RESEARCHERID
THOMSON REUTERS

[Deshveer, 6(6): June 2019] ISSN 2348 – 8034
IDSTM-2019 Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

ANALYSIS OF TRANSIENT STABILITY OF MULTI MACHINE POWER SYSTEM WITH FACT DEVICE

Deshveer[*1], Rohit Kumar Gupta[2] & Ajay Chillar[3]
[1,2,3]Assistant Professor EE Department S.E.T, Ganga Technical Campus, Soldha, Bahadurgarh

ABSTRACT

This thesis includes a FACTS device called as the Unified Power Flow Controller (UPFC). It is used to control simultaneously real and reactive power flows on a transmission line as well as to regulate voltage at the bus where it is connected, these devices creates a huge quality impact on power system stability. These features can be taken out to be even more significant because UPFC allows the loading of the transmission lines which is close to their thermal limits, forcing the power to flow through the desired paths. This gives to the power system operators more needed flexibility to satisfy the demands. A power system with a UPFC is highly non-linear. The most efficient control method for such a system is to use non-linear control techniques to achieve the system oscillations damping. The non-linear control methods are independent on the system operating conditions. Advanced non-linear control techniques are generally requires a system being represented by purely differential equations whereas a power system is normally represented by a sets of differential & algebraic equations. From this, a new method is used to generate a dynamic modeling for power network which is introduced such that the full power system with UPFC can be represented by wholly differential equation. This representation help us to convert the non-linear power system equations into standard parametric feedback form. Once the standard form is obtained, the conventional and advanced non-linear control techniques can be simply implemented. To design of a UPFC controllers (AC voltage-control, DC voltage-control and damping control) a comprehensive approach is presented. The damping controller is designed using non-linear control technique by an appropriate Lyapunov-function. This analytical expression of the non-linear control law for the UPFC is obtained using back stepping the method. Then after, combining the non-linear control strategy with the linear one for the other variables, a complete linear and nonlinear stabilizing controller is developed. An adapted method for estimating the uncertain parameters is derived. This one relaxes the need for the approximating the uncertain parameters like damping co-efficient, transient synchronous reactance etc., which are difficult to be measured precisely.

Keywords: *Flexible AC Transmission System, Static VAR Compensator, Thyristor controlled series-capacitor, static synchronous compensators, Unified power flow controllers, interline power flow controllers, power system stabilizer, single-input single-output, pulse width modulation, controllable series capacitor, sub-synchronous resonance, electric power research institute, quantitative feedback theory, Gate turn-off singular value decomposition.*

I. INTRODUCTION

The accessible of power generating plants are often located at distant locations for the economic, environmental and safety reasons. For instance, it becomes cheaper to install a thermal power station at pit-head instead of transporting coal to load centers. Hydro power is generally available in remote areas and a nuclear plant may be located at a place away from urban areas. Additionally, modern power systems are highly interconnected. Splitting of generation reserves, exploiting the load diversity and the economy gained from the use of large efficient units without sacrificing reliability are the advantages of interconnection. Thus power must consequently be transmitted over long distances. To meet the load and electric market demands, new lines should be added to the system, but due to environmental reasons, the installation of electric power transmission lines are often restricted. Hence, the utilities are forced to rely on already existing infra-structure instead of building new transmission lines. In order to maximize the efficiency of generation, the transmission and distribution of the electric power, the transmission networks are very often pushed to their physical limits, where outage of lines or other equipments could result in rapid failure of the entire system. The power system may be thought of as a non-linear system with many lightly damped electro-mechanical modes of oscillation. The basically three modes of electro-mechanical oscillations are:

1. Local plant mode oscillations
2. Inter-area mode oscillations
3. Torsional modes between the rotating plant

In local mode, one generator swings against the rest of system at 1.0 to 2.0 Hz. The impact of the oscillations is localized to the generator and the line connecting it to the rest of system is normally modeled as a constant voltage source whose frequency is assumed to remains constant. This is known as the SIMB model. Inter area modes of oscillations is observed by a large part of the network which involves two coherent groups of generators swinging against each other at 1Hz or less. This complex phenomenon involves many parts of the system with highly non-linear dynamic behavior. for the Damping characteristic of the inter area mode is dictated by the tie line strengths, the nature of loads and the power flow through the interconnection and the interactions of the loads with the dynamics of generators and their associated controls.

The Torsional modes of oscillations is associated with a turbine generator shaft system in the frequency range of 10-45 Hz. Usually these modes are excited when a multi-stage turbine generator is connected to the grid system through a series compensated line. A mechanical torsional mode of shaft system is interacts with the series capacitor at the natural frequency of a electrical network. The shaft resonance appears when the network natural frequency equals synchronous frequency minus torsional frequency. The latest generations of the FACTS controllers is based on the concept of the solid state synchronous voltage sources (SVSs) introduced by L. Gyugyi in the late 1980s [4]. The SVS, behaves as an ideal synchronous-machine, i.e., it generates three-phase balanced sinusoidal voltage of controllable amplitude and phase angle with fundamental frequency. It can internally generate both inductive and capacitive reactive power. If it coupled with an appropriate energy storage devices, i.e., D.C storage capacitor, battery etc., SVS can be exchanged the real power with the A.C system. The SVS can be implemented by the used of the voltage source converters (VSC).

The major advantages of SVS-based compensators over the mechanical and conventional thyristor compensators are:

1.Improved operating and performance characteristics
2. Uniform use of same power electronic device in different compensation and control applications
3. Reduced equipment size and installation labor.

The SVS can be used as in shunt or series compensators. If it is operated as a reactive shunt compensator, it is called static synchronous compensator (STATCOM); and if it is operated as a reactive series compensator, it is called static synchronous series compensator (SSSC). A special arrangement of two SVSs, one connected in series with the AC system and the other one connected in shunt with common DC terminals, is called Unified Power Flow Controller (UPFC). The UPFC is combination of the two in a single device. UPFC is most promising device in the FACTS technologies. It has the ability to do adjust all the three control parameters, i.e., the bus voltage, transmission line reactance and phase angle between two buses, either simultaneously or independently. A UPFC can perform this through the control of in-phase voltage and quadrature voltage and shunt compensation.

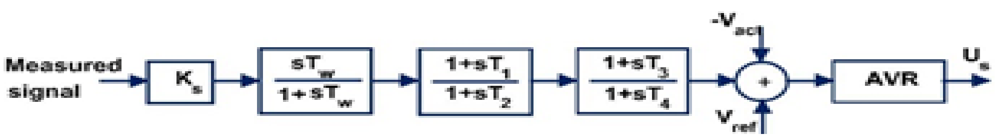

Fig1.Block diagram of a conventional power system stabilizer

Static Synchronous Compensator (STATCOM)

STATCOM is a static counter-part of the rotating synchronous condenser but it generates or absorbs the reactive power at a faster rate because no moving parts are involved.

According to the definition of the IEEE PES Task Force FACTS Working Group: A Static synchronous generator operates as a shunt-connected static Var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.

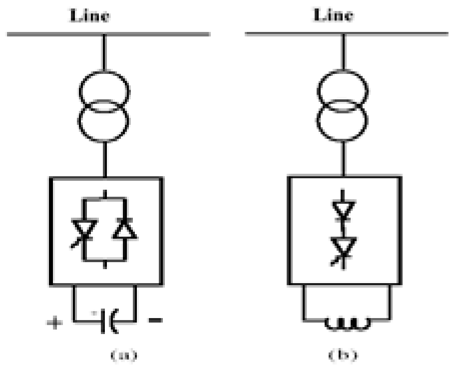

Fig.2. Static Synchronous Compensator (STATCOM) based on (i) voltage- sourced and (ii) current-sourced converter.

UPFC(Unified power flow controllers)

A Unified power flow controller is a electrical device for providing the fast-acting reactive power compensation on high voltage electricity transmission networks. It uses a pair three phase controllable bridges to produce the current that is injected into a transmission line using a series transformer.It is a device which is placed between two buses referred to as the UPFC sending-bus and the UPFC receiving-bus. It consists of two voltage-source converters, as illustrated in Fig. . The back-to-back converters, labeled "shunt converter" and "series converter" in the Fig., are operated from a common DC link provided by a DC storage capacitor. A shunt converter is primarily used to provide the active power demand of the series converter through the common DC link. Shunt converter can also generate/absorb the reactive power, if it is desired, and thereby it provides independent shunt reactive compensation for the line. Series converter provides the main function of UPFC by injecting a voltage with the controllable magnitude and phase angle in series with the line

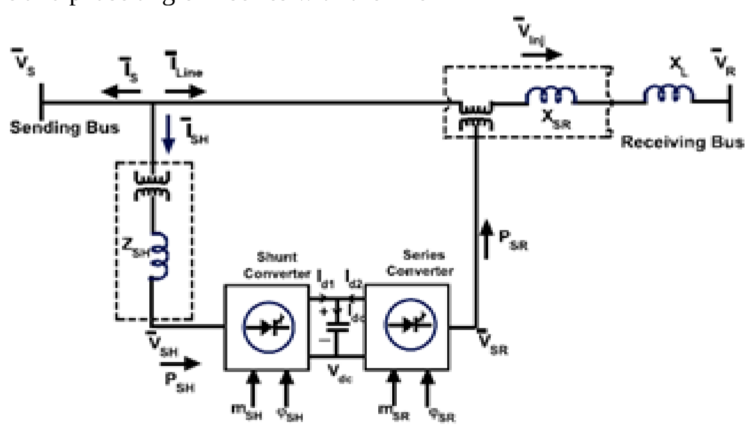

Fig. 3.Basic Circuit Configuration of the UPFC

Applying the Pulse Width Modulation (PWM) technique to the two VSCs the following equations for magnitudes of shunt and series injected voltages are obtained

$$\begin{cases} V_{SH} = \dfrac{m_{SH} V_{dc}}{2\sqrt{2} V_B} \\ V_{SR} = \dfrac{m_{SR} V_{dc}}{2\sqrt{2} V_B} \end{cases}$$

The phase angle of $\bar{V}_{SH}$ and $\bar{V}_{SR}$ are

$$\begin{cases} \phi_{SH} = \lfloor(\phi_S - \varphi_{SH}) \\ \phi_{SR} = \lfloor(\phi_S - \varphi_{SR}) \end{cases}$$

II. RESEARCH OBJECTIVE

Though technological barriers exist, as in most technology areas, it is important to overcome them by developing proper understanding of the process with related attributes. The next chapters explain the various efforts directed for improving the inter-area oscillation damping applied to multi-machine power system. The literature review reveals that the nonlinear controllers are least explored out of different methods.

Similarly, current work emphasizes the nonlinear control technique applied to multi-machine power system. Based on these guiding principles, the objectives of the current research are as follows:
1. Explore the existing methods and models for power system stability study.
1.2. Develop an advanced nonlinear controller for transient stability improvement using UPFC as a stabilizing device.
1.3. Derive an adaptive law for uncertain parameters which are otherwise difficulty to be measured precisely.
1.4. Develop the software program to simulate small scale and transient phenomena..

Facts technologies

1. Series compensation

In the Series compensation FACTS is connected in series with power system. It works as a controllable voltage-source. Series [[inductance]] exists in all the AC transmission lines. On long lines, when a large current flows, then this causes a large voltage drop. And to compensate, series capacitors are connected, decreasing the effect of inductance

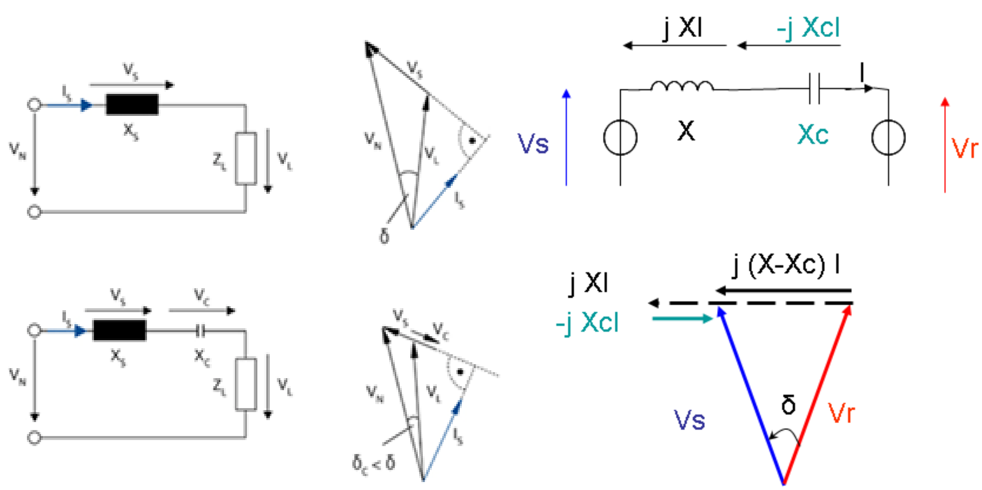

Fig.4. series compensation

2. Shunt compensation

In shunt compensation, power system is connected in shunt (electrical) or shunt (parallel) with the FACTS. It works as a controllable current source. Shunt compensation is of two types:

a. Shunt capacitive compensation
b. Shunt inductive compensation

ISSN 2348 – 8034
Impact Factor- 5.070

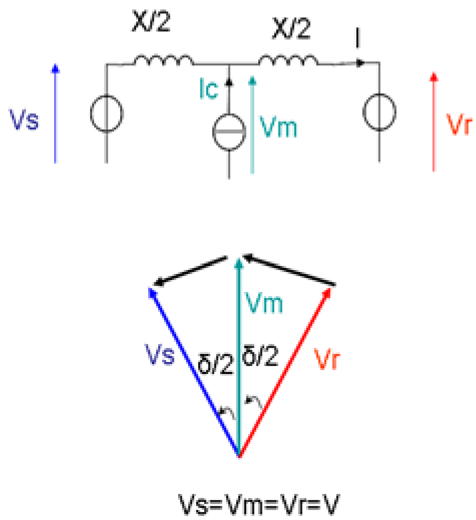

Fig.5. Shunt compensation

Principle	Devices	Scheme	Impact on System Performance		
			Load Flow	Stability	Voltage Quality
Variation of the Line Impedance: Series Compensation	FSC (Fixed Series Compensation)		●	●●●	●
	TPSC (Thryristor Protected Series Compensation)		●	●●●	●
	TCSC (Thyristor Controlled Series Compensation)		●●	●●●	●
Voltage Control: Shunt Compensation	SVC (Static Var Compensator)		O	●●	●●●
	STATCOM (Static Synchronous Compensator)		O	●●	●●●
Load-Flow Control	HVDC (B2B, LDT)		●●●	●●●	●●
	UPFC (Unified Power Flow Controller)		●●●	●●●	●●●

Influence: *
O low or no
● small
●● medium
●●● strong

* Based on Studies & practical Experience

Table: FACTS overview & description

III. MODELING AND SIMULATION

Dynamic modeling and non-linear control of multi-machine power system with UPFC
A single-machine infinite bus model is used to apply nonlinear adaptive control schemes. However, the infinite bus assumption required for this approach is not valid for large multi-machine systems when fault affects the power system. The over parameterization problem that usually appears in the adaptive method will be more predominant with multi-machine power systems.

Nonlinear dynamic representation: The system analyzed is shown in Fig. It has one low frequency inter-area mode. Generators are represented as classical model with internal voltages behind transient reactance assumed constant. This representation is adequate for the control formulation since only the generator speed variations are of concern. While deriving the equations, resistance of power system components are ignored. Mechanical input power and loads are assumed to be constants. Power system's differential equations are given below:

$$\begin{cases} \dot{\delta}_t = \omega_t - \omega_0 \\ \dot{\omega}_t = \frac{1}{M_i}\left(P_{mi} - B_{i,j+n}E_iV_{i+n}\mathrm{Sin}(\delta_i - \emptyset_{i+n})\right) \end{cases} \quad i = 1, \ldots..n$$

The bus voltages and phase angles of all the power system buses are constrained by the following set of algebraic power balance equations

$$\begin{cases} P_{L3} + \sum_{j=1}^{N+n} B_{3j} V_3 V_j \mathrm{Sin}(\emptyset_3 - \emptyset_j) = 0 \\ P_{L4} + \sum_{j=1}^{N+n} B_{4j} V_4 V_j \mathrm{Sin}(\emptyset_4 - \emptyset_j) = 0 \\ -Q_{L3} + \sum_{j=1}^{N+n} B_{3j} V_3 V_j \mathrm{Cos}(\emptyset_3 - \emptyset_j) = 0 \\ -Q_{L4} + \sum_{j=1}^{N+n} B_{4j} V_4 V_j \mathrm{Cos}(\emptyset_4 - \emptyset_j) = 0 \end{cases}$$

$V_j = E_j$; $\emptyset_j = \delta_j$ for $1 \le j \le n$. In addition N, is the number of non-generator buses in the power system. N

The injected real and reactive powers at buses 3 and 4, as explained above, are given by [67]

$$\begin{cases} P_{3inj} = B_{34} V_{SR} V_4 \mathrm{Sin}\left((\emptyset_3 + \varphi_{SR}) - \emptyset_4\right) \\ P_{4inj} = -B_{34} V_{SR} V_4 \mathrm{Sin}\left((\emptyset_3 + \varphi_{SR}) - \emptyset_4\right) \\ Q_{3inj} = B_{34} V_{SR} V_3 \mathrm{Cos}(\varphi_{SR}) \\ Q_{4inj} = -B_{34} V_{SR} V_4 \mathrm{Cos}\left((\emptyset_3 + \varphi_{SR}) - \emptyset_4\right) \end{cases}$$

Where $u_1 = V_{SR} \cos(\varphi_{SR})$ and $u_2 = V_{SR} \mathrm{Sin}(\varphi_{SR})$ are the control signal of UPFC.

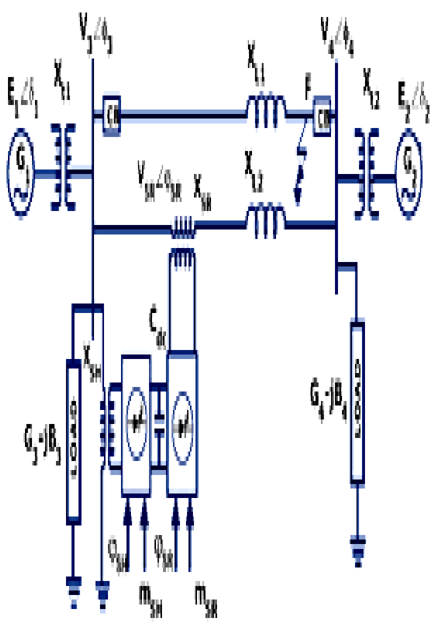

Figure 6.Sample two area power system

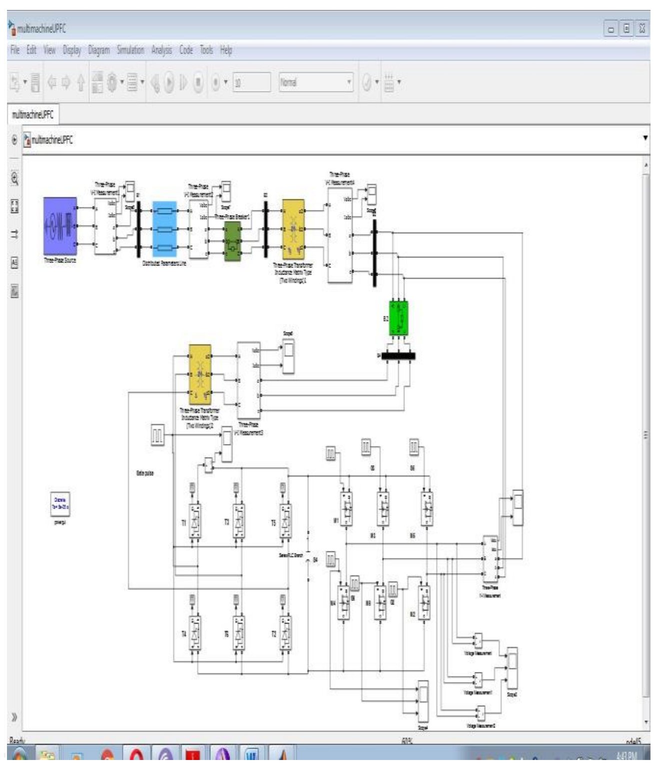

Fig.7. Simulink Model of Multi-machine

ISSN 2348 – 8034
Impact Factor- 5.070

IV. CONCLUSION AND RESULT

A general nonlinear dynamical model for power systems with UPFC as a stabilizing controller is introduced. This representation is appropriate to model a nonlinear power network with different FACTS devices. The advantage of this approach is that no algebraic equations are involved in the control design while the nonlinear behavior is retained. As demonstrated this representation helps us to convert the non-linear power system equations into standard parametric feedback form. when the standard form is achieved then conventional and advanced non-linear control techniques can be easily implemented. The net result is a power system dynamic representation that can be used for the design of a sophisticated FACTS damping controller. A nonlinear control scheme is developed to stabilize and damp the oscillations resulting from a disturbance such as a three phase to ground fault. The nonlinear control scheme is independent of the operating point. We target the stability of the generators by defining an appropriate Lyapunov function. The analytical expression of the non-linear control law for the UPFC is obtained by using a back stepping method. Then, combining the nonlinear control strategy with the linear one for the other variables, a complete linear and non-linear stabilizing controller is obtained.

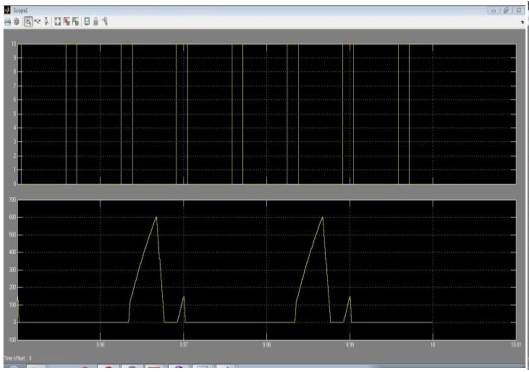

Fig 8.Input &Output current of Multi-machine

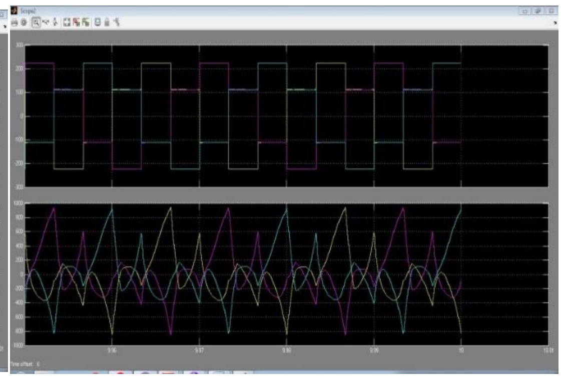

Figure.9.Input-Output Power of Multi-machine

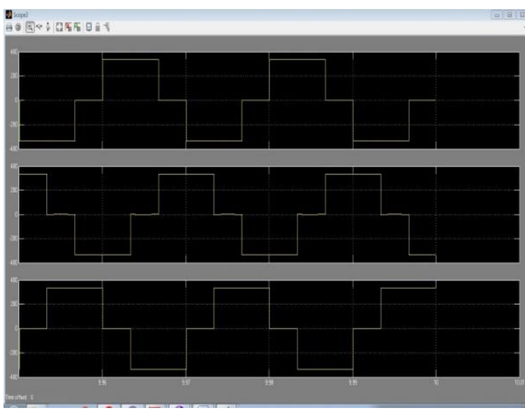

Fig 10.Active current of Multi-machine

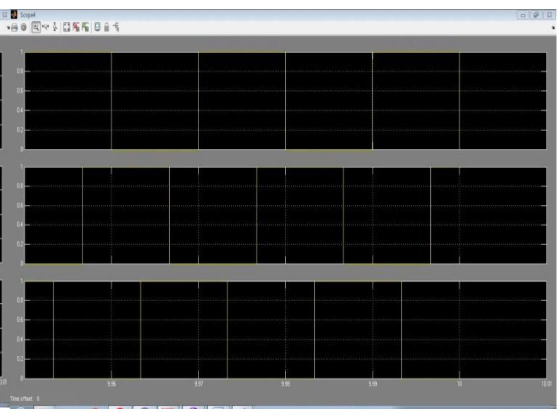

Figure.11.Reactive current of Multi-machine

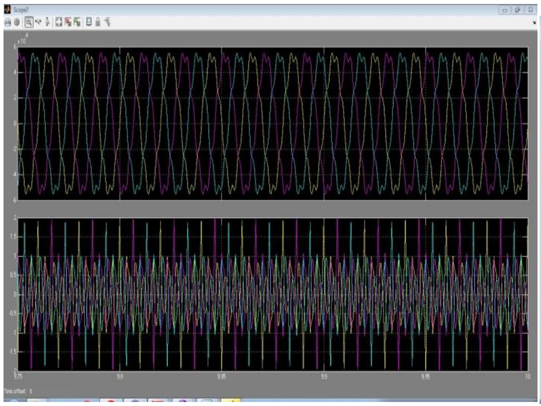

Fig 12. Reactive power of Multi-machine

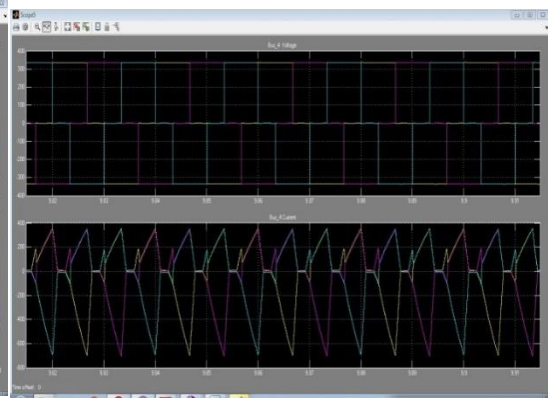

*Fig.13 Multi-machine bus voltage, current*and *power*

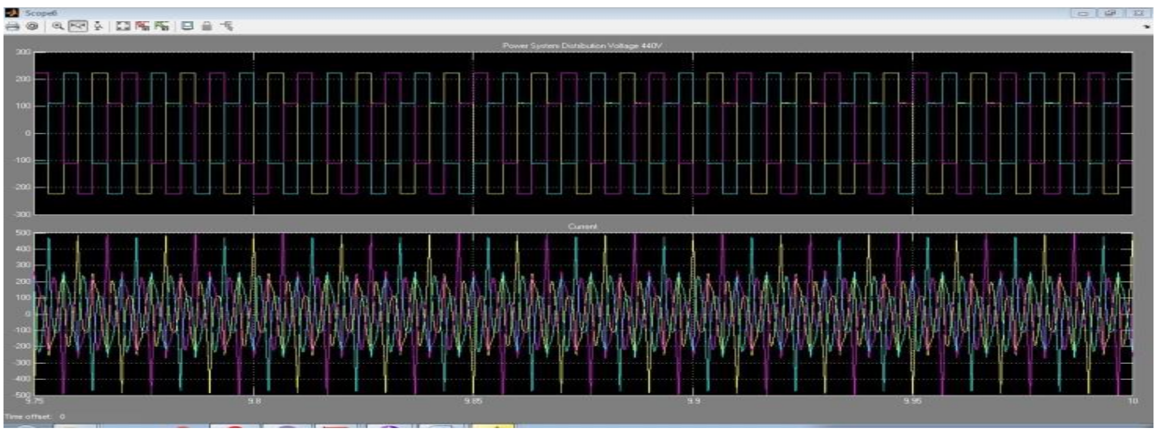

Figure.14 Power transmission distribution at 430/440v.

Comparison of active powers

Sr. No	Reactive Loading	Active Power (TCSC &SVC)	Active Power (UPFC)
1.	100 %	0.0405	0.0385
2.	150%	0.0432	0.0427
3.	200 %	0.0572	0.0540

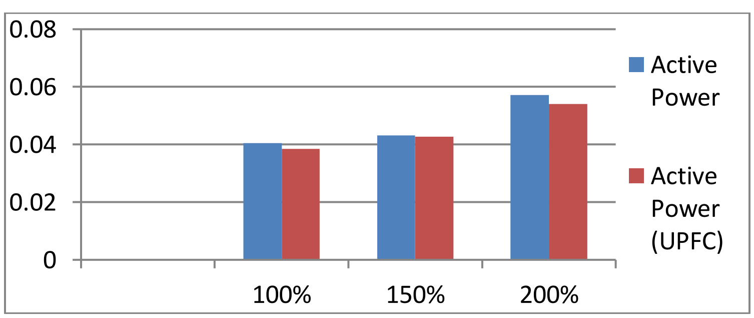

Figure15. Comparative-analysis of the Active power

V. FUTURE SCOPE

In future, studies may focus on design and implementation of a non-linear control schemes with the several FACTS devices in a multi-machine power system. The 68 bus NYPS-NETS test power system can be used for this purpose. Advanced random search on-line dynamic controllers like PSO, can be used for optimization. Secondly, a hardware setup can be used to fully understand the dynamic performance of the multiple FACTS devices, which would validate software simulation.

REFERENCES

1. *Rogers, G., "Power system oscillations", Kluwer Academic Publishers, USA, 2000.*
2. *Fregene, K., Kennedy, D., "Stabilizing control of a high-order generator model by adaptive feedback linearization", IEEE Transactions on Energy Conversion, vol.18, no.1, pp. 149- 156, 2003.*
3. *Mathur, R. M., Basati, R. S., "Thyristor-Based FACTS Controllers for Electrical Transmission Systems", IEEE Press Series in Power Engineering, 2002..*
4. *Wang, H. F., Li, H., Chen, H., "Application of cell immune response modeling to power system voltage control by STATCOM", IEE Proceedings on Generation Transmission and Distribution, vol. 149, no. 1, pp. 102–107, 2002*
5. *Farsangi, M.M., Song, Y.H., Lee, K.Y., "Choice of FACTS device control inputs for damping inter-area oscillations", IEEE Transactions on Power Systems, vol. 19, no. 2, pp. 1135-1143, 2004.*
6. *Rajasekaran, S., Vijayalakshmipai, G. A., "Neural networks, fuzzy logic and genetic algorithms: synthesis and applications," PHI Learning Pvt. Ltd. 2006.*
7. *Huang, Z., Ni, Y., Shen, C.M., Wu, F.F., Chen, S., Zhang, B., "Application of unified power flow controller in interconnected power systems -- modeling, interface, control strategy and case study", IEEE Transactions of Power Systems, Vol. 15, No. 2, pp. 817-824, 2000.*
8. *Wang, H.F., "Applications of modeling UPFC into multi-machine power systems", IEE Proceedings on Generation, Transmission and Distribution, Vol. 146, No. 3, pp. 306-312, 1999*
9. *Karagiannis D., Astolfi A., "Nonlinear adaptive control of systems in feedback form: an alternative to adaptive back-stepping", Syst. Control Lett., vol. 9, pp. 733-739, 2008..*
10. *Khalil, H.K., "Nonlinear systems," Upper Saddle River, NJ: Prentice Hall, 2002..*
11. *Tambey, N., Kothari, M.L., "Damping of power system oscillations with unified power flow controller (UPFC)", IEE Proceedings on Generation, Transmission and Distribution, vol.150, no.2, pp. 129- 140, 2003.*
12. *Hemlata,"Transient stability analysis of Multi Machine Power System with Fact Device".*
13. *Noroozian, M., Angquist, L., Ghandhari, M., Andersson, G., "Use of UPFC for optimal power flow control", IEEE Transactions on Power Delivery, vol.12, no.4, pp.1629-1634, 1997.*
14. *Prabhashankar, K., Janischewsy, J. W., "Digital simulation of multi-machine power systems for stability studies", IEEE Transactions on Power Apparatus and systems, vol. 87, no.1, pp.73-80, 1968.*
15. *Hammad, A. E., "Analysis of power system stability enhancement by static VAR compensators", IEEE Transactions on Power Systems, vol. 1, no. 4, pp. 222–227, 1986.*
16. *SadeghVaez-Zadeh, " Robust power system stabilizers for enhancement of dynamic stability over a wide operating range", Electric Power Components and Systems, vol. 29, no. 7, pp. 645-657, 2001.*
Author's Last name, First initial, Middle initial, "Title," Journal or book (italics),Vol, No #., date, pp.
Author's Last name, First initial, Middle initial, "Title," Journal or book (italics),Vol, No #., date, pp.