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Modelling Of Unified Power Flow Controller Using Advanced Control Techniques

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Abstract*—Flexible Ac Transmission System devices are power electronic based controllers which can influence transmission system voltage, currents, impedances and phase angle rapidly. The Unified Power Flow Controller (UPFC) is a member of FACTS device that utilizes the synchronous voltage sources (VSC) to provide comprehensive control of traditional power flow concepts. It can provide functional capabilities of controlling both the active and reactive power independently. This paper discusses the designing of advanced control techniques for the operation of UPFC. The modern controller ANFIC and Fuzzy-PI controller have been designed and tested for controlling series and shunt part of UPFC respectively. The system responses on different operating conditions are tested on 4-bus system. Computer simulation are done by MATLAB/SIMULINK.

***Keywords*-Flexible Ac Transmission System, Unified Power Flow Controller, Adaptive Neuro Fuzzy Inference Controller.**

NOMENCLATURE

V_{ser}	Series injected voltage
V_{sh}	Shunt injected voltage
V_1	Sending end voltage
V_2	Receiving end voltage
ΔP	Change in real power
ΔQ	Change in reactive power
V	Voltage on right side of UPFC
δ	Transmission angle
β	In-phase series injected voltage
γ	Quadrature series injected voltage
KX	Short Circuit Level
η	In-phase shunt voltage
ξ	Quadrature shunt voltage
P_{sh}	Shunt real power
Q_{sh}	Shunt reactive power
P_{ex}	Real power exchanged

I.INTRODUCTION

With the growing demand of electricity, at times, it is not possible to erect new lines to face the situation. FACTS make use of the thyristor controlled devices and optimally utilize the existing transmission network [1]. FACTS are high-power electronics-based devices capable of altering voltage, phase angle, and impedance at particular points in power systems. Their fast response offers high-power stability enhancement, therefore preventing possible voltage collapse. UPFC is the second generation of FACTS devices that is able to provide series and shunt compensations in transmission systems [2]. Within its operating limits, a UPFC can independently control three power system parameters. Since the proposal of the UPFC, there has been increasing interest in finding a suitable control method to suit a range of system operating conditions.

Various controllers have been proposed to regulate the operation of UPFC. Cross-coupling proportional- integral (PI) controllers, decoupling PI controllers, hybrid PI controller were commonly used. The interaction between the real and reactive power flow is minimized by Cross-coupling PI controllers [3]. The use of decoupling PI controllers is proposed to reduce the effect of harmonics in the current measurement [4]. A hybrid (direct coupling and cross coupling) PI controller was suggested to oscillation damping [5]. But, PI controllers do not

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perform satisfactorily over a wide range of operating points. This is caused by the control parameters being determined based on certain system conditions. The robust control theory has been used in the UPFC controller design. This requires a defined mathematical model of the power system, and online computation to solve the optimization equations. Recently used control technique is based on fuzzy control theory. A main drawback of using fuzzy logic is that the chosen membership functions are not adapted according to the system operating condition. ANFIS combines the fuzzy qualitative approach with the adaptive capabilities of neural networks to achieve improved performance [6]. Compared to a standard fuzzy-logic controller, a control system based on this concept can be trained without significant expert knowledge.

In this paper adaptive neuro fuzzy inference controller (ANFIC) is proposed and analyzed for UPFC. ANFIC is proposed to control the series part of the UPFC based on the relationship between the required power flow and the inserted voltage components. When the desired operating point of the power system would cause the UPFC to violate its voltage and/or current limits, the controller responds according to real-power priority logic. As a result, the best acceptable operating point is achieved for the power system while the UPFC remains within its operating limits. The effect of maximum inserted voltage on the system feasible region is also investigated. The best acceptable operating point is achieved for the power system while the UPFC remains within its operating limits. The impacts of the system fault level on the system operating area are also analyzed.

The function of the shunt part of the UPFC is to supply the real power demand of the series inverter and to support the system bus voltage. In this work, a fuzzy-like PI is used to control the operation of the shunt inverter [7]. A PI controller is used in each case for the assessment of the proposed ANFIC controller, and the PI control parameters are designed in order to limit the maximum overshoot during the transient period and to reduce the interaction between the real and reactive power-control loops. The designed controller is tested using a UPFC computer model in the MATLAB/SIMULINK environment.

II. UPFC CONTROL MODES

The structure of UPFC with its shunt and series inverters offers great flexibility in controlling

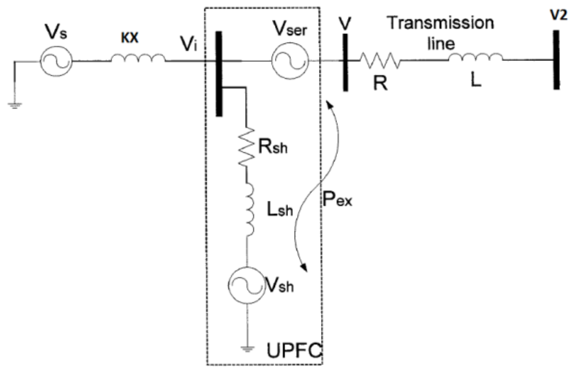
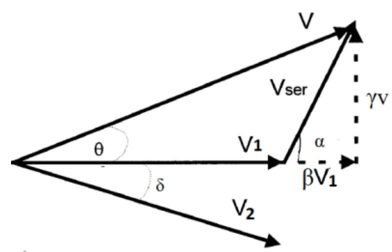
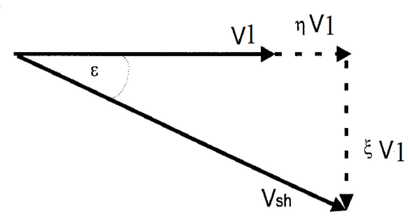


Figure. 1. A simple transmission system including UPFC



(a)



(b)

Figure.2. UPFC vector diagram. (a) . series inverter (b). shunt inverter

all power transfer parameters (transmission voltage, transmission impedance, and transmission phase angle). This flexibility is due to the ability of the shunt and series inverters of generating output voltages with controllable magnitude and angle which provide the possibility of many operating modes [8]. The general operating modes are to have the shunt inverter operated in automatic voltage control mode and the series inverter to be in automatic power flow control mode. The shunt inverter is operated to absorb or generate reactive power to regulate the bus voltage at which UPFC is connected.

The series inverter operating mode depends on the relative phase angle and magnitude of the injected voltage, and they are controlled maintain or vary active and reactive power flow through the transmission line within a predetermined region.

III. MODELLING OF UPFC

In this study, single-phase equivalent circuit of a simplified transmission system, including a transmission line and two voltage sources V_{ser} and V_2 are considered as shown in Figure 1.

The UPFC is modeled as two controllable voltage sources; V_{ser} represents the series inverter and V_{sh} represents the shunt inverter [8]. Two perpendicular components: one in-phase with the system bus voltage and the other in quadrature are used to represent both compensation voltages generated by each inverter of the UPFC. The vector diagram series and shunt inverters of UPFC is represented in Figure 2.

IV. CONTROL OF SERIES INVERTER

When considering the series compensation voltage V_{ser} and with respect to the vector diagram of series inverter per-unit change of real and reactive power flow as a function of series inserted voltage components are expressed as

$$\Delta P=\beta\sin\delta+\gamma\cos\delta \qquad (1)$$

$$\Delta Q=\gamma^2+\gamma\sin\delta+(2-\cos\delta)\beta+\beta^2 \qquad (2)$$

By solving equations (1) and (2), the values of β and γ corresponding to the desired change of the real and reactive power may be obtained.
Where,

$$\beta = V_{ser}\cos\delta$$
$$\gamma = V_{ser}\sin\delta$$

The real roots of β and γ require the inequality in the above equation to be satisfied.

A. UPFC INTERNAL LIMITS:

The power system feasible operating region is determined by system topology and physical limits of its components [9]. The most common constraints that should be taken into account when dealing with UPFC control are,

- Maximum injected current by shunt inverter
- Maximum injected voltage by series inverter
- Maximum current in series inverter
- Maximum power transfer between inverters
- Line voltage limits for transmission line.

These limits are summarized as VA rating of UPFC inverters. Other constraints that limit the operation of UPFC are

- Line voltage at the UPFC right side
- The system short circuit level

These limits are determined based on the transmission system topology and power demands. The series compensation voltage will control line current and line voltage at the UPFC right side. These limits are given mainly at maximum inserted voltage. Controller should find an appropriate operating point within the system feasible limits before control limit is exceeded. The solution depends on the system operating conditions, and neurofuzzy techniques are inherently advantageous in such a decision-making process.
The per unit change in real and reactive power in transmission system can be rewritten as

$$\Delta P=V_{ser}\sin(\delta+\alpha) \qquad (3)$$

$$\Delta Q=V_{ser}^2-V_{ser}\cos(\delta+\alpha) + 2V_{ser}\cos\alpha \qquad (4)$$

B. ADAPTIVE NEURO FUZZY INFERENCE CONTROLLER (ANFIC)

Fuzzy systems and neural networks have attracted the interest of researchers in various scientific and engineering areas. The main idea of fuzzy logic control (FLC) is to build a model of a human control expert who is capable of controlling the plant without thinking in terms of a mathematical model. The control expert specifies his control actions in the form of linguistic rules. These control rules are translated into the framework of fuzzy set theory providing a calculus which can simulate the behavior of the control expert The quality of fuzzy logic controller can be drastically affected by the choice of membership functions. Thus, methods for tuning fuzzy logic controllers are necessary.

Neural network has the shortcoming of implicit knowledge representation, whereas, fuzzy logic systems are subjective and heuristic. The determination of fuzzy rules, input and output scaling factors and choice of membership functions depend on trial and error that makes the design of fuzzy logic system a time consuming task. These drawbacks of neural network and fuzzy logic systems are overcome by the integration between the neural network technology and the fuzzy logic systems.

The concept of fuzzy logic can be incorporated into the neural network to substantially reduce the development time while improving performance[10]-[11]. The data's used for training ANFIC are two vectors of the real power deviation (ΔP) and reactive power deviation (ΔQ). Series injected voltage components β and γ are the training output. β and γ are given by,

$$\gamma=(\Delta P-\sin\delta)/\cos\delta \qquad (5)$$

$$\beta=\left(\frac{-b\pm\sqrt{b^2-4ac}}{min}\right) \qquad (6)$$

V. CONTROL OF THE SHUNT INVERTER

The function of the shunt part of the UPFC is to supply the real power demand of the series inverter and to support the system bus voltage. The real and reactive power through shunt branch is given by,

$$P_{sh}=(V_1^2/X_{sh})\xi \qquad (7)$$

$$Qsh=-(V_1^2/X_{sh})\eta \qquad (8)$$

Where,

ξ represents the in-phase shunt inverter voltage

η represents the quadrature shunt inverter voltage

The difference between the VA rating of the shunt inverter and the real power demand of the series inverter can be used to exchange the reactive power with the transmission system in order to enhance the UPFC voltage-control capability.
The control parameters of the shunt inverter ξ and η are obtained as,

$$\xi= (Xsh/V_1^2)P_{ex} \qquad (9)$$

$$\eta=-(Xsh/V_1^2)\ Qsh \qquad (10)$$

Where,
$P_{ex} = P_{sh}$ is the real power exchanged between the series inverter and the AC system.

In this paper, a fuzzy-like PI is used to control the operation of the shunt inverter. P_{ex} or P_{sh} is used to define ξ which will guarantee the stability of the dc-link voltage. The bus voltage deviation is used to define η.

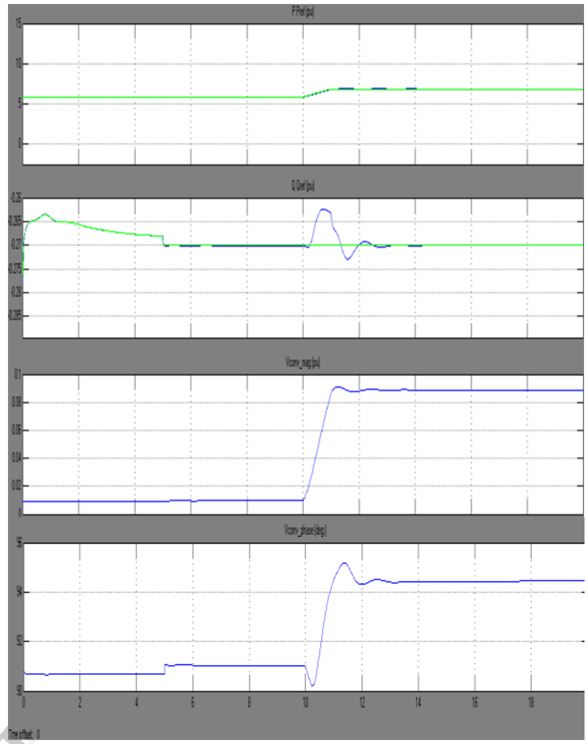


Figure.3.System response to HSCL

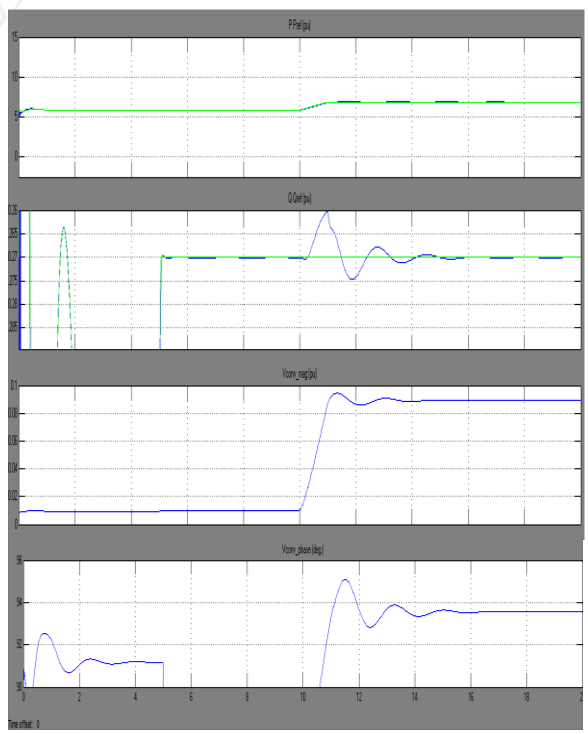


Figure.4. System response for low SCL

VI. SIMULATION OF UPFC

Performance of ANFIC controller in regulating UPFC is analyzed by simulation of transmission system with UPFC model in MATLAB/SIMULINK. The system is tested under different SCL for 4-bus system. The simulation results shown in Figure.3 represent the system response for high short circuit level. The system response for low short circuit level is shown in Figure.4. The proposed controller has good performance in real and reactive power flow control.

Comparing the response in the two graphs, the ANFIC is less sensitive to fault level, while the PI controller has slower response for low short-circuit levels. This can be modified by choosing appropriate gains. The figure also shows the capability of the UPFC to regulate the bus voltage at which the shunt inverter is connected regardless of the controller type for the shunt inverter.

VII. CONCLUSION

In this paper, an advanced method to control the operation of UPFC is investigated. Depending on the relationship between required power flow and inserted voltage components an ANFIC is proposed to control series part of UPFC. A fuzzy-like PI is used to control the operation of the shunt inverter. Simulation is done for UPFC model on 4-bus system. Results show that ANFIC controller provides better performance when compared to PI controller irrespective of position of operating points.

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