International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-2 Issue-4, April 2013

Unified Power Flow Controller (UPFC) for Dynamic Stability in Power System using Modern Control Techniques

B.Gopinath, S.Suresh Kumar, Juvan Michael

Abstract— Flexible AC Transmission System (FACTS) technology was introduced to overcome the operational difficulties with conventional method of power compensation. Unified Power Flow Controller (UPFC) is a sort of multi-function controller that can influence the transmission parameters individually or simultaneously. UPFC allows precise control of both real and reactive power flow in transmission line. This paper deals with the advanced control technique for UPFC to provide effective real and reactive power compensation. Adaptive Neuro Fuzzy Inference Controller (ANFIC) concept is introduced to control the system under different operating conditions. The system is tested on a 5-bus system. The computer simulations are done by MATLAB/SIMULINK.

Index Terms— Adaptive Neuro Fuzzy Inference Controller, Flexible AC Transmission System, Fuzzy based PSO, Fuzzy-PI Controller, Particle swarm optimization algorithm.

I. INTRODUCTION

Stability of power system can be preserved and enhanced by proper design and operation. This is achieved through a compromise between operating the system near its stability limit and operating a system with excessive reserve of generation and transmission. At transmission level to enhance stability VAR compensators and phase angle regulators are used to avoid the risk of instability. The advanced power electronics based controllers used to enhance stability are collectively called as FACTS devices [1]. FACTS are the alternating current transmission system incorporating power electronics based controllers used to enhance controllability and increase power transfer capability.

FACTS technology provides a great operating flexibility for power system and hence better utilization of existing systems. UPFC controls the power transfer through a transmission system which can be adjusted to suit the overall system loading conditions [2].

Operation of UPFC is regulated by different controllers. Different PI controllers like Cross-coupling proportional-integral (PI) controllers, decoupling PI controllers, hybrid PI controller were commonly used. By using cross-coupling PI controllers the real and reactive power flow interactions are reduced [3]. Harmonics in current measurement can be minimized by the decoupling PI control techniques [4]. The combination of direct coupling and cross coupling PI controller called hybrid controller was suggested to damp the oscillations in power system [5].

Under wide operating region PI controllers fails to perform in a satisfactory manner. Another advanced control technique for UPFC is based on robust control theory. In this method UPFC require particular mathematical model is required. Online communication is done to solve the optimization equations. Most advanced control technique recently used is based on fuzzy logic control. When compared to conventional controllers fuzzy controller has a number of distinguished advantages. But the membership cannot be adapted with respect to the system operations. Adaptive Neuro Fuzzy Inference System (ANFIS) combines the fuzzy qualitative approach with the adaptive capabilities of neural networks to achieve improved performance [6].

In this paper UPFC model with ANFIC concept is proposed and analyzed for controlling the UPFC. ANFIC control the series part of UPFC based on the relationship between the required power flow and the inserted voltage components. The impacts of the system fault level on the system operating area are 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. The designed controller is tested using a UPFC on 4-bus system. Computer simulation is done by MATLAB/SIMULINK environment.

II. UNIFIED POWER FLOW CONTROLLER

UPFC is the versatile voltage source FACTS device that is capable of controlling transmission system parameters. It consists of two voltage source inverter connected back-to-back through a common dc link as shown in Fig. 1. This arrangement function as an ideal ac to ac converter in which the real power can flow in either direction between ac sides of two inverters. Due to different functions of two inverters in the system, inverter 1 is referred as exciter and inverter 2 as booster. The reactive power on the two ac sides of inverter can be controlled independently.

Manuscript published on 30 April 2013.
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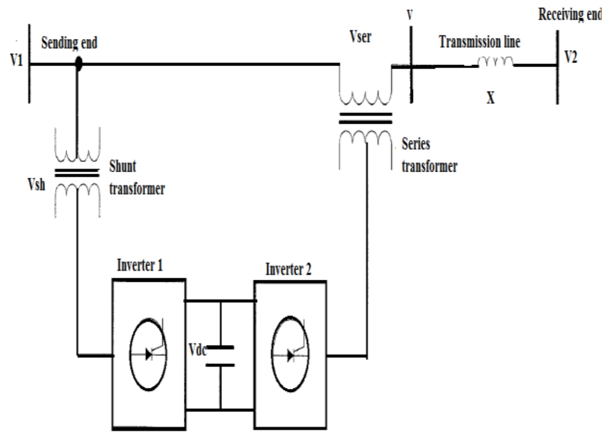

Fig.1 Schematic diagram of a UPFC system

A. Analysis of Series Part

The series injected voltage is split into two orthogonal components as shown in Fig.2.The components of the injected voltage are in-phase and quadrature with the reference. The two components are normalized by introducing new parameters β and γ which represent the injected voltage.

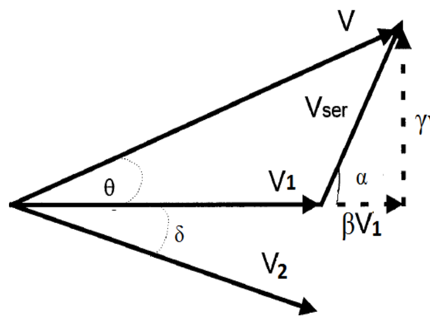

Fig.2. UPFC vector diagram of series part

B. Analysis of Shunt Part

Real power exchanged between shunt inverter and the ac system is determined by the level of quadrature component of inverter output voltage (ξ).This power must be balanced by the real power demand of series inverter. The reactive power generated or absorbed by the shunt inverter is controlled by the in-phase component of inverter output voltage (η). Vector diagram of shunt part of UPFC is shown in Fig. 3.

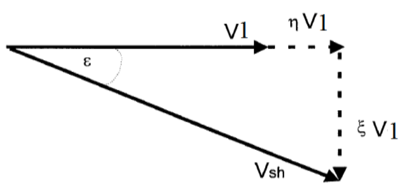

Fig.3.UPFC vector diagram of shunt part

III. UPFC INTERNAL LIMITS

For analyzing the UPFC control capabilities following constraints should be considered:

- 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 most common constraints that should be taken into account when dealing with UPFC control are,

- VA rating of UPFC inverters
- 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.

IV. CONTROL OF UPFC

A. Series part

By considering series compensation voltage V_{ser} and considering the vector diagram of series inverter per-unit change of real and reactive power flow of series inserted voltage components are expressed as,

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

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

The values of β and γ corresponding to the desired change of the real and reactive power may be obtained by solving Eq.(1) and Eq.(2).

$$\beta = V_{ser}\cos\delta \qquad (3)$$

$$\gamma = V_{ser}\sin\delta \qquad (4)$$

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

$$\Delta P=V_{ser}\sin(\delta+\alpha) \qquad (5)$$

$$\Delta Q=V_{ser}^2-V_{ser}\cos(\delta+\alpha) + 2V_{ser}\cos\alpha \qquad (6)$$

B. Shunt part

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

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

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

Where,

ξ represents the in-phase shunt inverter voltage

η represents the quadrature shunt inverter voltage

The control parameters of the shunt inverter ξ and η are obtained as,

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

$\eta = -(Xsh/V_1^2)\, Qsh$ (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. The bus voltage deviation is used to define η.

V. CONTROLLING TECHNIQUES

A. Adaptive Neuro Fuzzy Inference Controller (ANFIC)

In order to overcome the disadvantages of fuzzy ANFIS is used [9]-[10]. ANFIC is based on the first-order Takagi–Sugeno model and enables only a single output. ANFIC has been used to train the gain-scheduling controller for a power system [11]. Five linear quadratic regulator (LQR) controllers have been designed, and the ANFIC controller is trained to choose the most suitable controller depending on the current system operating point.

To train the ANFIC, there is a need to generate two sets of data: input data and the corresponding output data. The training input data are two vectors of the deviation in real power and the deviation in the reactive power within the system feasible region. The training output data are the two components of the corresponding series-inserted voltage. The main advantage of ANFIC is the reduction in interaction between real and reactive power flow because the controller is presented with changes in real and reactive power in same time.

B. Particle Swarm Optimization(PSO) Algorithm

Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality [12]. This algorithm was simplified and it was observed to be performing optimization. PSO gets better results in a faster, cheaper way compared with other methods. There are only few parameters to adjust. PSO does not use the gradient of the problem being optimized, which means PSO does not require that the optimization problem be differentiable .PSO makes few or no assumptions about the problem being optimized can search very large spaces of candidate solutions.

PSO also used on optimization problems that are partially irregular, noisy, change over time, etc. This new approach features many advantages; it is simple, fast and easy to be coded. Also, its memory storage requirement is minimal. Moreover, this approach is advantageous over evolutionary and genetic algorithms in many ways. First, PSO has memory. That is, every particle remembers its best solution (local best) as well as the group best solution (global best). Another advantage of PSO is that the initial population of the PSO is maintained, and so there is no need for applying operators to the population, a process that is time and memory storage- consuming. In addition, PSO is based on ”constructive cooperation” between particles, in contrast with the genetic algorithms, which are based on ”the survival of the fittest”.

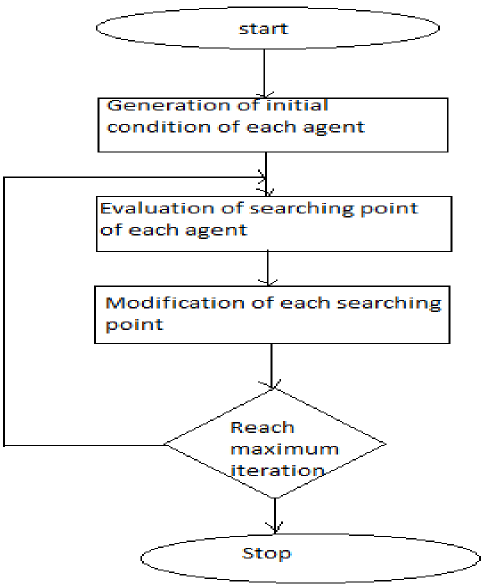

Fig.4 Flow Chart of PSO

VI. SIMULATION OF UPFC

The performance of ANFIC controller for controlling UPFC is analyzed by simulation of 5-bus system with UPFC model in MATLAB/SIMULINK.

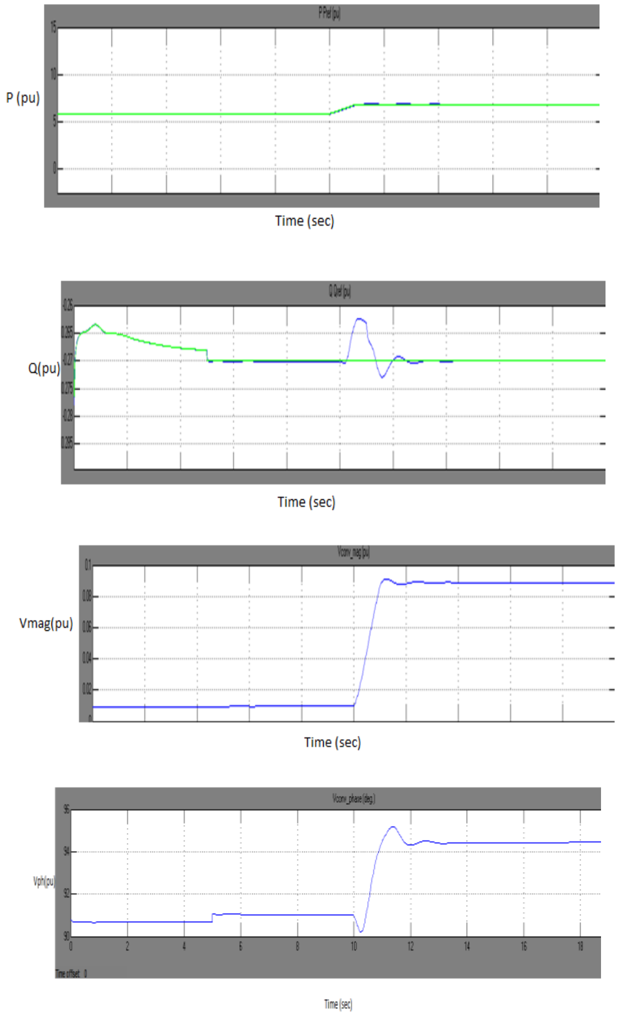

Fig 4. System response for HSCL

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From the simulation output it is clear that proposed controller shows good performance in controlling real and reactive power flow. The system response is obtained for different short circuit levels. The Fig.4 and Fig.5 also shows the capability of the UPFC to reduce the interactions between real and reactive power by step changes in the power flow. Simulation result shows the stabilization of real and reactive power flow after the disturbance.

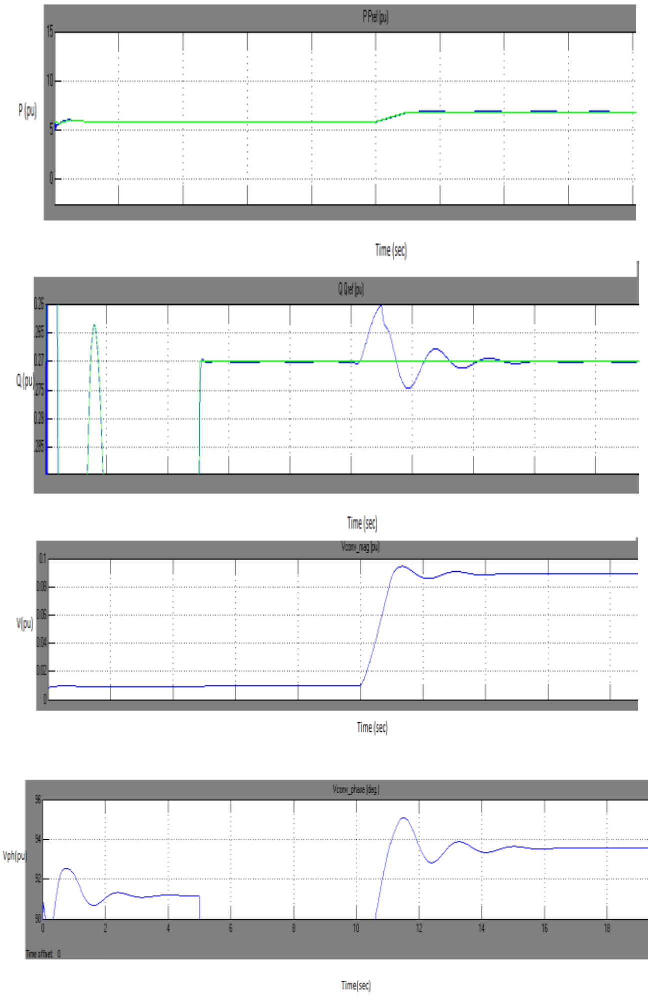

Fig 5.System response for LSCL

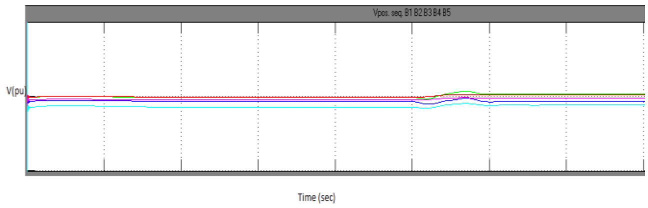

Fig 6. Voltage regulation on 5-bus system

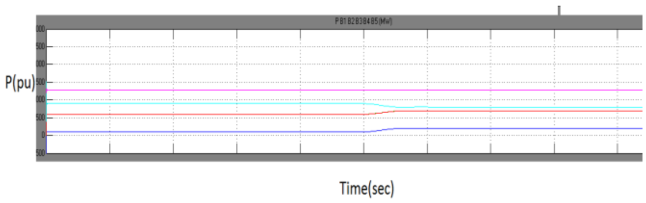

Fig 7.Real power flow in 5-bus system

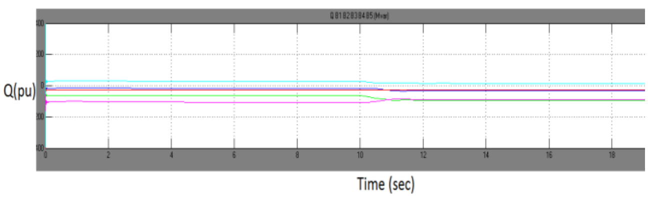

Fig 8. Reactive power on 5-bus system

In Fig.6, Fig.7 and Fig.8 the voltage sequence, real power and reactive power through each bus are analyzed. The graph obtained explains the stabilization after the disturbance occurred in power system.

VII. CONCLUSION

A modern control method to control the operation of UPFC is investigated. An ANFIC is proposed to control series part of UPFC depending on real and reactive power relations. The feasible operating area of a transmission system incorporating a UPFC has been determined based on real power priority concept. The real and reactive power flow is analyzed under different operating conditions. The impact of high short circuit on UPFC operations is tested. Also the real and reactive power flow through each bus is analyzed. Further the performance of Fuzzy based PSO can be analyzed and can be compared with ANFIC.

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