Optimization of UPFC Controller Parameters Using Bacterial Foraging Technique for Enhancing Power System Stability

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Abstract

To control the power flow,for increasing the transmission capacity & for power system stability,FACT devices are used.Unified Power Flow Controller is most widely used. This paper presents a novelBacterial foraging technique (BFO) for optimizing the PI controller parameters of UPFC for the transient stability enhancement of SMIB system .Complete modeling is done for SMIB system with UPFC controller.PI controller parameters computedbyconventional method [23] are usedas base for BFO, Bacterial Foraging Optimization Technique is applied for computing better optimized values.Results exhibit that BFO technique is able to find a better quality solution as compared to conventional technique for the proposed problem.

Keywords: *UPFC, Transient Stability, Bacterial Foraging Optimization Technique, SMIB (single machine on infinite bus bar), Synchronous MachineModeling.*

Nomenclature:

S=number of bacteria in the population,N_s=maximum number of swim length,N_c=chemotactic steps,$N_{re=}$number of reproduction steps,N_{ed}=elimination and dispersal events,P_{ed}=elimination and dispersal with probability.

1. INTRODUCTION

In recent years, power demand has increased substantially while there is a limited expansion of power generation and transmission due to limited resources and environmental restrictions. As a result some transmission lines get loadedheavily and the system stability becomes a power transfer limiting factor.In last two decades number of power devices have been developed and implemented and kept under the term Flexible AC Transmission System (FACTS) However, recent studies reveal that FACTS controllers could be used to enhance power system stability in addition to their main function of power flow control. FACT devices increase the reliability of AC grids and reduce power delivery costs. They improve transmission quality and efficiency of power transmission by supplying inductive or reactive power to the grid AUnified Power Flow Controller(or UPFC) is the most versatile member of the Flexible AC Transmission Systems (FACTS) family [1] for providing fast-actingreactive powercompensation onhigh-voltageelectricity transmissionnetworks. It uses a pair of three-phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line. The UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link as shown in fig.2. The UPFC concept was described in 1995 by L. Gyugyi of Westinghouse.It has an important function such as stability control to suppress power system oscillations & thus improving the transient stability of power system. Both voltage source converters can independently provide reactive power compensation & real power can flow freelyin either direction between the ac terminal of the two converters.The UPFC can provide simultaneous control of all or selected basic parameters of power system [5, 6] i.e. transmission voltage, line impedance and phase angle or any one of these and dynamic compensation of AC power system. Fig. 1 shows the equivalent circuit of the UPFC in which UPFC can be represented as a two port device with controllable voltage source V_{se} in series with line and controllable shunt current source I_{sh}. The voltage across the dc capacitor is maintained constant because the UPFC as a whole does not generate or absorb any real power.Requirement of the power quality is the today's major issue for the power utilities & their vital task is to reduce the transients. In this paper UPFC is used to damp the transients & improve the transient stability of the SMIB system. Proportional & Integral strategy is used for UPFC controller. The PI parameters of UPFC controller are optimized using Bacterial Foraging to attain desired results more speedly and thus making the system more reliable ,stable & secure.The present paper is laid out as follows: section I - Introduction, section II describes about the Unified Power Flow Controller. Section III explains theartificial intelligence techniquesfor power system stability.Section IV gives the description of thebacterial foraging optimization technique (BFO). SectionV describes the study system taken whereas section VI explains the mathematical modeling of the unified power flow controller. Section VIIdescribes the formulation of an objective function to be minimized .Section VIIIillustrates the simulation results of the system without UPFC controller,with conventional UPFC controller & with BFO UPFC controller and section IX concludes and expresses the future scope of work.

2. UPFC DESCRIPTION

The general structure of UPFC consists of a back to back AC to DC voltage source converters operated from a common DC link capacitor. First converter is connected in shunt that operates as STATCOMand the second converter in series with the line which operates as SSSC. The main function of the shunt converter is to supply real power to the series converter through a common DC link. Series Converter has the main function of injecting the controlled voltage magnitude &phase angle in series with the line. Both converters can also generate or absorb reactive power, if desired, thereby provide independent shunt reactive power compensation for the line.

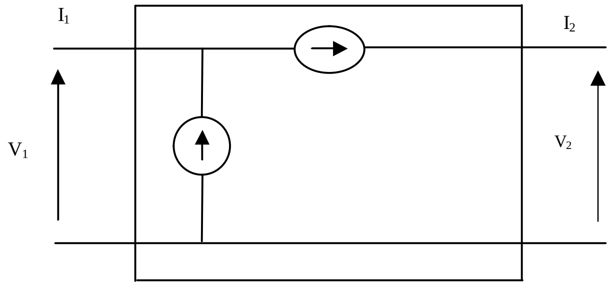


Fig. 1.Equivalent Circuit of UPFC

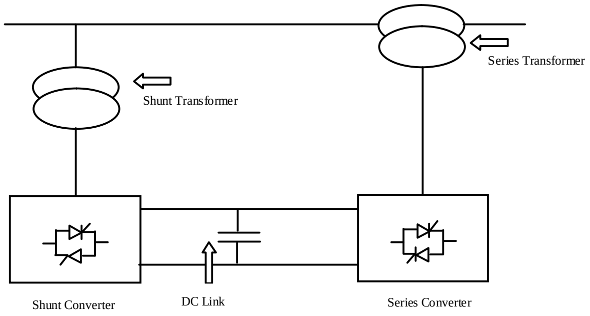


Fig 2: Basic block diagram of UPFC

3. AI TECHNIQUES FOR POWER SYSTEM STABILITY

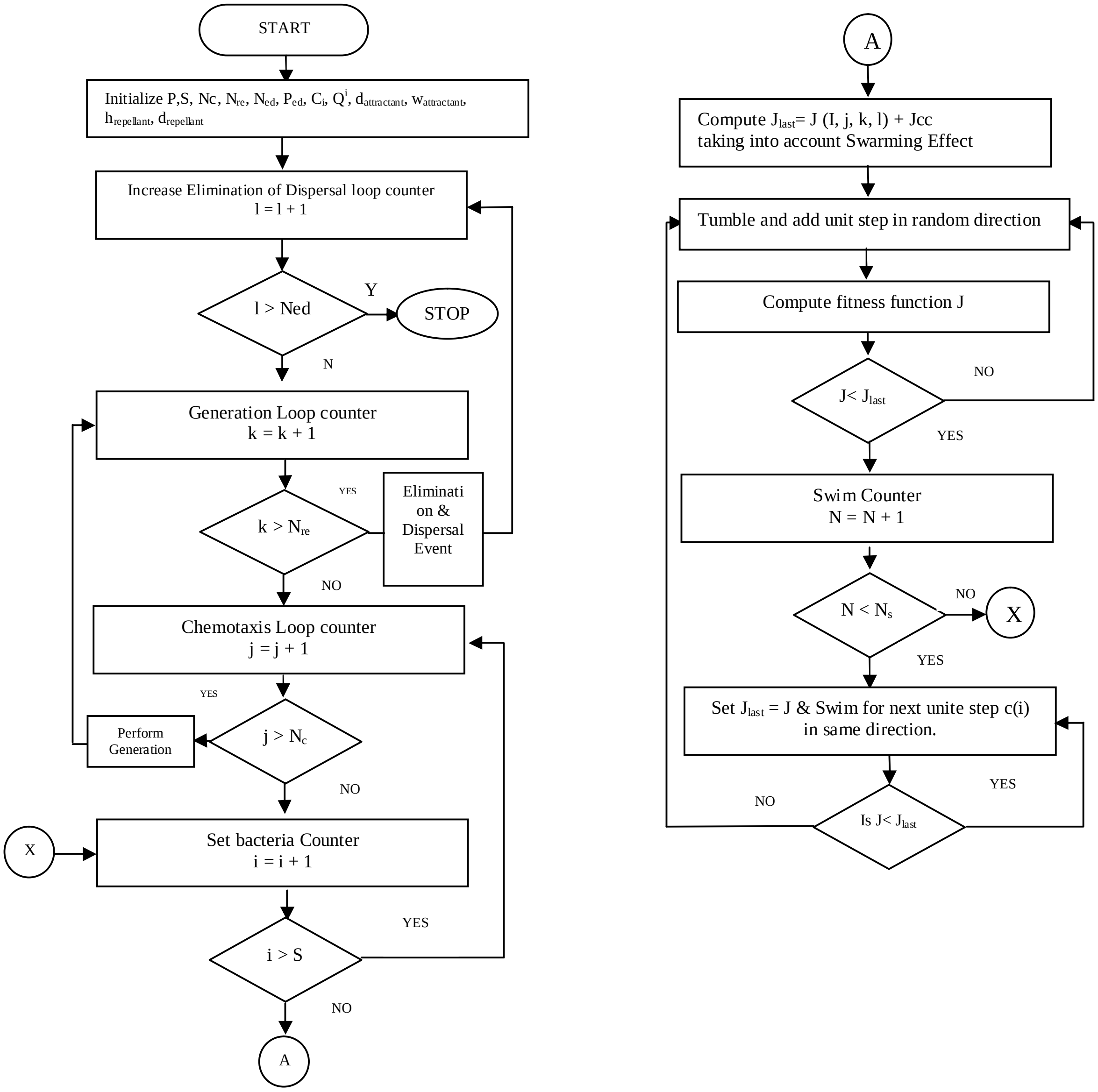
A number of evolutionary techniques like Bacterial Foraging optimization, Genetic Algorithm, Particle Swarm optimization, Ant Colony optimization,and water droplet optimization technique have been proposed by many researchers [14-21] for optimizing parameters of FACTS controller.Though GA is much faster than PSO as PSO has the problem in trapping to local minima due to large computations. BFO technique has been proposed by passino [18, 19] in which the number of operations used for searching the total solution space is much higher compared to GA &PSO, hence better optimal solution can be achieved. Among various methods for the optimization, BF is selected because of its better capability of locating optimal solution and higher convergence rate. However it shall be too early to conclude that BF is the best optimization algorithm among rest others existing.

4. ABOUT BACTERIAL FORAGING OPTIMIZATION TECHNIQUE (BFO)

BFO is an effective AI technique to optimize the variables effectively and efficiently. BFO technique is inspired by the pattern exhibited by animal that have successful forging strategies (locating, handling &ingesting food). The author in [18, 22] explains the biology & physics of E. coli bacteria & applies that in adaptive controller.The control system of these E. coli bacteria can be explained by five operations: Chemotaxis, Swarming, Reproduction, Elimination and Dispersal. In this technique a group of bacteria moves in search of food and away from noxious elements. In chemotaxis step, the bacteria swim and tumble in its entire life span.

The nutrients concentration is computed at its initial position before tumbling with the help of flagella. If the bacteria gets more nutrients in that direction than it will swim in the same direction and if less, then tumbles and find new direction. Half of them which are weak, die out and healthier reproduce. The new born bacteria then also go under chemotaxis step &again healthier bacteria survive and weaker die out but bacteria population remains constant. During this process, the healthy bacteria attract other healthy bacteria which are quite away from them & repel those which are weaker; this takes the variable to best possible value.

4.1 Flow Chart



4.2. Algorithm

1) Initialize dimension of search space, number of bacteria, chemotaxis steps, swim steps, reproductionsteps, elimination & dispersal steps, probability of elimination & run length unit C(i)i=1,2,…..S), θ^i (initial position of bacterium). Cell to cell attractant & repellant parameters.
2) Initialize elimination dispersal loop control, l=l+1
3) Check $l=N_{ed}$, stop else continue
4) Initialize reproduction loop count k=k+1

5) Check $k<N_{re}$, continue else go to step 2
6) Initialize chemotaxis loop count j=j+1
7) Check $j<N_c$ continue else go to step 4
    a) Compute fitness value of objective function , J for each bacterium i,J(i,j,k,l) = J(I,j,k,l) + J_{cc}
        Where $J_{cc}= \Sigma[-d_{attaractant}\exp(-w_{attractant}\Sigma(\theta_m-\theta_m^{\ i})^2]+\Sigma[h_{repellant}\exp(-w_{repellant}\Sigma(\theta_m-\theta_m^{\ i})^2]$
    b) Check J (i, j, k, l) < J (i, j-1, k, l), save it.
    c) Tumble: Generate a random vector Δ (i) in range (-1,1).
    d) Move: $\theta^i(j+1,k,l) = \theta^i(j,k,l) + C_i\Delta(i)/(\Delta^T(i)\Delta(i))^{1/2}$.
    e) Again compute J(i, j+1, k, l) &compare, if least continue, else Tumble.
8) Initialize swim loop counter N=N+1
9) Check N<Ns go to 7(d) else tumble.
10) Perform Reproduction of healthy bacteria.
11) Perform Elimination & dispersal.
12) Continue the process till the maximum computations are over.

5. SYSTEM DESCRIPTION

For analysis of the UPFC for damping the power swings, parameters of the system like generator rotor angle, theta, terminal voltage, active power and reactive power are considered. A200MVA, 13.8KV, 50Hz generator supplying power to an infinite bus through two transmission circuits as shown in fig(3) is considered.The network reactance shown in fig. is in p.u. at 100 MVA base. Resistances are assumed to be negligible. The initial system operating condition, with quantities expressed in p.u. on 100MVA, 13.8 KV base are: P=0.4p.u.& Q=0.6p.u. The other generator parameters in p.u. are given in appendix. The three phase fault at infinite bus bar is created for 0.1 sec duration& simulation is carried out for 10sec. to examine the transient stability of the study system.

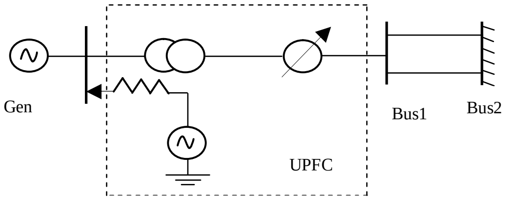


Fig. 3. Single Machine Infinite Bus system

6. MATHEMATICAL MODELING

6.1 Synchronous Machine Model

Mathematical models of synchronous machine vary from elementary classical model to more detailed one. Here, the synchronous generator is represented by third order machine model [2]. Different equations for stator, rotor, excitation system etc. are as follows:

Stator : $V_q = E_q^{'} - r_s i_q - x_d^{'} i_d$

$$V_d = E_d^{'} - r_s i_d - x_q^{'} i_q$$

$$V_1 = v_d + jv_q \qquad I = i_d + ji_q$$

$$S = V_1 I^*$$

$$P = v_d i_d + v_q i_q$$

$$Q = v_q i_d - v_d i_q$$

Where,

$$\omega = \omega_o + \frac{d\delta}{dt}$$

$$\frac{\delta\omega}{dt} = \frac{P_m - P_e}{M}$$

Let D and K=0

r_s is rotor winding resistance

x'_d is d-axis transient reactance

x'_q is q-axis transient reactance

E'_d is d-axis transient voltage

E'_q is q-axis transient voltage

Rotor :

$$T'_{do}\frac{dE'_q}{dt} + E'_q = E_f - \left(x_d - x'_d\right)i_d$$

$$\frac{dE'_q}{dt} = \frac{E_f - E'_q - \left(x_d - x'_d\right)i_d}{T'_{do}}$$

Where, T'_{do} is d-axis open-circuit transient time constant T'_{qo} is q-axis open-circuit transient time constant E_f is field voltage

Torque Equation

$$T_e = E'_q i_q + E'_d i_d + \left(x'_q - x'_d\right)i_d i_q$$

Excitation System

$$\frac{d(\Delta E_{fd})}{dt} = \frac{K_e(V_{ref} - V_t)}{T_e} - \frac{\Delta E_{fd}}{T_e}$$

Where -0.6≤ E_{fd}≤ 0.6

6.2 UPFC Controller Structure

UPFC works in two modes: Voltage Regulation Mode and PQ Mode
In first case, the reactive power component of shunt converter is controlled to regulate the voltage magnitude at the bus as proposed for STATCOM by Schauder& Mehta [11].In this paper the proposed controller [23]can works in both voltage regulation mode and in PQ mode. Simulations are carried out for PQ mode only.P-Q demand on load side is met by controlling series voltage injection. In order to achieve the system stability, it is required to control the in phase & quadrature component of the series injected voltage after fault at infinite bus.

1. Series Converter

Let the voltage injected by the series converter isV_L. In d-q frame of reference,V_L can be written as

$V_{Ld} = V_L \sin\left(\theta - \varphi\right)$, $V_{Lq} = V_L \cos\left(\theta - \varphi\right)$

$V_L = \sqrt{\left(V_{Ld}\right)^2 + \left(V_{Lq}\right)^2}$

Where, $\theta = \tan^{-1}\frac{v_d}{v_q}$

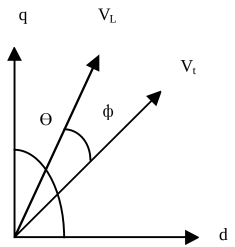


Fig. 4.d-q representation of series converter

In phase and quadrature components ofV_L are responsible for active and reactive power flow in line.

$$V_{Lp} = V_{Lpo} + \Delta V_p$$
$$V_{Lq} = V_{Lqo} + \Delta V_q$$
$$V_{bd} = V_{Ld} + \left(X_d^{'} + X_1\right)i_q - X_1 i_{sq}$$
$$V_{bq} = V_{Lq} + e_q^{'} - \left(X_d^{'} + X_1\right)i_d - X_1 i_{sd}$$
$$V_b = \sqrt{V_{bd}^2 + V_{bq}^2} \qquad (6)$$
$$P_{ref} = (V_d + V_{Ld})(i_d - i_{sd}) + (V_q + V_{Lq})(i_q - i_{sq}) \; Q_{ref} = (V_q + V_{Lq})(i_d - i_{sd}) - (V_d + V_{Ld})(i_q - i_{sq})$$

Where,

$$V_{Lpo} = V_{Ld} \sin\left(\tan^{-1}\frac{i_d - i_{sd}}{i_q - i_{sq}}\right) + V_{Lq} \cos\left(\tan^{-1}\frac{i_d - i_{sd}}{i_q - i_{sq}}\right)$$
$$V_{Lqo} = V_{Lq} \sin\left(\tan^{-1}\frac{i_d - i_{sd}}{i_q - i_{sq}}\right) + V_{Ld} \cos\left(\tan^{-1}\frac{i_d - i_{sd}}{i_q - i_{sq}}\right)$$

$$\Delta V_p = k_{p1}\Delta P + k_{i1}\int_0^T \Delta P \qquad \Delta V_q = k_{p2}\Delta Q + k_{i2}\int_0^T \Delta Q$$
$$\Delta P = P_{ref} - P \qquad \Delta Q = Q_{ref} - Q$$

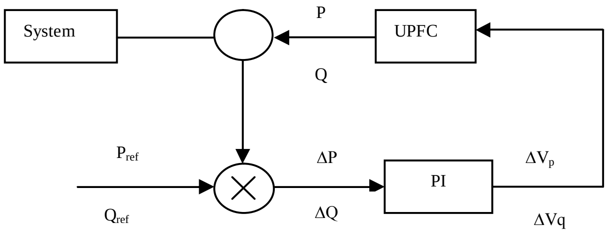


Fig.5. PI controller of the study system in PQ Mode

2. Shunt Converter

Let i_s be the current injected by shunt voltage source converter which is in same phase as that of generator terminal voltage, hence it will not supply or absorb reactive power & its aim is to provide the real power pdemand of series power voltage source converter.

Let lossless UPFC device is considered, then

$$R\left(\overline{V_1}\,\overline{I_1^*} - \overline{V_2}\,\overline{I_2^*}\right) = 0$$

And with losses, to maintain the voltage across the capacitor, shunt power should be equal to sum of series power and capacitor power.

$$V_t i_s = V_{Ld}\left(i_d - i_{sd}\right) + V_{Lq}\left(i_q - i_{sq}\right) + V_{dc} C \frac{dV_{dc}}{dt}$$

From the above equation, i_s can be obtained.

Where,

$$i_{sd} = i_s \sin\theta \,, \qquad i_{sq} = i_s \cos\theta$$

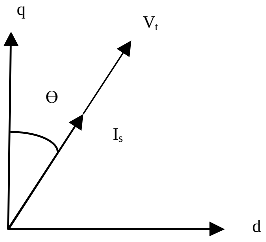


Fig.7.d-q representation of shunt converter

6.3 Transmission Line currents

The transmission line current i_t is split into d-q components represented as i_{td} and i_{tq}.

$$i_{td} = i_d - i_{sd} \, , \qquad i_{tq} = i_q - i_{sq}$$

6.4 Capacitor Dynamics

The difference between the shunt power and series power is the capacitor power.
Mathematically,
Capacitor power=Shunt power– Series power $\left(C \frac{dV_{dc}}{dt} \right) V_{dc} = P_{sh} - P_{se}$

$$P_{sh} = V_t i_s$$

$$P_{se} = V_{Ld}\, i_{td} + V_{Lq}\, i_{tq} \left(C \frac{dV_{dc}}{dt} \right) V_{dc} = V_t i_s - \left(V_{Lp}\, i_{td} + V_{Lq}\, t_{tq} \right)$$

i_s then can be computed from the above equation

7. OBJECTIVE FUNCTION

It is worth mentioning that the UPFC controller isdesigned to minimize the power system oscillations after a disturbance so as to improve the stability. These oscillations are reflected in the deviations in the generator rotor speed(Δw), active power (ΔP)&reactive power(ΔQ). In the present study the objective function J is formulated as the minimization of:

$$J = \int_0^t \left[t \left(\Delta \omega \left(t, x \right) \right)^2 + t \left(\Delta P \left(t, x \right) \right)^2 + t \left(\Delta Q \left(t, x \right) \right)^2 \right] dt$$

In the above equations, Δw(t,x) denotes the rotor speed deviation,ΔPdenotes the change in Real Power flow & ΔQ denotes the change in Reactive Power flow for a set of controller parameters x(note that here xrepresents the parameters to be optimized; k_{p1}, $k_{i1,}$ $k_{p2,}$ k_{i2} are the parameters of UPFC controller), and tis the time range of the simulation. With the variation of theparameters x, the Δw(t,x), ΔP(t,x), ΔQ(t,x), will also be changed. For objective function calculation, the time-domain simulation of the power system model is carried out for the simulation period. It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots.

8. SIMULATION

The SMIB system with UPFC is considered and system is modeled&simulated with conventional controller &BFO controller using MATLAB. The number of parameters to be optimized are four (k_{p1},k_{p2} , k_{i1}&k_{i2}). The analysis is carried out with 3 phase fault at Infinite bus for 0.1 sec& system is run for 10 sec. the result have been shown with PI controller parameters tuned by conventional method & PI controller parameters tuned by BFO (each bacterium is assigned with a set of 4 variables to be optimized and assigned with random value within the universe of disclosure).

The following are the simulation results of the system without controller, with conventional UPFC controller & with BFO based UPFC controller.

Simulation for P= 0.4p.u, Q=0.6 p.u and X_1= 0.3p.u (Figure 8 (a) to (g))

……Without Controller
------ With conventional UPFC controller
____With BFUPFC Controller

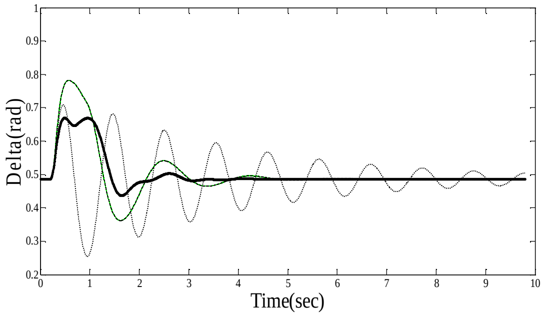


Fig. 8(a)

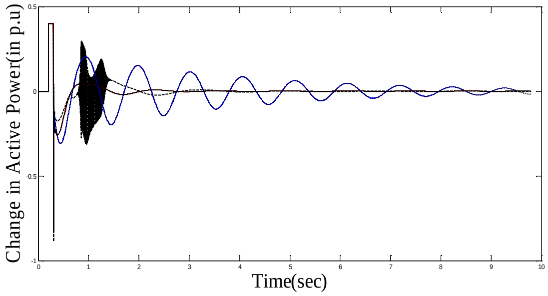


Fig. 8(b)

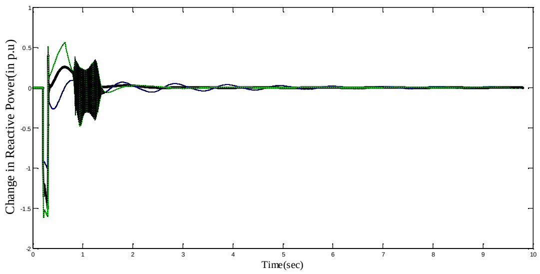


Fig. 8(c)

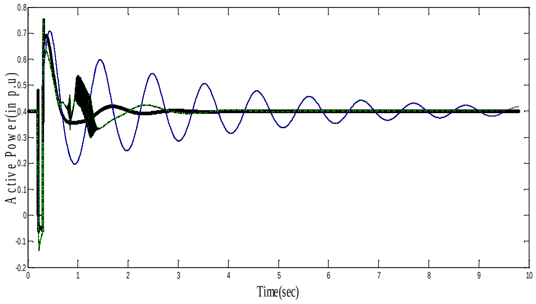


Fig. 8(d)