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Single area load frequency control problem using particle swarm optimization

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ABSTRACT

This paper deals with a novel method of quenching transients of load frequency of a single area power system. The load frequency power system dynamics are represented by selecting deviation in frequency and its derivatives as variables. The validity of this model was compared in terms of its uncontrolled response obtained in the earlier work [1]. This new model representation is used for further studies in this paper. For a practical single area power system the behaviour of uncontrolled system with range of values of regulation constant (R) and for various load disturbances (ΔP) are obtained. The responses of single area power system with range of values of load changes for different switching times, Particle Swarm Optimization (PSO) control are evaluated. The time of state transfer in general is increasing with increase of load disturbance. When fuzzy control is applied the frequency transients are quenched at much faster rates without any oscillations.

KEYWORDS: *Load frequency control, Transient response, Single area power system and PSO controller*

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I. INTRODUCTION

The development of design techniques for load frequency control of a power system in the last few years is very significant. The conventional proportional plus integral control is probably the most commonly used technique. This method does not work well if the parameters are changing for different load conditions. The transient response of the system will have overshoots and undershoots. In recent years many researchers have applied optimal control theory to solve LFC problem [1, 2]. Many researchers have used fuzzy logic controllers for load frequency control of two area power system [3-9] with and without nonlinearities. In their findings it is observed that the transient response is oscillatory and time to reach the steady state is more.

Some other elegant technique is needed to achieve a deadbeat response so that the time to reach the steady state is the least. In this work a single area power system is considered for the study. Most of the researchers have taken the dynamic equations of the single area power system as given by O. I. Elgerd [1]. The work reported here deals with a new model derived with change in frequency (Δf) and derivative of frequency $(\dot{\Delta f})$ without any integral control and the control parameter (u) being the speed changer position (ΔP_c). The change in frequency and its derivative are taken as crisp values to the fuzzy controller and the output of the controller is 'u'. An attempt is made in this work by applying PSO controller at a predetermined time (t_c) of uncontrolled system, the system response is observed. The system responses for range of values of regulation constant (R) for different values of load disturbance (ΔP_d) and (t_c) are obtained for uncontrolled and with fuzzy controller. It is observed that in all theses studies with fuzzy controller the response of the system is deadbeat in nature and the total time taken to reach final value is $\Delta f = 0$ after disturbance is the least. Since the controller is simple and needs Δf and derivative of Δf the on line implementation may be easier and convenient.

II. SYSTEM DYNAMICS

The new state variable model is derived by means of block diagram for single area power system shown in fig.1 with the speed changer position is taken as control parameter.

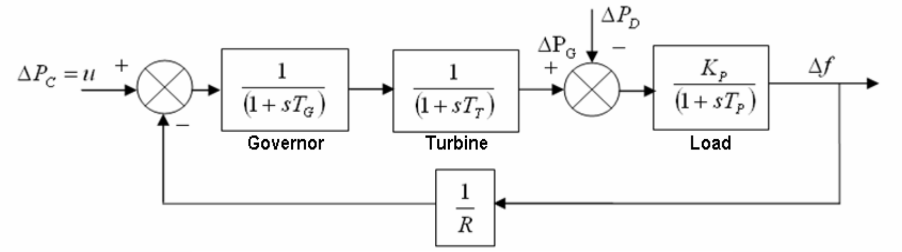

Fig.1: Block diagram of single area power system with out controller

The state variable equations from block diagram are derived as follows:

$$\left(u - \frac{\Delta f}{R}\right) = (1 + s\,T_G)(1 + s\,T_T)\Delta P_G = \left[1 + s(T_G + T_T) + s^2\,T_G\,T_T\right]\Delta P_G \tag{2.1}$$

$$(\Delta P_G - \Delta P_D) = \frac{\Delta f\,(1 + s\,T_P)}{K_P} \Rightarrow \Delta P_G = \Delta P_D + \frac{\Delta f\,(1 + s\,T_P)}{K_P} \tag{2.2}$$

From eq.'s. (2.1) and (2.2)

$$\left(u - \frac{\Delta f}{R}\right) = \left[1 + s(T_G + T_T) + s^2\,T_G\,T_T\right]\left(\Delta P_D + \frac{\Delta f\,(1 + s\,T_P)}{K_P}\right)$$

Assuming ΔP_D is a constant then its first and second derivates are zero.

$$\left(u - \frac{\Delta f}{R}\right)K_P = \left(K_P\,\Delta P_D + \Delta f + T_1\,\dot{\Delta f} + T_2\,\ddot{\Delta f} + T_3\,\dddot{\Delta f}\right)$$

$$\Rightarrow \dddot{\Delta f} = \frac{1}{T_3}\left[\frac{-(K_P + R)}{R}\Delta f - T_1\,\dot{\Delta f} - T_2\,\ddot{\Delta f} - K_P\,\Delta P_D + K_P\,u\right] \tag{2.3}$$

Where

$T_1 = (T_P + T_G + T_T);\ T_2 = (T_G T_P + T_P T_T + T_T T_G)$ and $T_3 = T_P T_G T_T$

Let the state variables are

$$\Delta f = x_1, \dot{\Delta f} = x_2 \text{ and } \ddot{\Delta f} = x_3$$

Then the eqn. (2.3) can be represented in state variable from as

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = x_3$$

$$\dot{x}_3 = \frac{1}{T_3}\left[\frac{-(K_P + R)}{R}\Delta f - T_1\,\Delta f - T_2\,\Delta f - K_P\,\Delta P_D + K_P\,u\right] \tag{2.4}$$

$$= \frac{1}{T_3}\left[\frac{-(K_P + R)}{R}x_1 - T_1 x_2 - T_2\,x_3 - K_P\,\Delta P_D + K_P\,u\right]$$

This can be represented as

$$\dot{X} = AX + Bu + Fw \tag{2.5}$$

III. THE LOAD FREQUENCY PROBLEM USING PSO CONTROL

In the so called LFC problem before the load disturbance and after the load disturbance the change in frequency is zero by the point A as shown in fig.2. The uncontrolled system behaviour (u = 0) is shown as AB for a particular time 't_c'. Now the problem is to transfer the system state from B to A using a suitable control strategy. The physics of the original system demands that a suitable trajectory is 'BCA' as shown in fig.2. From the behaviours of the load frequency control problem the value of the speed changer position is selected as u (control parameter). PSO control technique is developed to transfer the state from B to A through C.

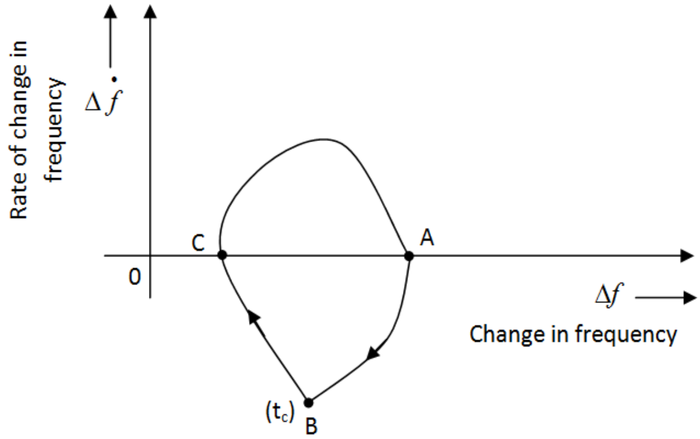

Fig. 2: Phase Plane Trajectory

PSO is a population-based optimization method includes some attractive features like the ease of implementation and the fact that no gradient information is required. It can be used to solve a wide array of different optimization problems. Like evolutionary algorithms, PSO technique conducts search using a population of particles, corresponding to individuals. Each particle represents a candidate solution to the problem at hand. In a PSO system, particles change their positions by flying around in a multidimensional search space until computational limitations are exceeded. This new approach features many advantages; it is simple, fast and can be coded in few lines. Also its strong requirement is minimal. Moreover, this approach is advantageous over evolutionary and genetic algorithm in many ways. First, PSO has memory. That is, every particle remembers its 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 [12]. Nowadays PSO is used in almost all sectors of industry and science, one of them is load frequency control. The main goal of LFC in power system is to protect the balance between production and consumption. Because of the complexity and multi – variable conditions of the power system, conventional control methods may not give satisfactory solutions. On the other hand, their robustness and reliability make PSO controllers useful in solving a wide range of control problems. The procedural steps of PSO as implemented for optimization are as follows:

Step 1: Initialize an array of particles with random positions and their associated velocities to satisfy the inequality constraints.
Step 2: Check for the satisfaction of the equality constraints and modify the solution if required.
Step 3: Evaluate the fitness function of each particle.
Step 4: Compare the current value of the fitness function with the particles previous best value (pbest). If the current fitness value is less, then assign the current fitness value to pbest and assign the current coordinates (positions) to pbestx.
Step 5: Determine the current global minimum fitness value among the current positions.
Step 6: Compare the current global minimum with the previous global minimum (gbest). If the current global minimum is better than gbest, then assign the current global minimum to gbest and assign the current coordinates (positions) to gbestx.
Step 7: Change the velocities.
Step 8: Move each particle to the new position and return to step 2.
Step 9: Repeat step 2-8 until a stop criterion is satisfied or the maximum number of iterations is reached.

In this method, the objective is to minimize the cost function 'J'. For this reason the objective function is chosen as the Integral of Time – multiplied Absolute value of the Error (ITAE). PSO minimize the fitness function, the minimization objective function is transformed to be as fitness function as follows,

$$\text{Fitness}=\frac{1}{\text{ITAE}} \tag{3.1}$$

IV. RESPONSE OF UNCONTROLLED AND CONTROLLED SYSTEM

A practical single area power system having the following data [1] is considered with following data: the numerical data for the system are K_P = 120.0, T_P = 20.0 Sec, T_G = 0.08 Sec, T_T = 0.3 Sec and range of values of regulation constant (R) and ΔP. Fig.3 to 6 shows PSO controlled and uncontrolled responses for t_c = 0.5 sec and 1 sec with ΔP_d = 0.01 and 0.02 for different values of R. The corresponding phase – plane trajectories are depicted in fig.7 to 10. Further studies are also to be conducted to get the response of the system for range of values of control inputs, load changes, regulation constants at different values of 't_c'. For selected t_c = 0.5 sec and 1 sec with ΔP_d = 0.01 and 0.02 the times of state transfer (from B to A through C) are shown in fig.'s (3 to 10) and for range of values of R.

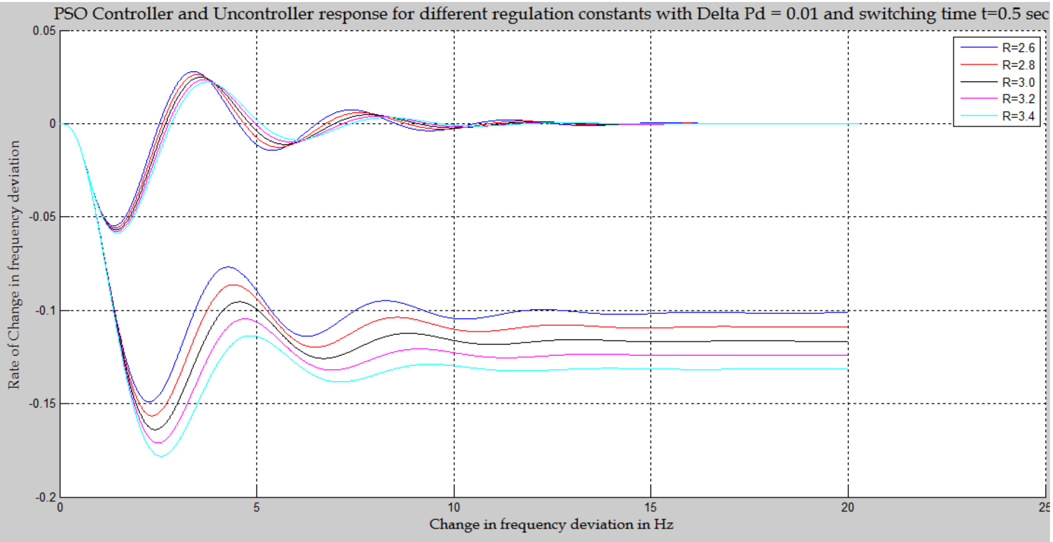

Fig.3: Time response of controlled and uncontrolled system with ΔP_d= 0.01 and t_c= 0.5 Sec

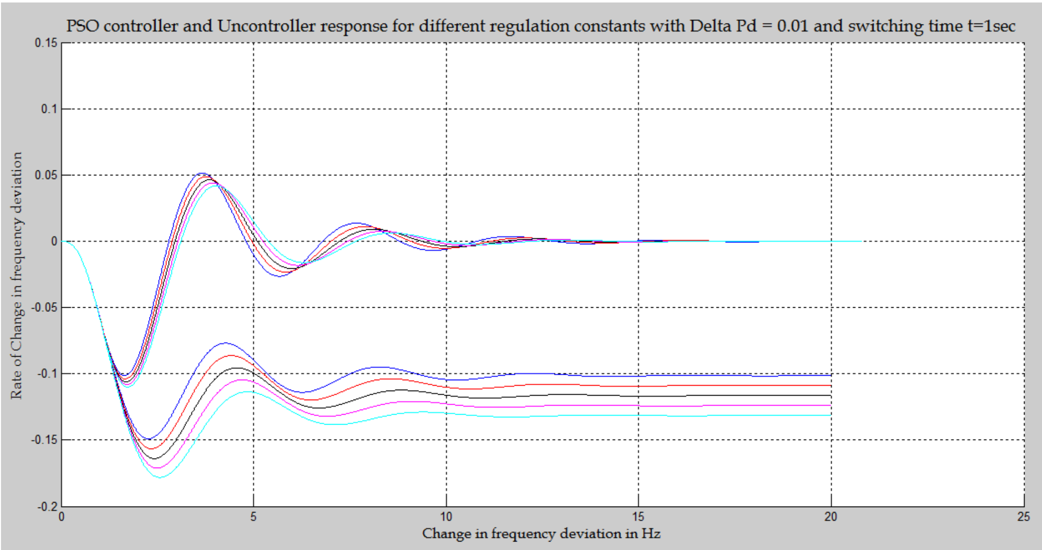

Fig.4: Time response of controlled and uncontrolled system with ΔP_d= 0.01 and t_c= 1 Sec

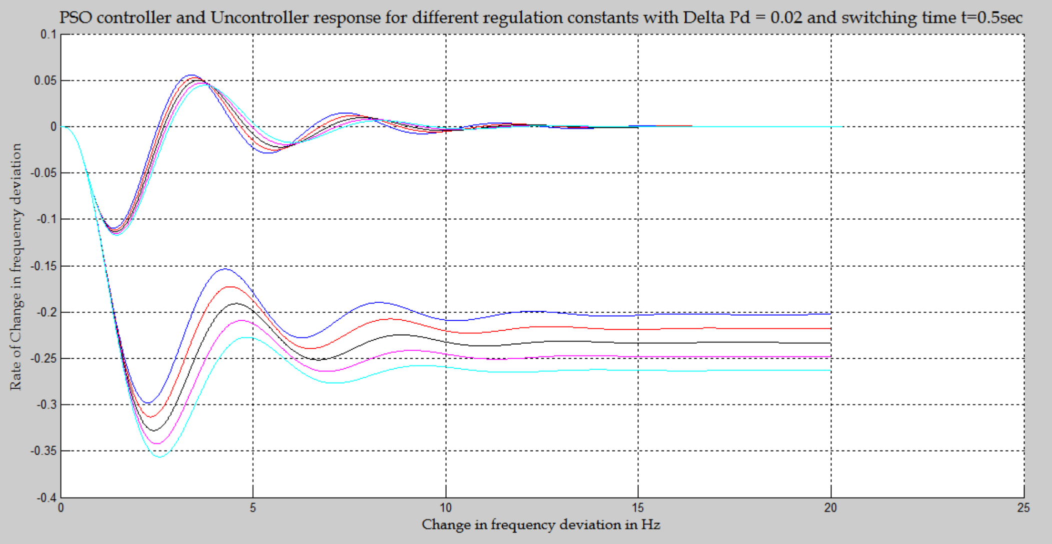

Fig.5: Time response of controlled and uncontrolled system with ΔP_d= 0.02 and t_c= 0.5 Sec

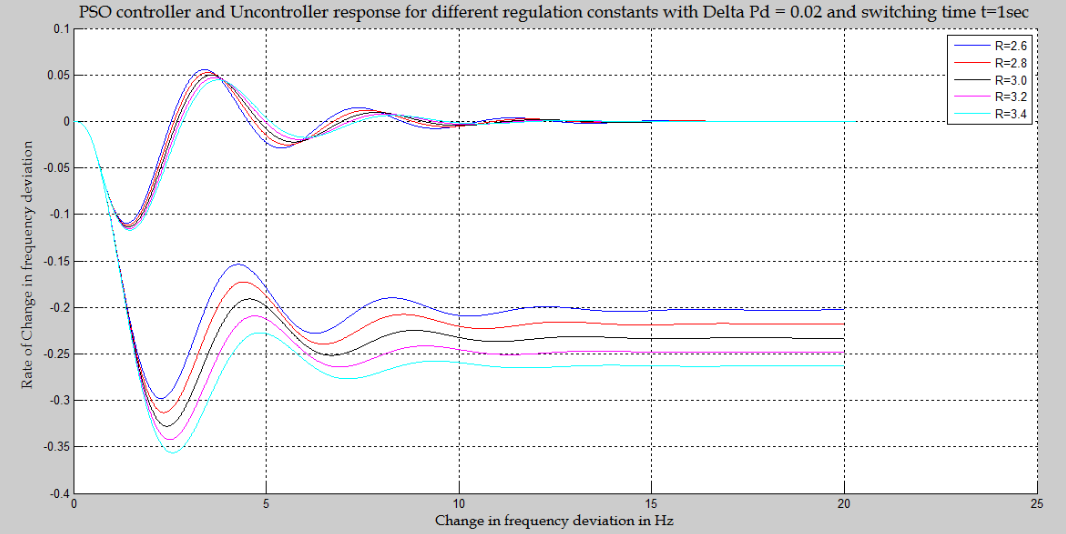

Fig.6: Time response of controlled and uncontrolled system with ΔP_d= 0.02 and t_c= 1 Sec

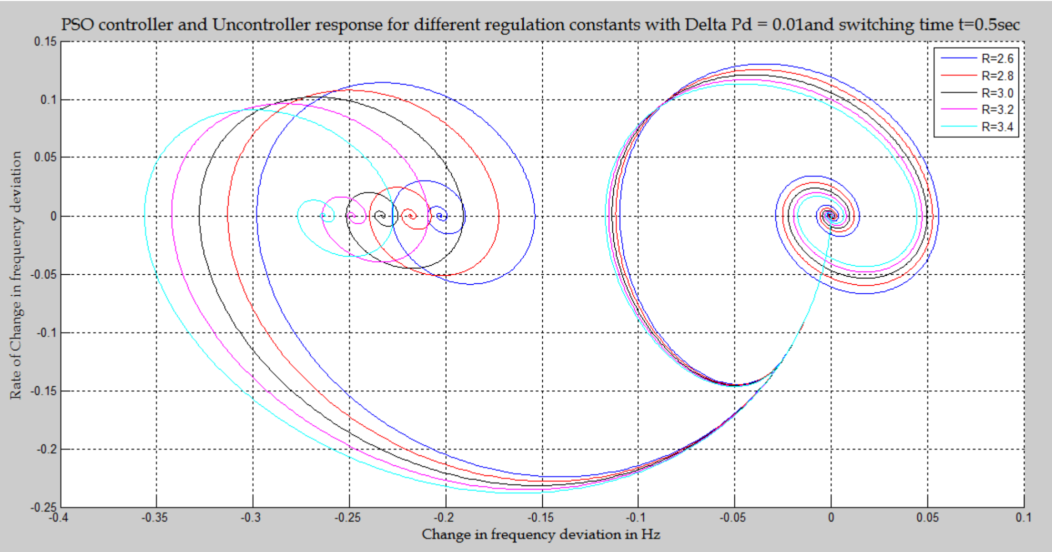

Fig.7: Phase–plane trajectories of controlled and uncontrolled system with ΔP_d= 0.01 and t_c= 0.5 Sec

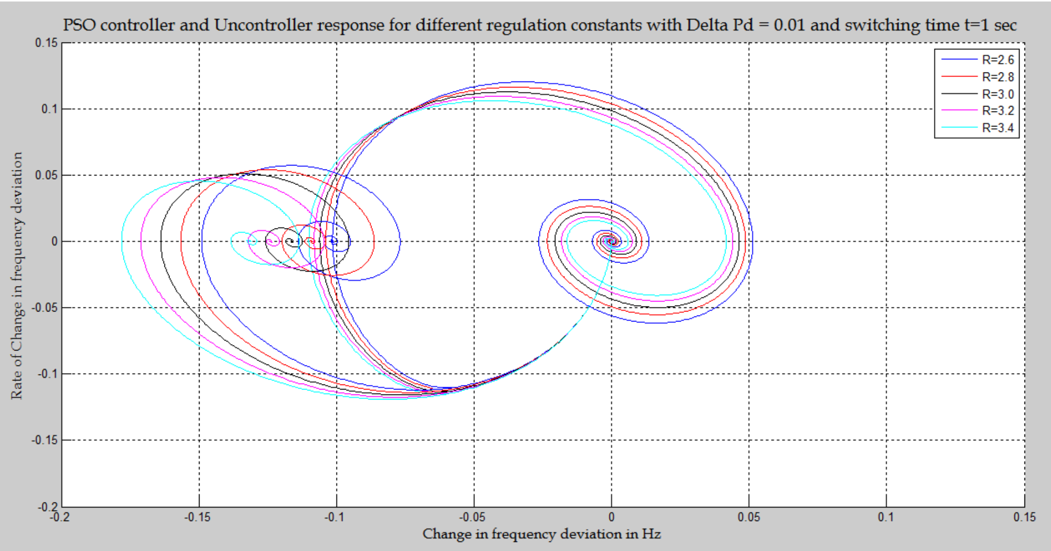

Fig.8: Phase–plane trajectories of controlled and uncontrolled system with ΔP_d= 0.01 and t_c= 1 Sec

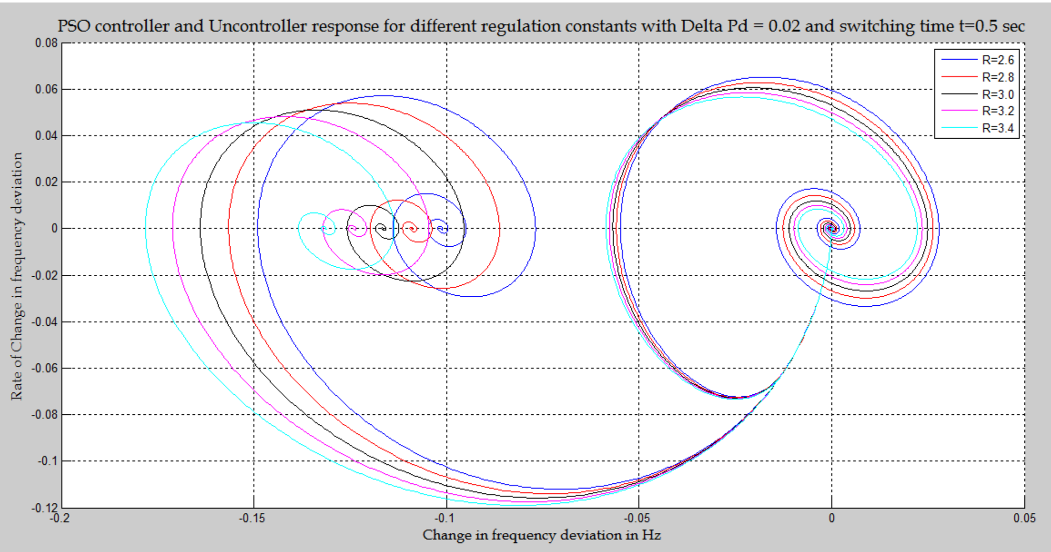

Fig.9: Phase–plane trajectories of controlled and uncontrolled system with ΔP_d= 0.02 and t_c= 0.5 Sec

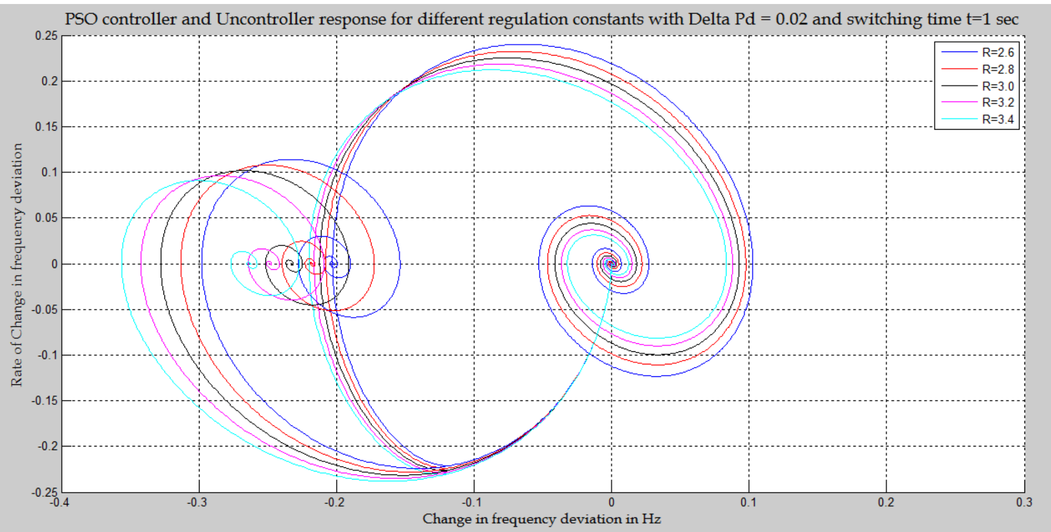

Fig.10: Phase–plane trajectories of controlled and uncontrolled system with ΔP_d= 0.02 and t_c= 1 Sec

V. CONCLUSIONS

A new model of load frequency control using $\Delta f, \dot{\Delta f}$ & $\ddot{\Delta f}$ is developed with ΔP_c as the control parameter (u). It is observed that the static errors are increasing as the regulation constant is increasing for a particular load change. PSO control studies are conducted on a single area power system for a particular load change , $\Delta P_d = 0.01$ and for a predetermined closing time, $t_c = 0.5\sec$, reveal that the response is dead beat with a less state transfer time. The time of state transfer is increasing with an increase of regulation constant. Similar results are observed for different load changes. It is also noticed that the static error and state transfer times are more with increase in load disturbance.

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NOMENCLATURE

ΔP_G	:	Generated power derivation
ΔP_D	:	Change in power demand
ΔP_C	:	Change in speed changer position
Δf	:	Frequency deviation
$\dot{\Delta f}$	:	Derivative of change in frequency
K_P	:	Static gain of power system inertia dynamic block
T_P	:	Time constant of power system inertia dynamic block
T_G	:	Governor time constant
T_T	:	Turbine (non reheat type) time constant
R	:	Speed regulation parameter
t_c	:	Switching time
J	:	Performance index
LFC	:	Load frequency control
ITAE	:	Integral of time – multiplied absolute value of the error
PSO	:	Particle swarm optimization