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Analysis of Multi Machine Power System Transient Stability Using FACTS Device

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Abstract: *The focus of this thesis is a FACTS device known as the Unified Power Flow Controller (UPFC). With its unique capability 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, this device creates a tremendous quality impact on power system stability. These features turn out to be even more significant because UPFC can allow loading of the transmission lines close to their thermal limits, forcing the power to flow through the desired paths. This provides the power system operators much needed flexibility in order to satisfy the demands. A power system with UPFC is highly nonlinear. The most efficient control method for such a system is to use nonlinear control techniques to achieve system oscillation damping. The nonlinear control methods are independent of system operating conditions. Advanced nonlinear control techniques generally require a system being represented by purely differential equations whereas a power system is normally represented by a set of differential and algebraic equations. In this thesis, a new method to generate a dynamic modeling for power network is introduced such that the entire power system with UPFC can be represented by purely differential equation. This representation helps us to convert the nonlinear power system equations into standard parametric feedback form. Once the standard form is achieved, conventional and advanced nonlinear control techniques can be easily implemented. A comprehensive approach to the design of UPFC controllers (AC voltage control, DC voltage control and damping control) is presented. The damping controller is designed using nonlinear control technique by defining an appropriate Lyapunov function. The analytical expression of the nonlinear control law for the UPFC is obtained using back stepping method. Then, combining the nonlinear control strategy with the linear one for the other variables, a complete linear and nonlinear stabilizing controller is developed. Finally, an adaptive method for estimating the uncertain parameters is derived. This relaxes the need for approximating the uncertain parameters like damping coefficient, transient synchronous reactance etc., which are difficult to be measured precisely.*

Keywords: FACTS, Unified Power Flow Controller (UPFC), stability, transient

I. INTRODUCTION

[1] In the Time Domain Simulations method, the Critical Clearing Time (CCT) has been determined by solving the system differential equations in the during-fault and post-fault conditions by using the numerical integration technique. A great deal of time domain simulation method has been carried out by Anderson (1977). [2] The fundamentals of this method have been clearly described by Prabha Kundur (1994). This approach results in repeated integration process for each fault involving large amounts of computer time. Even though this method has excellent modeling capability, the degree of stability could not be found from the outcome (CCT) of this method. The significant increase in the dimensionality of the problem with the system size, the numerical integration methods are not suitable for real world planning or for online operation. [3]The Transient Energy Function method of transient stability evaluation is based on analytical formulae for determination of transient kinetic and potential energy for the post contingency system as presented by Pai (1989). This method involves modeling simplifications and some mathematical approximations. The Structure Preserving Energy Function (SPEF) allows transfer conductance, better load, machine modeling and power electronics converters but they are computationally more demanding. [4]The construction procedure of a SPEF for a power system along with some realistic types of active and reactive load models have been presented by Van Custem

(1985). Fouad and Vittal (1992) have presented the basics of transient energy function for determination of energy margin, first and second order sensitivity of energy margin with respect to the real power generation. [5] Hsiao-Dong Chian (1995) has clearly described the theory, applications and perspective of transient stability analysis of electric power system using energy function. [6]The first swing stability behaviour of generators in New England 39 bus system has been detected by constructing a hybrid corrected TEF by Da-Zhong Fang (2000). [7]The CCT of New England 39 bus system for a three phase short circuit fault near bus 14 has been computed by constructing an energy function for the post fault system by Smanmit (2002). Yoshinori Yamada (2002) has applied energy function method to quantify the severity of each fault, and the difference of severities between scenarios with and without transaction. [8] Another direct method, so-called EEAC has proved to be substantially faster than the Lypunov Criterion. It was developed by Rahimi (1987) and Xue (1988) and extended by Lemmon (1989). [9] A significant advantage is the algebraic equations which are provided for the calculation of CCT and stability margins. This makes the conventional TSA particularly easy, and furnishes analytical sensitivity tools, and there from means to control. The key idea of EEAC is to reduce the multi-machine system to a Single Machine Infinite Bus (SMIB) System and to apply modified direct methods to get simpler expressions. [10] The problems are obtaining the candidate critical machines correctly and reconcile the inconsistencies between the system stability mode and the SMIB. Chan (2002) has established a hybrid method incorporating the EEAC into the time domain simulation to provide stability margin index for deriving effective transient stability control actions. [11]Chunyan Li (2007) has presented an emergency control strategy of transient stability, where EEAC has been used to predict and analyze the degree of stability. Chiodo (1994) has proposed Probabilistic Transient Stability Studies based on Monte Carlo approach to find the transient stability index. [12]SalehAboreshaid (1996) has employed the method of bisection for the same. Here, the number of stability runs required to determine the Probabilistic transient stability indices have been reduced. [13] Dharmarao (1962) and Luis Aromataris (2002) have used the Phase Plane of for solving the swing equation in a SMIB system. It provides the critical clearing time and angle of a fault using single numerical integration. The phase plane method and probabilistic methods are not suitable for large scale systems and systems with refinements. A large number of publications have appeared on ANN application to TSA. Sobajic (1989) explored the capability of ANN for TSA. [14] Ping Yan (2000) has estimated the stability status of power system by a multi layer feed forward neural network, which has been trained using patterns of swing curves. This paper investigates the stability of power system, by formulating the problem of transient stability as a pattern recognition problem using ANN. [15] Bahhah (2004) has presented a method using recurrent ANN to predict the rotor angles and angular velocities of generators.[16] A strategy based on pattern discovery algorithm and extended to k-Nearest Neighbour classifier to design the power system stability assessment scheme has been proposed by Wang Tongwen (2007). Neuro-Fuzzy (NF) methods, which are a combination of NN and Fuzzy Logic Systems, have been employed by many researchers, since it combines the advantages of both NNs and fuzzy systems.

II. System Configuration

UPFC is a device 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. 1. 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. The shunt converter is primarily used to provide active power demand of the series converter through the common DC link. Shunt converter can also generate or absorb reactive power, if it is desired, and thereby it provides independent shunt reactive compensation for the line. Series converter provides the main function of the UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line. For the fundamental frequency model, the VSCs are replaced by two controlled voltage sources [60]. The UPFC is placed on the high-voltage transmission lines. This arrangement requires step-down transformers in order to allow the use of power electronics devices for the UPFC.

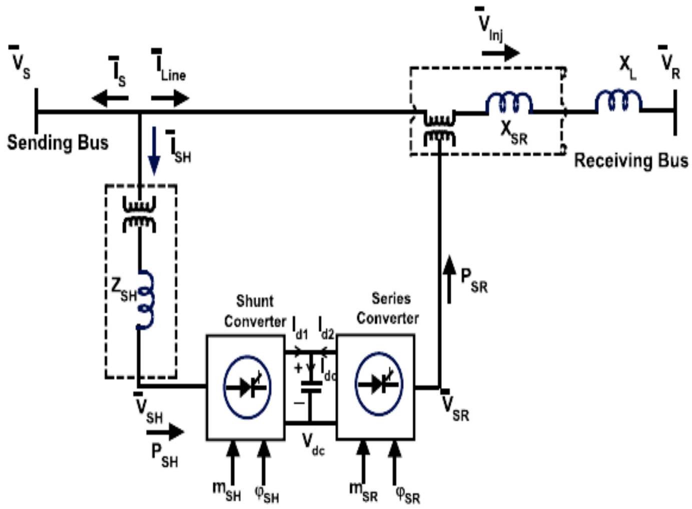

Fig. 1: Basic Circuit Configuration of the UPFC

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

$$\begin{cases} \emptyset_{SH} = \lfloor(\emptyset_S - \varphi_{SH}) \\ \emptyset_{SR} = \lfloor(\emptyset_S - \varphi_{SR}) \end{cases}$$

The series converter injects an AC voltage$\bar{V}_{SR} = V_{SR}\lfloor(\emptyset_S - \varphi_{SR})$in series with the transmission line. Series voltage magnitudeV_{SR} and its phase angle $\varphi_{SR}$with respect to the sending bus are controllable in the range of $0 \leq V_{SR} \leq V_{SRmax}$ and $0^\circ \leq \varphi_{SR} \leq 360^\circ$respectively. The shunt converter injects controllable shunt voltage such that the real component of the current in the shunt branch balance the real power demanded by the series converter. The real power can flow freely in either direction between the AC terminals. On the other hand, the reactive power cannot flow through the DC link. It is absorbed or generated locally by each converter. The shunt converter operated to exchange the reactive power with the AC system provides the possibility of independent shunt compensation for the line. If the shunt injected voltage is regulated to produce a shunt reactive current component that will keep the sending bus voltage at its pre-specified value, then the shunt converter is operated in the Automatic Voltage Control Mode**.** Shunt converter can also be operated in the VAR control mode**.** In this case shunt reactive current is produced to meet the desired inductive or capacitive VAR request. The basics of VSCs and PWM techniques are briefly discussed in the next section.

The typical three-phase VSC is shown in Fig. 2 [5]. It is made of six valves, (1-1') to (6-6') each consisting of a gate turn off device (GTO) paralleled with a reverse diode, and a DC capacitor. The designated order 1 to 6 represents the sequence of valve operation in time. It consists of three-phase legs, which operates in concert, 120 degrees apart. An AC voltage is generated from a DC voltage through sequential switching of the GTOs. Being an AC voltage source with low internal impedance, a series transformer is essential to ensure that the DC capacitor is not short-circuited and discharged rapidly into a capacitive load such as transmission line. The DC voltage always has one polarity and the DC current can flow in either direction. Controlling the angle of the converter output voltage with respect to the AC system voltage controls the real power exchange between the converter and the AC system.

The real power flows from the DC side to AC side (inverter operation) if the converter output voltage is controlled to lead the AC system voltage. If the converter output voltage is made to lag the AC system voltage, the real power will flow from the AC side to DC side (rectifier operation). Inverter action is carried out by the GTOs while the rectifier

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action is carried out by the diodes. Controlling the magnitude of the converter output voltage controls the reactive power exchange between the converter and the AC system. The converter generates reactive power for the AC system if the magnitude of the converter output voltage is greater than the magnitude of the AC system voltage. If the magnitude of the converter output voltage is less than that of the AC system, the converter will absorb reactive power.

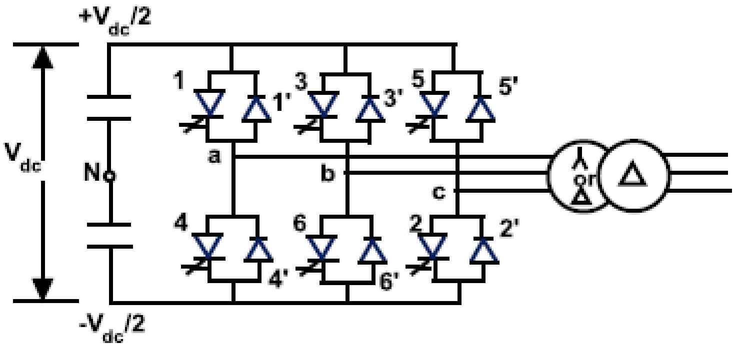

Fig. 2: Three Phase Voltage Source-Converter

The converter output voltage can be controlled using various control techniques. Pulse Width Modulation (PWM) techniques can be designed for the lowest harmonic content. It should be mentioned that these techniques require large number of switching per cycle leading to higher converter losses. Therefore, PWM techniques are currently considered unpractical for high voltage applications. However, it is expected that recent developments on power electronic switches will allow practical use of PWM controls on such applications in the near future. Due to their simplicity many authors, viz., [58], [59], [60], have used PWM control techniques in their UPFC studies. Hence, the same approach is used in this thesis.

When sinusoidal PWM technique is applied, turn on and turn off signals for GTOs are generated comparing a sinusoidal reference signal$V_R$of amplitudeA_R with a saw tooth carrier waveform $V_C$of amplitudeA_C as shown in Fig. 3.4 [5]. The frequency of the saw tooth waveform establishes the frequency at which GTOs are switched.

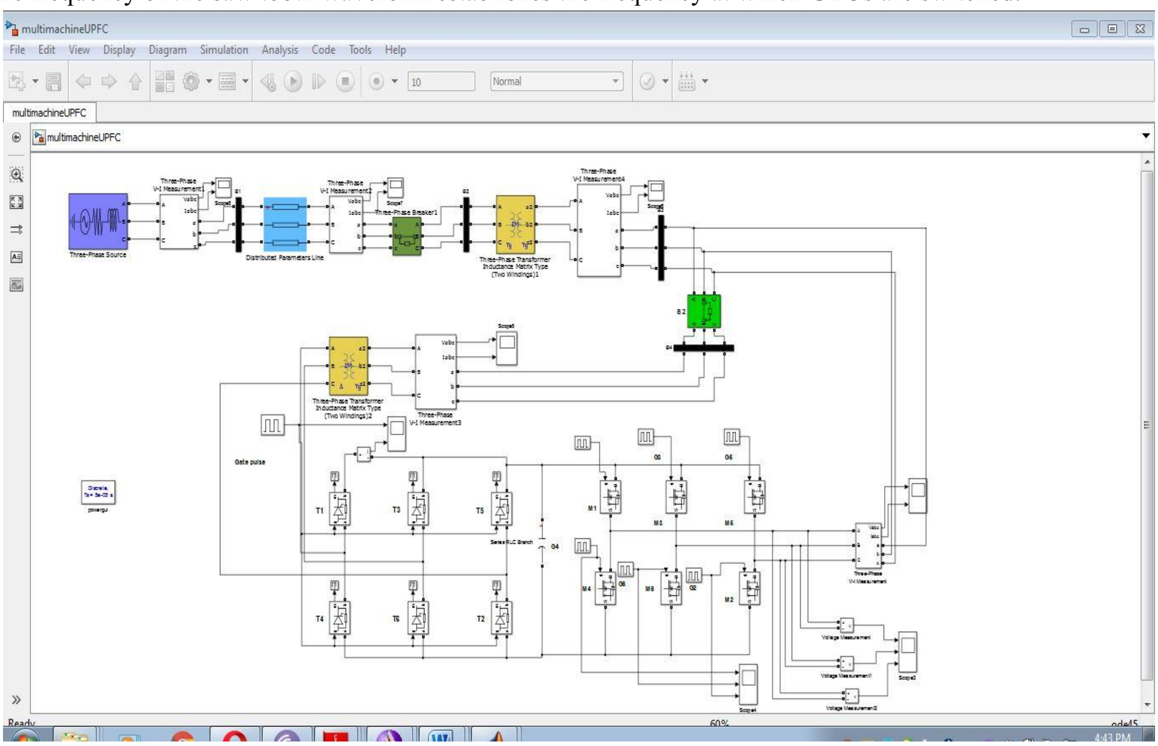

Fig 3 Simulation Model of Multimachine

Consider a phase-leg as shown in Fig. 3.3. In Fig. 2.4,V_R>$V_C$results in a turn on signal for the device 1 and gate turn off signal for the device 4 andV_R>$V_C$results in a turn off signal for the device 1 and gate turn on signal for the device 4. The fundamental frequency of the converter output voltage is determined by the frequency of the reference signal. Controlling the amplitude of the reference signal controls the width of the pulses. In two-level or multilevel converters, there is only one turn-on, turn-off per device per cycle. With these converters, the AC output voltage can be controlled, by varying the width of the voltage pulses, and / or the amplitude of the DC bus voltage. It goes without saying that more pulses means more switching losses, so that the gains from the use of PWM have to be sufficient to justify an increase in switching losses. For FACTS technology with high power in the tens of megawatts and converter voltage in KVs and tens of KVs, low frequencies in the few hundred Hertz or may be the low kilohertz range may seem feasible and worth considering. The least cost and simplest controllable three-phase converter would seem to be a six-valve converter with one turn-off device / diode per valve. In FACTS applications, there will usually be a need for a transformer between the converter valves and the AC system; there is therefore a certain flexibility provided by the transformer turn ratio to match the available device current and voltage rating.

III. RESULTS

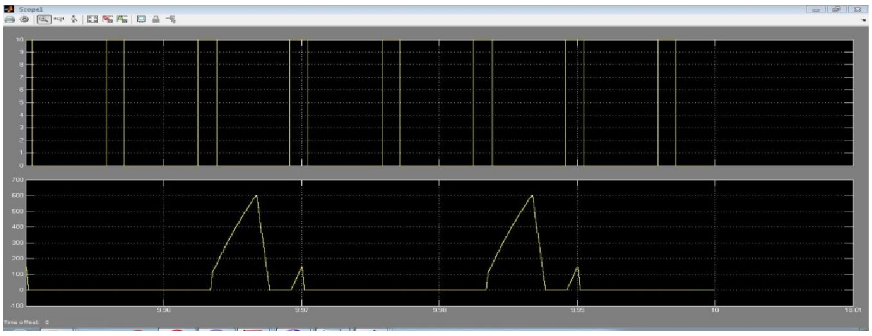

Figure 4 Input-Output current of Multimachine

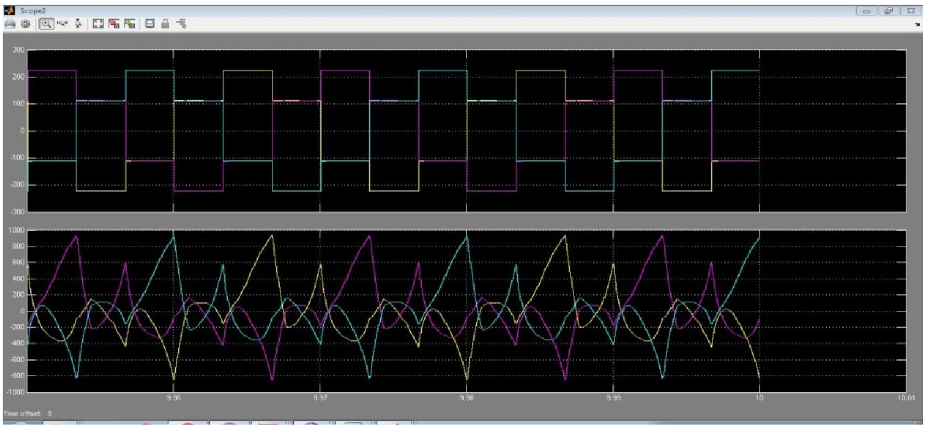

Figure 5 Input-Output Power of Multimachine

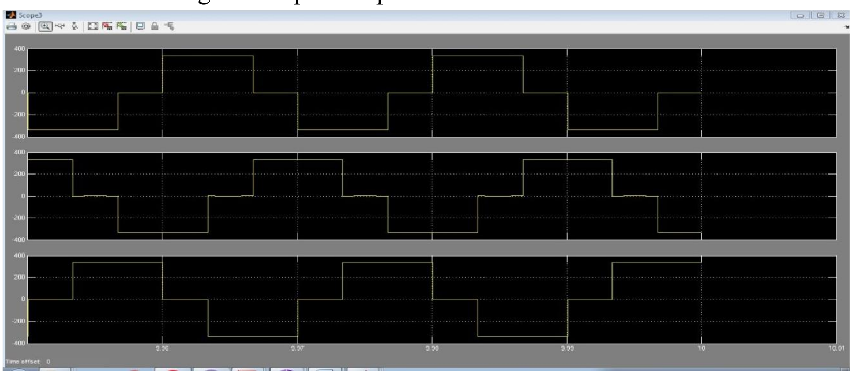

Fig 6 Active current of Multimachine

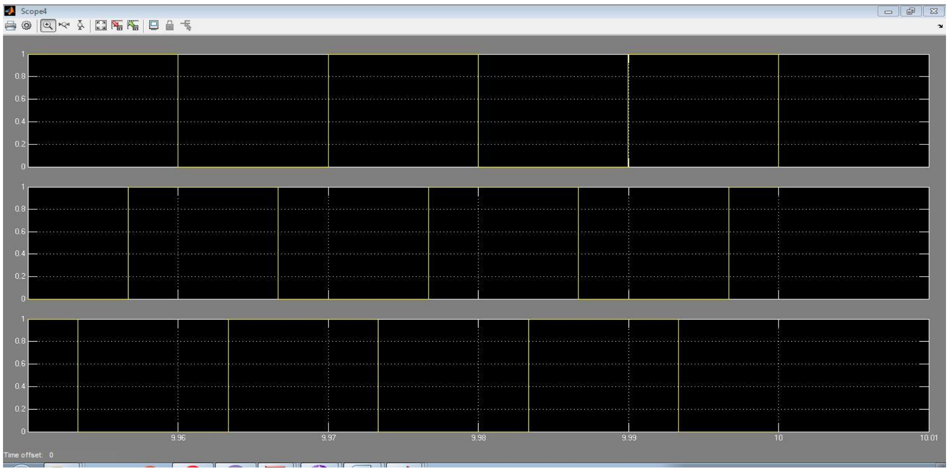

Fig 7 Reactive current of Multimachine

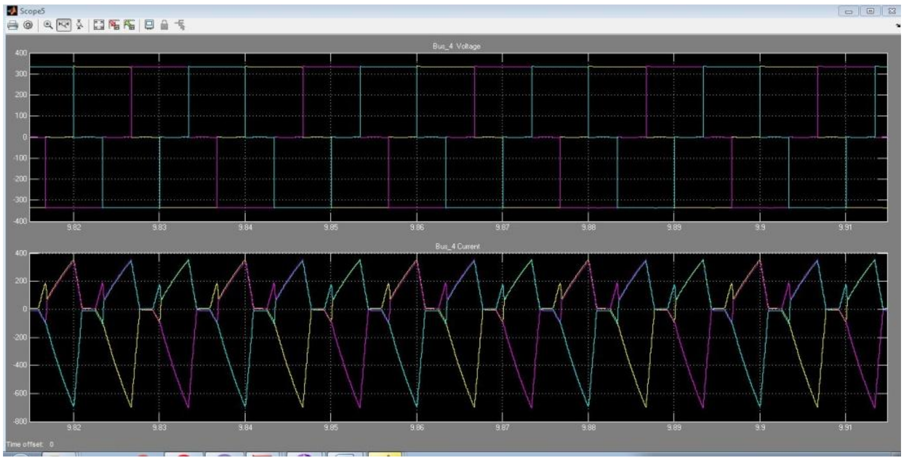

Fig 8 Multimachine bus voltage ,current& power

Fig 9 Power transmission distribution at 440v

IV. Conclusion

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 in Chapters 4, 5 and 6, this representation helps us to convert the nonlinear power system equations into standard parametric feedback form. Once the standard form is achieved, conventional and advanced nonlinear 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 nonlinear control law for the UPFC is obtained using back stepping method. Then, combining the nonlinear control strategy with the linear one for the other variables, a complete linear and nonlinear stabilizing controller is obtained

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