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Research paper

Optimization of Two Area AGC based Power System Using PSO Tuned Fuzzy PID Controller and PSO Trained SSSC And TCPS

Geoffrey Eappen [1]*, T. Shankar [2]

[1] *PhD Scholar, Department of Communication Engineering, SENSE, VIT Vellore-632014 India*
[2] *Associate Professor, Department of Communication Engineering, SENSE, VIT Vellore-632014 India*
**Corresponding author E-mail: geofz121@gmail.com*

Abstract

Automatic generation control or AGC system is significant controlling system that operates efficiently to balance the load and generation in power system at minimum cost for economical operation. System frequency will vary from nominal value if there is mismatch occurs between generation and demand. Due to this high frequency deviation system may breakdown. A very fast, reliable and accurate controller is needed to maintain the system frequency within the range to maintain stability. In this paper the proposed model consisting of PID controller whose parameters have been optimized using PSO tuned Fuzzy Logic Controller and it's been compared with conventional PSO-PID controller. Each control area in power systems includes the dynamics response of the systems. The results contained in this paper present the strength of the particle swarm optimizer for tuning the Fuzzy based PID controller parameter for two area power system network, for better performance PSO trained SSSC and TCPS has been introduced to the system. The enhancement in the dynamic response of the power system network is verified. The output response of the proposed work is compared with conventional PSO-PID & PSO Fuzzy-PID based AGC system. Simulation experiments so conducted in MATLAB showed that the proposed system outperformed the conventional one by achieving better response.

Keywords: *Automatic Generation Control, Particle Swarm Optimization, Fuzzy PID controller, PSO-PID, Dynamic response*

1. Introduction

Key purpose in the working and control of power system is to make available the continuity of power supply with an acceptable range, for all the customers near to the system. When there is balance between the power generation and the demand, the system will be in equipoise condition. There are two types of control methods used to accomplish reactive power balance (adequate frequency values) and real power balance (adequate voltage profile). The former is called the ALFC (automatic load frequency control) or AGC (automatic generation control) and the latter is called AVR (automatic voltage regulator) [1]. The objective of parallel operation of multi area control structure is that to achieve prerequisite with the expansion in scope of electrical power structure, keeping up the recurrence of multi-zone control framework is very difficult [3]. The frequency variation from the desired value and tie-line deviation happens on account of alterable load deviations, which emerge because of a contrast between the produced power and the desired power [1]. The main purpose of adding an AGC is to maintain system's frequency at desired level.

1.1. Automatic Generation Control: a Review

Here Automatic generation system is used for maintaining the system frequency at its formal value for first & second loop. The ALFC is designed to maintain the frequency variation to desired level which is performed by regulating the real power balance within the power system. Figure 1 of AGC system consist of ALFC loop, also known as main or first ALFC loop. It gains with effort the first or most important goal of real power balance by changing to fit new conditions in the turbine output. The restoring of the frequency to the very small value is done with the help of added control loop known as the additional or supplementary loop. With the help of integral controller this goal is achieved, so that there is zero frequency differences [2]. The ALFC with the extra loop is known as the Automatic Generation control system.

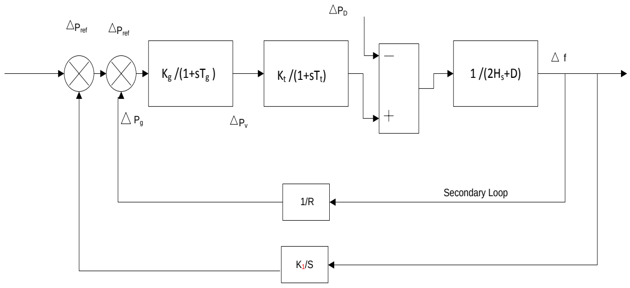

Fig1: Block diagram representation of AGC unit [14]

In a single area power system, there is no tie-line program to be kept up. Along these lines the capacity of the AGC is just bring the recurrence to assume esteem [2]. This, will be picked up with exertion utilizing the supplementary loop that helps the critical controller to change the orientation power setting to change the speed set focuses.

1.2. Fuzzy Logic:

A fuzzy logic system **(FLS)** is a structure which handles both number-based data and language based knowledge at the same time. Mapping nonlinear input information (feature) vector into a scalar yield is its basic working principle, i.e. it maps numbers into numbers. Fuzzy set explanation and fuzzy judgment ascertain the specifics of the nonlinear mapping [12]. Fuzzy logic working is especially like way human thinks when contrasted with the traditional coherent frameworks. Essentially, it gives a viable method for translating this present reality's conduct. So, with respect to this nature of fuzzy logic, the fuzzy logic controller (FLC) has two important parts, one is set of dialect(logically) based control rules linked with the dual ideas of fuzzy standards and the other one is speculating in light of compositional rule. Basically, then, the FLC with the help of instruction set converts the language based control approach rooted with expert knowledge into an automatic control goal.
Generally, a FLS does mapping between nonlinear input data vector and a scalar output (the vector output case is a gathering of MISO (multi input single output) systems). The benefits of FLS is that it provides large possibilities through which different mappings can be achieved. This demands a better perception between Fuzzy Logic and the strands that contain a FLS.

1.3. Particle Swarm Optimization (PSO):

PSO was coined on 1995 by James Kennedy & Eberhart [19]. It is similar to flocking & schooling pattern of fishes & birds. In PSO a search area is provided to determine the maximum & minimum values of the particles. Its sound like very complicated but it is a simple algorithm: [7] [9].

The PSO algorithm having three variables [9]
1. True value or conditions.
2. gbest or Global best Value.
3. pbest or Positional best value.

The True value indicates the target or the actual value that can be particles trying to achieve.The gbest or the Global best value indicate the currently closest value to the target i.e. the maximum value or the minimum value. The pbest or Positional best value indicates best position in the search space for the particles.

2. System Modelling

2.1. Linearized Model of Two Area System Using Fuzzy PID:

Proposed model so considered have a two-area power system network. The gains for the Fuzzy-PID controller are being optimized by using PSO. There is 10% load tolerance considered for the dynamic response of the system. In the proposed model TCPS is used for frequency stabilization, and it is placed near Area I in series with the tie-line. Resistance offered from tie-line is negligible. Another proper substitute for TCPS for stabilization is SSSC which can also be employed in place of TCPS in series with tie-line near Area 1. SSSC by means of self-commutated voltage-source switching converters processes a three-phase voltage which is in quadrature with the line current and shows the reactance (capacitive or inductive) nature which in turn influences the power flow in the transmission lines [16].
An SSSC, employed in the proposed model is placed along with TCPS in series with tie-line between the interconnected areas, stabilizes the area frequency oscillations by high speed control of the tie-line power through interconnection. For the controllability and stability of AC transmission FACTS can be considered [18].

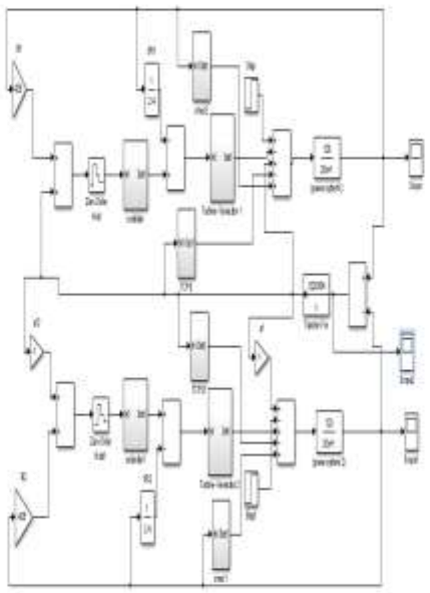

Fig2: Two area AGC system with Fuzzy PID, SSSC & TCPS

2.1. Fuzzy PID Controller

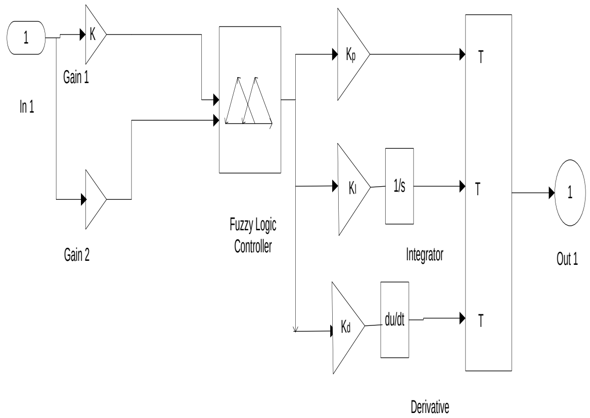

Fig 3: Fuzzy PID controller

Fuzzy based PID controller user for system optimization by reducing the frequency deviation is shown in Fig 3. Parameters of PID controller is optimized using PSO. Its working is being explained in the subsection PSO-Fuzzy PID controller.

2.3. SSSC Modeling in Linear form:

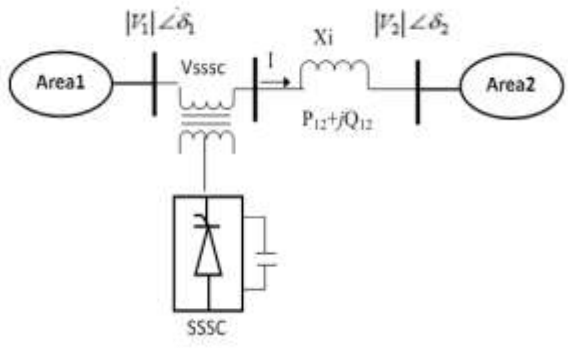

Fig4: SSSC model for two area power system

Incorporating SSSC improves the frequency response of interconnected power system :[16] and [17].Fig 4 shows the interconnected SSSC in series with the tie line between the two areas, which has been proposed in [15].Proposed work in [7] used SSSC with RFB(Redox Flow Battery) for optimizing AGC system. The equivalent circuit of SSSC for MATLAB simulation connected in the system between buses 1 and 2 is shown in Fig 5 [7].

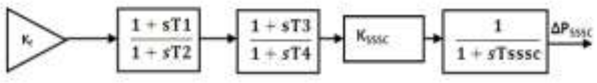

Fig5: SSSC for frequency stabilization

SSSC based frequency stabilizer has two gain blocks with gain K_f equivalent to nominal frequency and K_{SSSC}, Time constant proportional block T_{SSSC} and phase compensation blocks for two-stage system with time constants T1, T2, T3 and T4: [15].

2.4. TCPS Modeling:

The equation for incremental Tie –Line power flow without TCPS is given as [15]:

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}}{s}(\Delta F_1(s) - \Delta F_2(s)) \quad (1)$$

Here T_{12} represents synchronizing constant without TCPS and $\Delta F_1(s)$,$\Delta F_2(s)$ represents frequency deviation of Area1 & Area2 respectively .Current flowing from Area 1 to Area 2 with TCPS placed in cascade form with tie-line is given as:

$$i_{12} = \{|V_1|\angle(\delta_1+\phi) - |V_2|\angle(\delta_2)\}\; jX_{12} \quad (2)$$

$$P_{tie12} - jQ_{tie12} = {|V_1|\angle -(\delta_1+\phi)\{|V_1|\angle(\delta_1+\phi) - |V_2|\angle(\delta_2)\}} \Big/ {jX_{12}} \quad (3)$$

The equation (3) can be re-written as equation (4),considering the real part.

$$P_{tie12} = \frac{|V_1||V_2|}{X_{12}}\sin(\delta_1 - \delta_2 + \phi) \quad (4)$$

$$\Delta P_{tie12} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^0 - \delta_2^0 + \phi^0)\sin(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \quad (5)$$

In the above equation, $\Delta\delta_1 - \Delta\delta_2 + \Delta\phi$ can be neglected, therefore,

$$\Delta P_{tie12} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^0 - \delta_2^0 + \phi^0)(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \quad (6)$$

$$\Delta P_{tie12} = T_{12}(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \quad (7)$$

Where, $$T_{12} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta_1^o - \delta_2^o + \phi^o) \quad (8)$$

$$\Delta P_{tie12} = T_{12}(\Delta\delta_1 - \Delta\delta_2) + T_{12}\Delta\phi \quad (9)$$

Since $\Delta\delta_1 = 2\Pi\int \Delta f_1 dt$ and $\Delta\delta_2 = 2\Pi\int \Delta f_2 dt$ (10)

So,

$$\Delta P_{tie12} = 2\Pi T_{12}\left(\int \Delta f_1 dt - \int \Delta f_2 dt\right) + T_{12}\Delta\phi \quad (11)$$

Laplace transform of equation (11) is given by [7]

$$\Delta P_{tie12} = \frac{2\Pi T_{12}}{s}(\Delta F_1(s)dt - \Delta F_1(s)dt) + T_{12}\Delta\phi(s) \quad (12)$$

The phase shifter angle $\Delta\phi$ is for controlling the Tie-Line power flow. Consider that the control input signal to the TCPS controller is $\Delta Error(s)$ and the transfer function of the signaling conditioning circuit is $K_\phi(s)$, where $K_\phi(s)$ is the gain of the TCPS controller [7]. The phase shifter angle can be written as

$$\Delta\phi(s) = \frac{K_\phi}{1+sT_{ps}}\Delta error(s) \quad (13)$$

Here K_ϕ =*TCPS's gain*, T_{PS} =*TCPS's* time constants and $\Delta error(s)$ represents control signals that controls the phase angle of the phase shifter. And therefore, the equation (12) is shown as:

$$\Delta P_{tie12} = \frac{2\Pi T_{12}}{s}(\Delta F_1(s)dt - \Delta F_1(s)dt) + T_{12}\frac{K_\phi}{1+sT_{ps}}\Delta Error(s) \quad (14)$$

$\Delta Error$ can be considered as signal such as the area frequency deviation Δf_1 or frequency deviation Δf_2 or ACE (Area Control error) of the other area to the TCPS unit which is used for controlling the TCPS phase shifter edge which controls the tie-line control stream.
TCPS simulation model is shown in Fig 6.

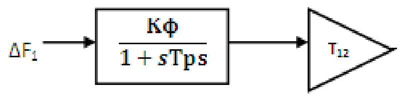

Fig6: Model of TCPS for frequency stabilization

2.5. Calculation of Area Control Error:

Area control error is the difference between schedule and generated power in electrical power system. Here we tries to keep the ACE or Area control error zero for the interconnected power system.[2].
Area control error for the system is represented by the following equation

$$ACE_i = B_i\Delta f_i + \Delta P_{tie-i-error} \quad (15)$$

Here B_i & f_i represents the frequency bias factor & frequency deviation for area the system.

2.6. PSO-Fuzzy PID Controller:

Trial and Error based methodology used for finding the supportable values of the scaling factors for each PID-Fuzzy controller

structure makes optimizing problem becomes difficult and weak. So, a meticulous and efficient methodology is required to deal with these optimization
problems. The tuning of this problem can be represented as a function with optimized scaling factors as the desired result:
{minimize F (y)
y €**D'**
$G_l(y) \leq 0; \forall L = 1, \ldots, n$}
Where F: $\mathbf{r}^m \rightarrow \mathbf{r}$ the cost function, **D'** = {y €(**D'**)^m y min $\leq y \leq y$ max} the earlier search space, that probably contains the required parameters for design, and $G_l : \mathbf{r}^m \rightarrow \mathbf{r}$ the problem's constraints. The tuning problem for optimization has the finest decision variables $y^* = (y^*1, y^*2, y^*3, y^*4, y^*5 .... y^*m)$ refers to PID-Fuzzy Controller structure's scaling factors, and it reduces IAE and ISE judging parameters based true cost function. Proposed PSO algorithm is used for reducing these cost functions, under the consideration of time-domain control parameters like steady state error e_{ss}, overshoot D, settling time T_s and rise time $T_{r\ \mathrm{for}}$ step response of the system, represented by the equations (16). Hence, in the case of the PID-type Fuzzy Controller structure without self-tuning method, the scaling factors to be minimized as ke, kp, k_d, α and β.The formulated optimization difficulties is defined as follows:
{*Minimize F(y)*
$y = (k_e, k_p, k_d, \alpha, \beta)^t$ € R^4_+
Subject to
$D \leq D^{\max}$; $T_s \leq T_s^{max}$; $T_r \leq T_r^{\max}$; $e_{ss} \leq e_{ss}^{\max}$} (16)
Here e_{ssmax}, $D_{\max}$, T_{smax},T_{rmax}, are the steady state error, overshoot, settling and rise times respectively, that limits the step response of the PSO optimized PID-Fuzzy logic controlled system.

3. PSO Working

As specify above the PSO algorithm works on search space by maintaining several particles. In this paper the different gains of PID controller (K_i, Kp, K_d) working as a particle on the search space. As we know that there is three types of PSO variables gbest, pbest & true or actual value, here gbest give the closest value to the true or actual value, pbest the is best position for different particles. PSO algorithms trying to find out the minimum values for the K_i, Kp, K_d so that the Area control error can be maintained to very small level [14]. In PSO each particle has a velocity equation because of which its possible to have data close to the possible solution. Fig 7 illustrates initial PSO state and shows how particles are initially distributed in the search space [8]. In this paper Different PID controller gains are used as particles used in search space for PSO algorithm.

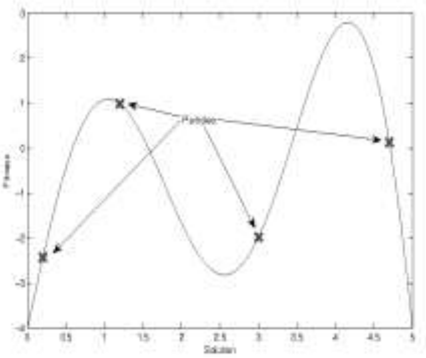

Fig7: Initial PSO State

A simple PSO coding is represented by
For every particle
{
Activate particle
}

Repeat these for max or min value
{
For every particle
{
Calculate actual value
If actual value is better than pbest
{
fix pbest = current actual value
}
If pbest is better than gbest
{
fix gbest = pbest
}
}

For each particle
{
Calculate particle Velocity
Use gbest and Velocity to validate particle Data
}

4. Fuzzy Controller Working

The working of the Fuzzy controller can be divided into three parts namely; allocation of the area inputs, rules associated with the inputs & defuzzifying of the output.

4.1. Allocation of the Area Inputs

Here frequency deviation and error are the two inputs for the fuzzy logic controller. Both the frequency deviation and error were divided into three control areas based on magnitude and sign. These are Negative (N), zero (Z), Positive (P) Here Fig 9(a) & 9(b) represents the input functions for the fuzzy logic controller.

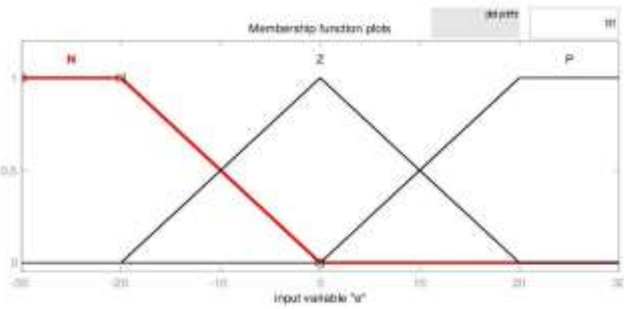

Fig9 (a): Membership function for input 1

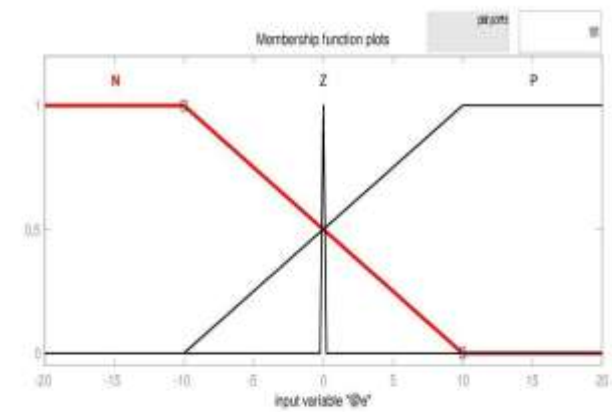

Fig9(b): Membership function for input 2

4.2. Rules Associated with Inputs

The rules used for the fuzzy controller are described in the fuzzy rule table shown in Table 1. The mathematical formula applied is the “minmax” rule for “and’ and “or” respectively. This was to reduce the calculation complexity and time.

Table 1: Fuzzy Rules

S.No	INPUT 1	INPUT 2	OUTPUT
1	n	n	p
2	n	p	p
3	z	n	z
4	z	p	z
5	p	n	n
6	p	p	n

Here: - n= Negative error deviation, p=Positive error deviation, z=Zero deviation

4.3 Defuzzifying of the Output Value

The output function of the fuzzy Controller is shown in Fig 10. Here 'centroid' method is used for defuzzification. In this method, for defuzzification center of the two inputs is used.

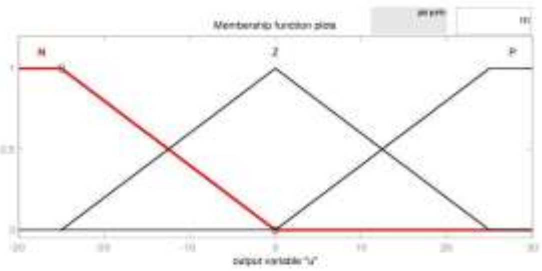

Fig10: Membership function for output

5. Simulation Results

Here we compare PSO-PID based system with PSO tuned Fuzzy PID based system with SSSC and TCPS

(a) Comparison between PSO-PID & PSO tuned Fuzzy PID system

5.1. PSO-PID Based Test System:

A two area power system is simulated on the MATLAB. Here gains for the PID controller are obtained by the PSO Optimization. Result so obtained is shown in Fig 11.

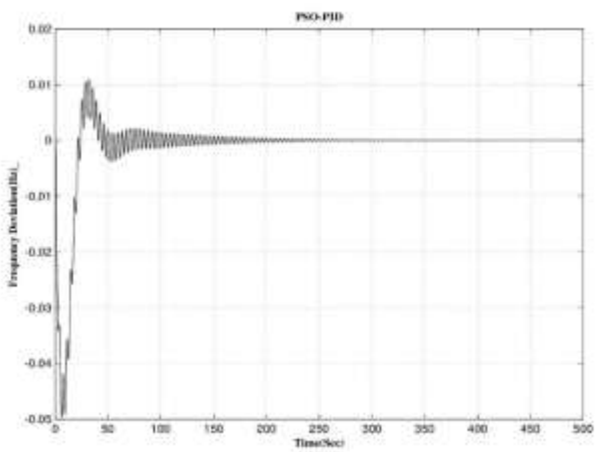

Fig11: Transient response of PSO based PID controller for a two-area unit

5.2. PSO Tuned Fuzzy PID Based Test System:

Secondly Optimization was performed with PSO tuned Fuzzy PID based two area system with SSSC, TCPS & the Result shown below.

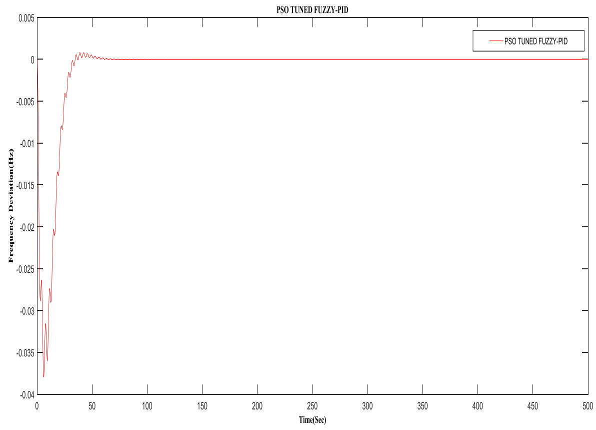

Fig12: Transient response of a PSO tuned Fuzzy PID controller with SSSC and TCPS

5.3. PSO Tuned Fuzzy PID Based Test System without SSSC & TCPS:

Proposed Optimization was performed with PSO tuned Fuzzy PID based two area system without SSSC, TCPS & the Result shown below.

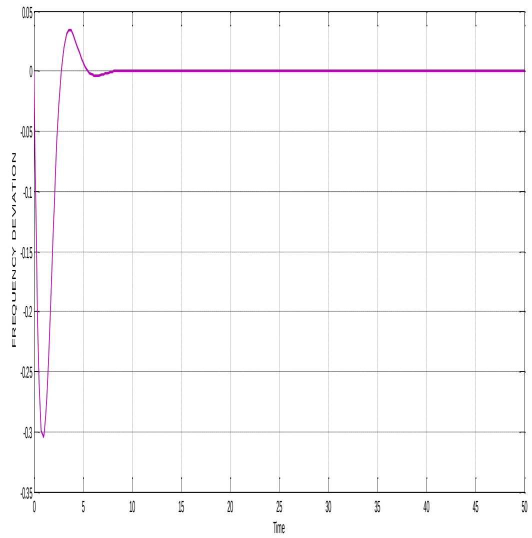

Fig13: Transient response of a PSO tuned Fuzzy PID controller without SSSC and TCPS

From the above two results it is clear that the PSO tuned Fuzzy PID controller has smooth curve with respect to the pulsated curve of PSO-PID and gives very fast settling time so the dynamic response was fast with better performance. And the performance of PSO tuned Fuzzy PID controller was further improved using SSSC and TCPS

(b) Comparison of Tie line power devotion in two area system:

5.4. PSO-PID Based Test System:

The Tie-line power variation for PSO-PID Based system has been shown below.

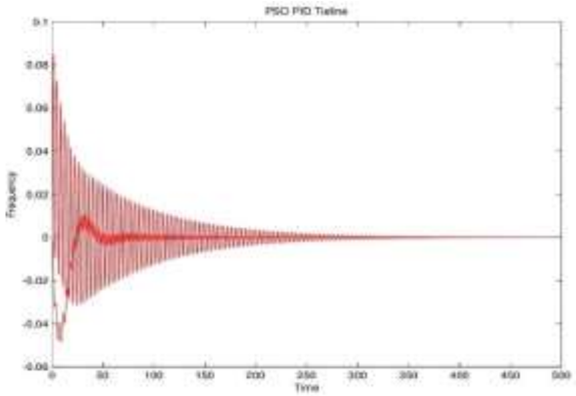

Fig14: Tie line deviation response of a PSO based Test system

5.5. Fuzzy Logic Based Test System:

Tie line deviation of a PSO tuned Fuzzy PID based test system is shown below:

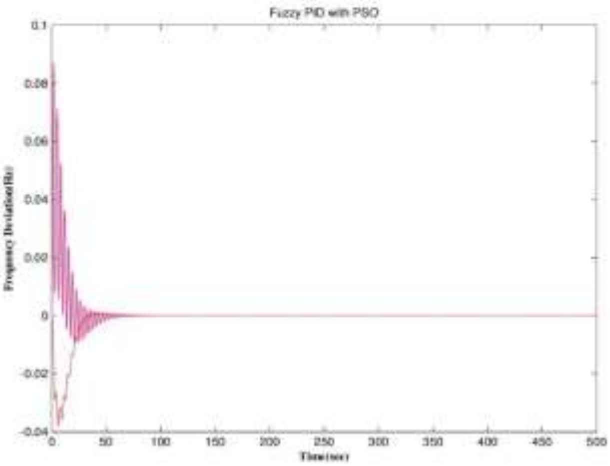

Fig15: Tie-line deviation for a PSO tuned Fuzzy PID based test system

From Fig 14 & 15 it can be seen that the settling time for the Tie line variation for PSO tuned Fuzzy PID based system is much better as compared to PSO-PID based test system.

5.6. Comparison between PSO-PID & PSO Tuned Fuzzy PID Based System with SSSC and TCPS

Table II: Comparison of Simulation Results

S.No	Automatic Generation System with	Settling time for Frequency Deviation (sec)	Frequency Deviation, Peak (Hz)	Settling time for Tie-line Deviation (sec)
1	PSO-PID	250	0.01	350
2	Fuzzy PID with PSO	100	0.003	90
3	Fuzzy PID with PSO & PSO SSSC-TCPS	10	0.001	90

6. Conclusion

Significant conclusion of this paper is as follows:
(a)First aim of the paper was to achieve optimal values of gains of PID controller and it has been successfully achieved via PSO based optimization algorithm and with which error of the system has been reduced to some extent.
(b) A comparison is made between PSO-PID, PSO tuned Fuzzy PID, and PSO tuned Fuzzy PID incorporated with PSO tuned SSSC and TCPS. With fuzzy controller its been able to reduce the frequency variation but settling time is still high, With proposed system i.e. PSO tuned Fuzzy PID with SSSC and TCPS, settling time has reduced drastically which is much effective and give the better response as compare to PSO-PID controller.
(c)PSO based Fuzzy PID based optimization technique have yielded good results and adding PSO trained SSSC and TCPS has given better settling time.
(d)In future different AI techniques can implemented with the proposed model for further improving the results and can also use this system for the Non-conventional energy sources.

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