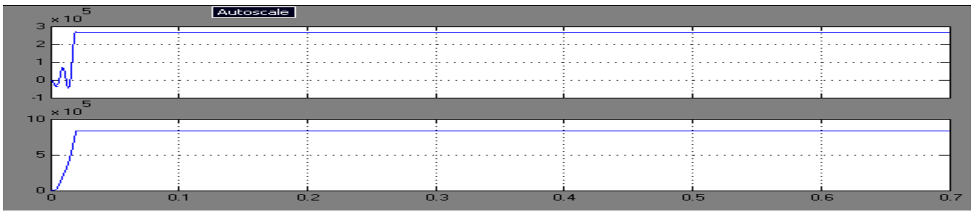

Fig 5. Real and reactive power across bus-3

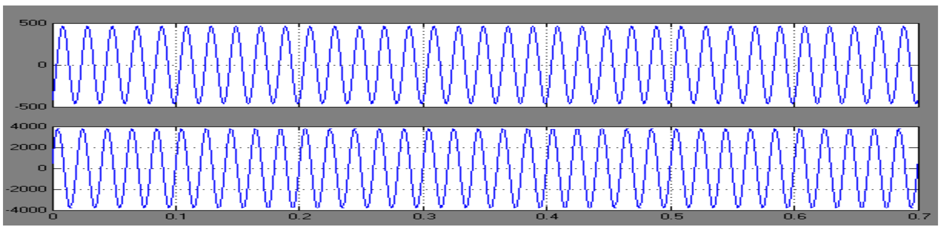

Fig 6 . Current and volatge across bus-3

EIGHT BUS SYSTEM WITH TCSC

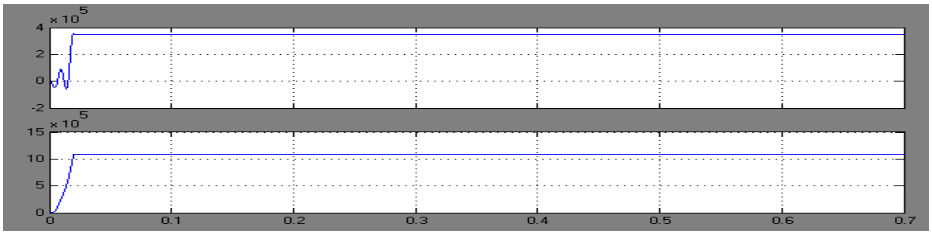

Fig7. Real and reactive power across bus-3

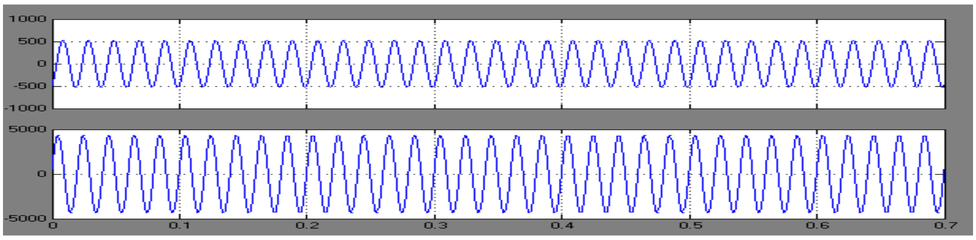

Fig8. Current and volatge across bus-3

Table1: Reactive power without and with TCSC of Eight bus system

BUS NO:	REACTIVE POWER WITHOUT TCSC (MVA)	REACTIVE POWER WITH TCSC (MVA)
BUS-7	0. 174	0. 198
BUS-1	0. 133	0. 148
BUS-3	0. 836	1. 090
BUS-11	0. 363	0. 456

Real and reactive power across bus-3 for fourteen bus system without TCSC is shown in Fig 9 . Current and volatge across bus-3 for fourteen bus system without TCSC is shown in. Fig 10. Real and reactive power across bus-3 for fourteen bus system with TCSC is shown in Fig 11 . Current and volatge across bus-3 for fourteen bus system with TCSC is shown in Fig 12. Reactive power without and with TCSC of fourteen bus system is shown in Table 2.

FOURTEEN BUS SYSTEM WITHOUT TCSC

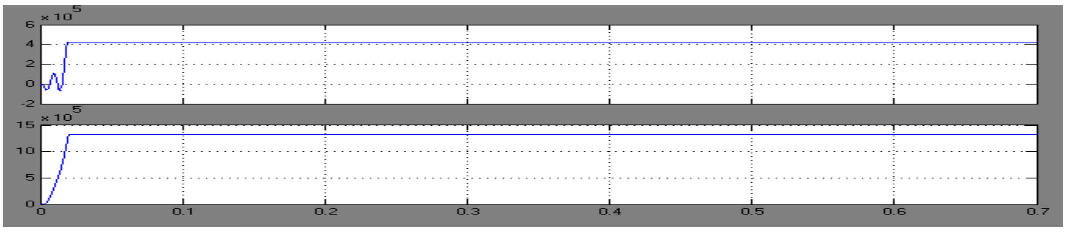

Fig 9. Real and Reactive power across bus3

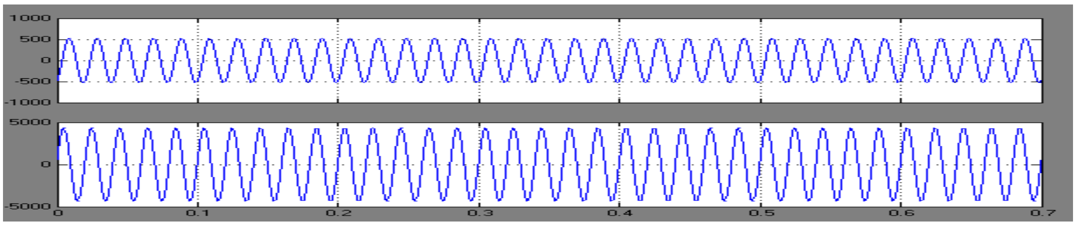

Fig10. Current and volatge across bus

FOURTEEN BUS SYSTEM WITH TCSC

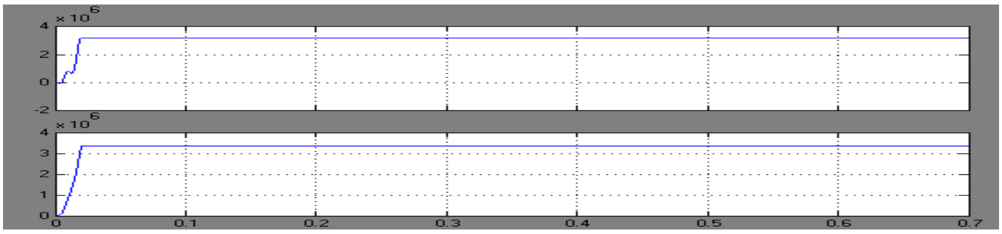

Fig11. Real and reactive power across bus-3

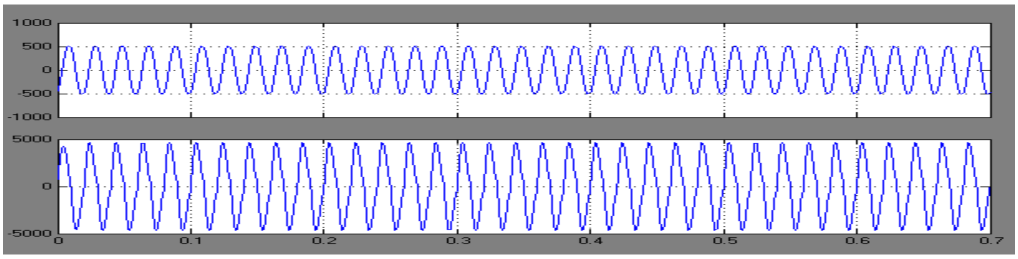

Fig12. Current and volatge across bus-3

Table 2: Reactive power without and with TCSC of Fourteen Bus system

BUS NO:	REACTIVE POWER (MVA) without TCSC	REACTIVE POWER (MVA) with TCSC
BUS-7	0. 0319	0. 05312
BUS-1	0. 303	0. 384
BUS-3	0. 132	1. 140
BUS-11	3. 35	3. 357

The current drawn from the source is shown in Fig. 13. The Source current after compensation using UPQC is shown in figure 14. From the results presented here it is clearly known that the UPQC is working efficiently in achieving the Source current compensation. The load voltage before compensation is shown in Fig. 15. The load voltage after compensation using UPQC is shown in figure 16. From the results presented here it is clearly known that the UPQC is working efficiently in achieving the load voltage compensation. Real power consumed by load is shown in Fig. 17. Reactive power consumed by load is shown in Fig. 18. FFT analysis for load voltage is shown in Fig. 19.

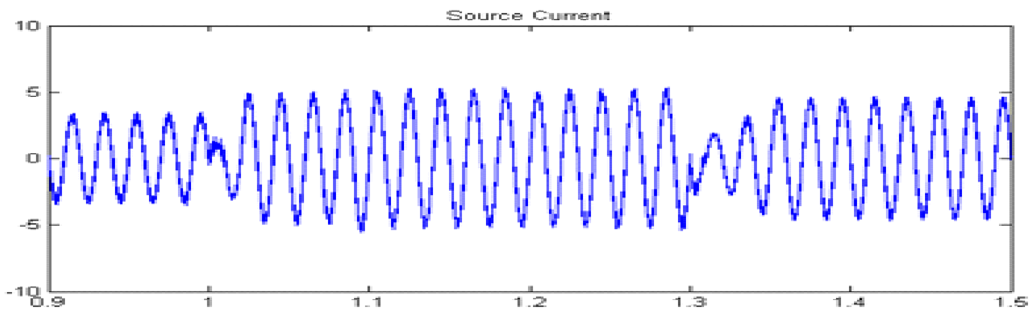

Fig13. Source current before compensation

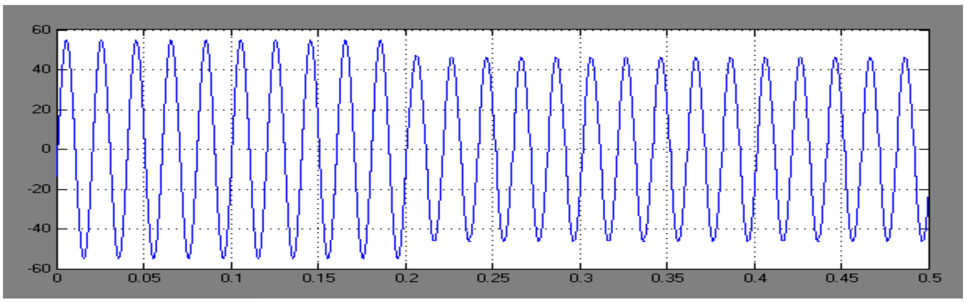

Fig14. Source current after compensation

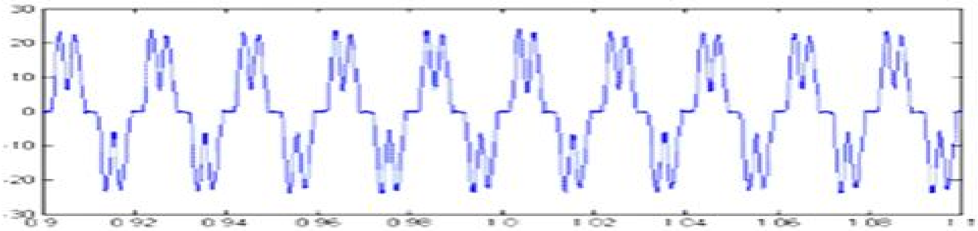

Fig15. Load voltage before compensation

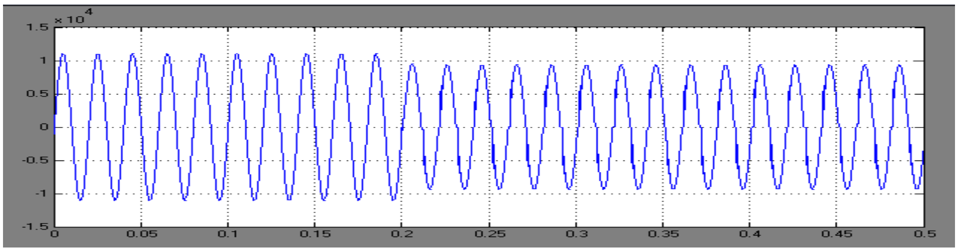

Fig16. Load voltage after compensation

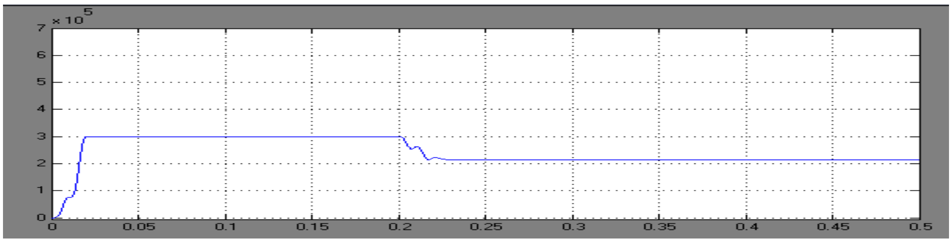

Fig17. Real power consumed by load

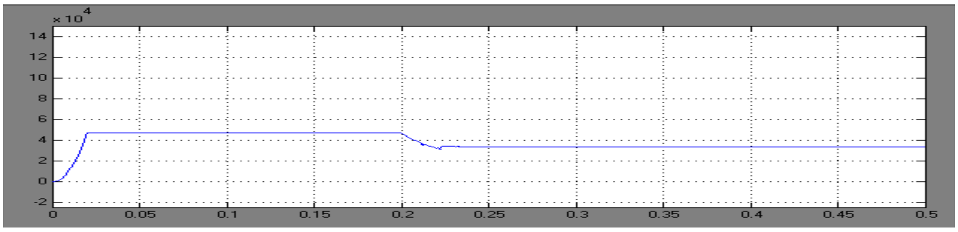

Fig18. Reactive power consumed by load

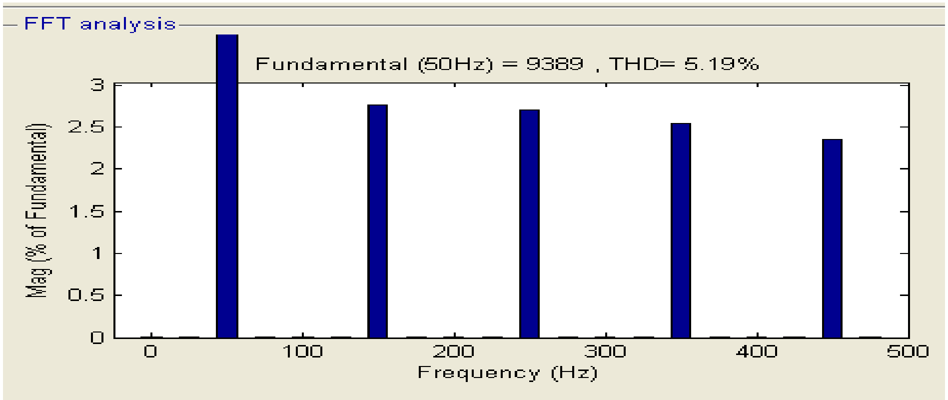

Fig19. FFT analysis for load voltage

7. CONCLUSION

Eight bus system and fourteen bus system without and with Thyristor controlled series capacitor are simulated and the results are presented using MATLAB simulink. The net reactance of the Thyristor controlled series capacitor can be varied by varying the firing angle of Thyristor controlled reactor. The real power and reactive power transferred from the sending end to the receiving end can be controlled by varying the firing angle α. so the steady state power limit can be increased. Thus the power system stability will be improved. Unified power quality conditioner with photo voltaic array are simulated and the results are presented using MATLAB Simulink. Additional load is connected at the receiving end and the effect of sag is presented. The sag is compensated by using the series injection provided by the DVR of the UPQC. DC from the solar cell is boosted and is converted into ac using an inverter. The output of the inverter in injected through a step up transformer. The results of voltage sag compensation is presented. The simulation results are inline with the predictions. Thus the power quality is improved by using UPQC system.

REFERENCES

[1] P. Mattavelli, G. C. Verghese and A. M. Stankovitctt, “Phasor dynamics of Thyristor-Controlled series capacitor systems, ” *IEEE Trans. Power System.,* vol-12, pp. 1259–1267. 1997.

[2] B. H Li, Q. H. Wu, D. R. Turner, P. Y. Wang and X. X Zhou, “Modeling of TCSC dynamics for control and analysis of power system stability, ”*Electrical Power & Energy Systs*., Vol-22, pp. 43–49. 2000.

[3] L Fan, A. Feliachi and K. Schoder, “Selection and design of A TCSC control signal in damping power system inter-area oscillations for multiple operating conditions. ” *Electrical Power & Energy Systs.,* vol-62, pp. 127-137, 2002.

[4] A. D Del Rosso, C. A Canizares and V. M. Dona, “A study of TCSC controller design for power system stability improvement, ” *IEEE Trans. Power Systs.*, vol-18, pp. 1487-1496. 2003.
[5] *M. Prodanovic., T. C. Green*, "Control and filter design of three-phase inverters for high power quality grid connection", IEEE Trans. on Power Delivery, Vol. 18, No. 1, Jan 2003, pp. 373-380.
[6] *B. Han., B. Bae, S. Baek, G. Jang*, "New Configuration of UPQC (Unified Power Quality Conditioner) for Medium voltage Application, " IEEE Trans on Power Delivery, Vol. 21, No. 3, pp. 1438-1444, July 2006.
[7] *N. G. Hingorani*, "Introducing Custom Power, " IEEE Spectrum, June 1995, pp. 41-48.
[8] *Hideaki Fujita, Hirofumi Akagi*, "The Unified Power Quality Conditioner”, The Integration of Series- and Shunt- Active Filters", IEEE Transactions on Power Electronics, Vol. 13, No. 2, March 1998.
[9] *Yunping Chen*, *Xiaoming Zha and Jin Wang*, & co. "Unified Power Quality Conditioner (UPQC) The Theory, Modeling and Application", proceedings. Power Con . International Conference on, vol. 3, pp. 1329-1333, 2000.
[10] *M. Aredes, K. Heumann, E. H. Watanabe*, "An universal active power line conditioner", IEEE Trans. on Power Delivery, Vol. 13, No. 2, Apr 1998, pp. 545-551.
[11] Kenjun Li, Member, IEEE, Jianguo Zhao, Chenghui Zhang, and Wei-Jen Lee”*Dynamic Simulator for Thyristor-Controlled Series Capacitor”.* IEEE Trans. Power Syst., Vol. 46 no. 3, 2010.
[12] Vinod Khadkikar, , Ambrish Chandra, “UPQC-S: A Novel Concept of Simultaneous Voltage Sag/Swell and Load Reactive Power Compensations Utilizing Series Inverter of UPQC” IEEE Transactions on Power Electronics, Vol. 26, No. 9, sep 2011
[13] Vinod Khadkikar, ”Enhancing Electric Power Quality Using UPQC: A Comprehensive Overview” IEEE Transactions on Power Electronics, Vol. 27, No. 5, May 2012.