Design of Fuzzy-Swarm Load Frequency Controller for Interconnected Power System

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***Abstract* — This paper is proposing a Load Frequency (LF) controller design for interconnected power system based on Fuzzy Logic Control (FLC). The FLC based LF controller's gains have been design using Particle Swarm Optimization (PSO) technique. The controller is designed to improve the dynamic response of system frequency and the tie line power flow under a sudden load changes. The LFC model for a two area interconnected power system is implemented in SIMULINK/MATLAB and the simulation results illustrate the effectiveness of the proposed LF controller compared to an existing FLC based LF controller and integral controller.**

***Index Terms* — Load frequency control, Fuzzy Logic Control , Particle Swarm Optimization**

I. INTRODUCTION

Modern power systems are normally composed of several control areas representing coherent groups of generators. The various areas are interconnected through tie lines. In recent years, usually large tie-line power fluctuations have been observed as a result of increased system capacity and very close interconnection among power systems. This observation suggests a strong need for establishing a more advanced Load Frequency Control (LFC) scheme. LFC of interconnected systems is defined as the regulation of power output of generators within a prescribed area, in response to change in system frequency, tie-line loading so as to maintain scheduled system frequency and/or established interchange with other areas within predetermined limits [1] and [2]. In general, LFC is a very important item in power system operation and control for supplying sufficient and reliable electric power with good quality. It is known that changes in real power affect mainly the system frequency and thus the rotor angle. The input mechanical power to generators is used to control the frequency of the output electrical power. The change in tie line real power (ΔP_{tie}) and the change in frequency (Δf) are sensed and transformed into a real power command signal ΔPv which is sent to the prime mover to call for the increment in the input torque or input mechanical power to the generator. Therefore, the prime mover makes change in the generator output by an amount of ΔPg, which will changes the values of Δf and ΔP_{tie} within a specified tolerance.

The tie lines are utilized for energy exchange between areas and provide inter-area support in case of abnormal condition such as loss of a generation unit or a sudden load increase [4]. Such abnormal conditions cause a change in the system frequency which may lead to a load shedding or even a frequency collapse leading to a total black out. Moreover abnormal conditions also cause a mismatch in scheduled power interchanges between areas. Therefore, frequency and tie line power deviations have to be corrected via a supplementary control system. One of the classical techniques is to use the integral controller [3], and [4]. However the dynamic response of such LF controller suffers a large over shoot and a considerable long settling time. To improve the dynamic response of the integral controller state feedback techniques are proposed such as the use of optimal control theory and pole placement [4]. However these techniques have disadvantages such as need of observer and communication system. One of the reliable techniques to improve the dynamic response of integral controller is to replace it by the PID controller such as the one presented in [8].

A more advanced option is to use FLC based controller. This type of control approach is presented in [9] and [10].The success of such controllers depends on proper selection of fuzzy inputs and the proper design of controller's gains. One of the most recent and powerful optimization techniques is Particle Swarm Optimization (PSO). It has been discovered in 1995 by simulation of social behaviors namely bird flocking [6] and, [7]. In this paper a FLC based LF controller for a two areas power system is designed. The gains of the proposed controller are optimized using PSO.

II. SYSTEM MODELING

Normally, a group of generators are coupled together and rotate in synchronism. The whole system can be represented by LFC loop, which is referred to as control area. Fig 1 shows the single line diagram of two interconnected systems (two-area). Each area is represented by an equivalent generating unit and a local load interconnected by a lossless tie line with reactance X. The system model was derived in [1] and [2]. The system model is based on the equations for the power equilibrium, the incremental tie-line flow, the change in generation, and the position of the speed governor. Area 1 equations are as follows:

$$T_{p1}\frac{d\Delta f_1}{dt} = -D_1\Delta f_1 + \Delta P_{T1} - \Delta P_{D1} - \Delta P_{12} \tag{1}$$

$$T_{T1}\frac{d\Delta P_{T1}}{dt} = -\Delta P_{T1} + \Delta P_{v1} \tag{2}$$

$$T_{g1}\frac{d\Delta P_{v1}}{dt} = -\frac{1}{R_1}\Delta f_1 - \Delta P_{v1} + \Delta P_{c1} \tag{3}$$

$$\frac{d\Delta\delta_1}{dt} = \Delta f_1 \tag{4}$$

$$\Delta P_{12} = T_{12}\left(\Delta\delta_1 - \Delta\delta_2\right) \tag{5}$$

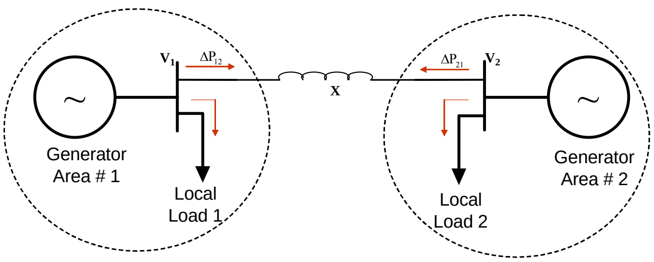

Fig. 1. Block Diagram of Two Area Interconnected Power System

Similarly for area 2:

$$T_{p2}\frac{d\Delta f_2}{dt} = -D_1\Delta f_2 + \Delta P_{T2} - \Delta P_{D2} - \Delta P_{21} \tag{6}$$

$$T_{T2}\frac{d\Delta P_{T2}}{dt} = -\Delta P_{T2} + \Delta P_{v2} \tag{7}$$

$$T_{g2}\frac{d\Delta P_{v2}}{dt} = -\frac{1}{R_2}\Delta f_2 - \Delta P_{v2} + \Delta P_{c2} \tag{8}$$

$$\frac{d\Delta\delta_2}{dt} = 2\pi\Delta f_2 \tag{9}$$

$$\Delta P_{21} = T_{12}\left(\Delta\delta_2 - \Delta\delta_1\right) \tag{10}$$

Each control area has two control loops, namely primary and secondary. The objective of primary control is to maintain a balance between generation and demand within the synchronous area, using turbine speed or turbine governors. Primary control aims at the operational reliability of the power system of the synchronous area and stabilizes the system frequency at stationary value after a disturbance or incident in the time-frame of seconds, but without restoring the reference values of system frequency and power exchanges. In addition, secondary control also maintains a balance between generation and demand within each control area as well as the system frequency within the synchronous area. Secondary control makes use of the automatic generation control, modifying the active power set points (LFC). Conventional LFC is based upon tie-line bias control, where each area tends to reduce the Area Control Error (ACE) to zero. The control error for each area consists of a linear combination of frequency and tie-line power deviation [3]. Therefore for a power system consists of n areas ACE can be expressed as:

$$ACE_i = \sum_{j=1}^{n}(\Delta P_{ij} + \beta_i \Delta f) \tag{11}$$

Where:

$$\beta_i = D_i + \frac{1}{R_i} \tag{12}$$

As presented in [4] ,[8] and [9] the conventional integral LF controller need to be enhanced by a supplementary controller in order to enhance the dynamics responses of the system frequency and tie-line power deviations . In this paper a LF controller is presented. The challenge is to add another control signals (Δu_1 and Δu_2) to improve the dynamic responses of the system. These two control signals shall be derived from the proposed FLC based controller.

III. PARTICLE SWARM OPTIMIZATION

PSO is based on swarm of birds. It is basically developed through simulation of a bird flocking in multi-dimension space [4], and [5]. Each particle or agent is represented by position vector V(t) and associated with velocity V(t). The agent is modified based on position and velocity information. Like many other optimizations techniques PSO is iterative. In each iteration the agent evaluated via objective function so that it knows its best value (pbest) as well as its position. In social live this information is analogy of personal experiences of each agent. Moreover, each agent knows the best value so far in the group (gbest) among pbest of all agents. This information is analogy of knowledge of how the other agents around them have performed [5]. PSO Algorithm is simple since its require a primitive mathematical operators as can be seen in the flow chart in Fig.2.

$$X_j(0) = \left[x_{j,1}(0) \quad \ldots \quad x_{j,m}(0)\right] \qquad \textit{within the rang}\left[x_k^{\min}, \quad x_k^{\max}\right]$$

$$V_j(0) = \left[v_{j,1}(0) \quad \ldots \quad v_{j,m}(0)\right] \qquad \textit{within the rang}\left[-v_k^{\max}, \quad v_k^{\max}\right]$$

<u>Initialization step:</u> starts by generating initial population randomly within the specified rang. Then,

for each generated position an associated velocity is generated randomly within a calculated range based on position range (Equation. 13).

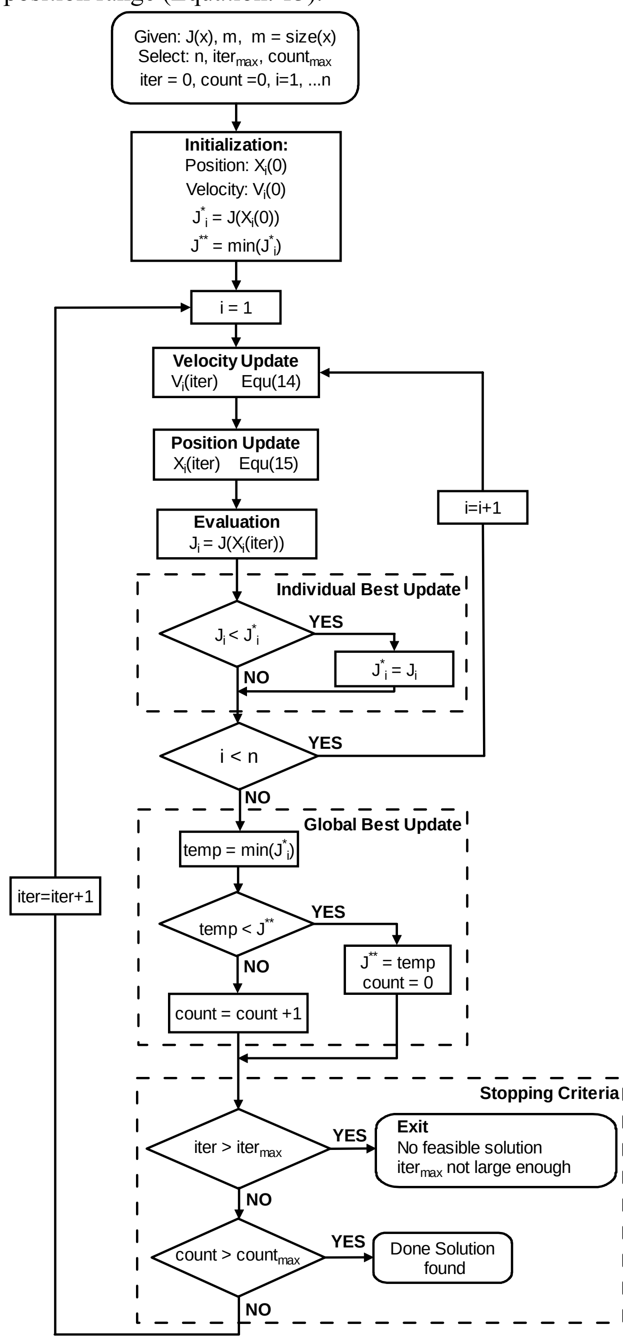

Fig. 2. Particle Swarm Optimization Algorithm

n: The number of randomly generated position and velocity.
m: Number of variables.

$$v_k^{max} = \frac{x_k^{max} - x_k^{min}}{N} \qquad (13)$$

Where:
N: is a chosen number of intervals in the kth dimension.

The random weighting of the control parameters in the algorithm results in a kind of explosion as particles' velocities and positional coordinates go toward infinity. The explosion has traditionally been contained through implementation of a parameter Vmax, which limits step size or velocity [4]. In other words , this parameter acts toward the converges PSO.

Velocity update: the velocity of each particle is modified by the following equation:

$$v_{j,k}(iter) = K\left[\begin{array}{l} v_{j,k}(iter-1) + c_1 r_1 \left(x^*_{j,k}(iter-1) - x_{j,k}(iter-1)\right) \\ + c_2 r_2 \left(x^{**}_k(iter-1) - x_{j,k}(iter-1)\right) \end{array}\right] \qquad (14)$$

Where:

$$K = \frac{2}{2 - \varphi - \sqrt{\varphi^2 - 4\varphi}} \qquad \text{where}: \varphi = c_1 + c_2, \varphi > 4$$

c_1 and c_2 are specified weighting factors.
r_1 and r_2 are generated random numbers.

Position updating step: based on the updated velocities each particle changes its position according to the following equation:

$$x_{j,k}(t) = v_{j,k}(t) + x_{j,k}(t-1) \qquad (15)$$

From physics respective it can be noted from this equation that the velocities is added with displacement because the time increment is always one unit [6].

Individual best updating step:

1) Each Particle is evaluated according to the updated position.
2) If Jj < J*j then the updated individual best as X*j(t) = Xj(t) and J*j = Jj.

Global best updating step:

1) Search for the minimum value J_{min} among J^*_j.
2) If $J_{min} < J^{**}$ then the updated individual best as $X^{**} = X_{min}(t)$ and $J^{**} = J_{min}$.

Stopping criteria step:
In this paper, the search will stop if one of the following criteria is satisfied:

1) The number of iterations reaches the maximum allowable number.
2) The number of iterations since the last change of the best solution is greater than or equal prespecified number.

IV. FLC BASED LF CONTROLLER

The fuzzy controller is composed of the following four elements:

1) A rule-base (a set of If-Then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve good control.
2) An inference mechanism (also called an "inference engine" or "fuzzy inference" module), which emulates the expert's decision making in interpreting

and applying knowledge about how best to control the plant.

3) A fuzzification interface, which converts controller inputs into information that the inference mechanism can easily use to activate and apply rules.
4) A defuzzification interface, which converts the conclusions of the inference mechanism into actual inputs for the process.

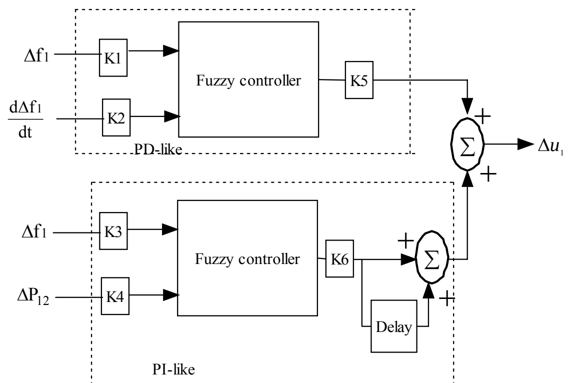

Fig. 3 Area 1 Fuzzy logic controllers

It has been proposed in [9] a fuzzy logic controller consisting of two fuzzy controllers working in parallel. The first is a PD-like fuzzy controller and the second is PI-like fuzzy controller. The controller structure is as shown in Fig 3. The fuzzy controller for area 2 is identical to Fig. 3 except another set of gains $K_7 \ldots K_{12}$ are used .

V. CASE STUDY & RESULTS

The block diagram shown in Fig 1 is implemented and simulated in MATLAB/Simulink. The system parameters are presented in Table I.

The objective function of PSO is to minimize the sum of ACE in both areas.

$$J = |ACE_1| + |ACE_2| \tag{17}$$

The "center of gravity" method used for defuzzification. Thus for a M rules the crisp output is [9].

$$u = \sum_{i=1}^{M} \mu_i \theta_i \Big/ \sum_{i=1}^{M} \mu_i \tag{18}$$

Where the strength of the ith rule is μ_i is calculated based on interpreting "and" connection as product of the input membership values. θ_i is the cetroid of i^{th} rule. Note that the net control action is the sum of the individual outputs of both PD-like and PI-like controllers. Triangular membership functions are used for inputs and output as described in [11]. The gains of the controllers tuned using PSO and found as shown in Table IV.

A symmetrical set of fuzzy rule is used to describe both the PD-like and PI-like fuzzy controller behaviors as shown in Table II and Table III.

TABLE I

PARAMETERS OF THE TWO AREA POWER SYSTEM

Parameters	Area 1	Area 2
Speed regulation R	0.05	0.0625
Frequency sensitive coefficient D	0.6	0.9
Inertia constant H	5	4
Governor time constant T_g	0.2	0.3
Turbine time constant T_t	0.5	0.6
Synchronizing coefficient T_{12}	2 pu	

TABLE II

RULE BASE FOR PD-LIKE FUZZY CONTROLLER

Δf	$\frac{d\Delta f}{dt}$						
	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NM	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	NS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

TABLE III

RULE BASE FOR PI-LIKE FUZZY CONTROLLER

Δf	P_{12}						
	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NM	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	NS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

NB: negative big, NM: negative medium, NS negative small, Z zero, PB: positive big, NM: positive medium, NS positive small

Fig 4 show the frequency response of area 1 for Fuzzy-swarm LF controller compared to the existing fuzzy [9] controller and the integral controller [1]. It is very clear that the frequency of Fuzzy-swam LF controller has better transient response and better settling time. It took less than 10 second for the Fuzzy swarm controller to reach the steady state value compared to more than 15 seconds for exiting fuzzy . The gains of the existing fuzzy controller [9] where not optimized whereas the gains of the Fuzzy –swarm controller optimized using PSO.

Fig 5 shows the response of tie-line power for Fuzzy-swarm LF controller compared to the existing fuzzy [9] controller and the integral controller [1]. It is also very clear that the tie-line power deviation of Fuzzy-swam LF controller has better transient response and better settling time. It is also worth to compare the area 2 frequency response of the Fuzzy-swarm compared to the mentioned controllers as shown in Fig 6.

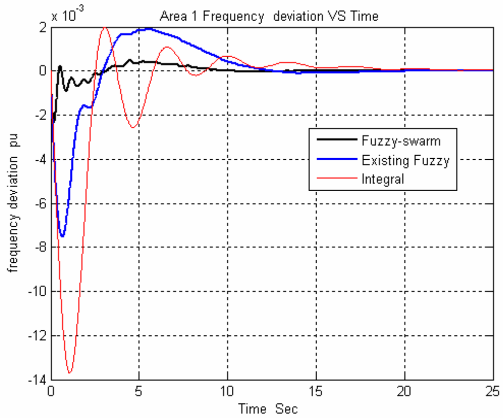

Fig.4. Δf_1 (FL-swarm, FL[9], and integral controller[1])

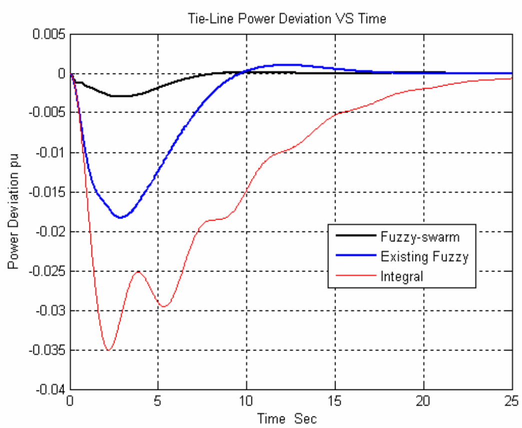

Fig. 5. ΔP_{tie} (FL-swarm,FL[9],and integral controller[1])

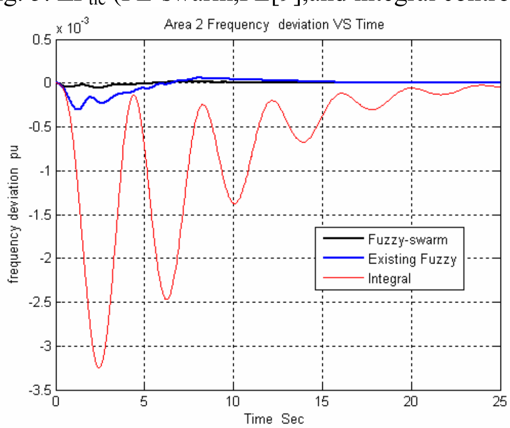

Fig.6. Δf_2 (FL-swarm, FL[9], and integral controller[1])

VI. CONCLUSION

This paper proposed a FLC based load frequency controller for an interconnected power system to damp out the frequency deviations and also to keep the tie line power at the scheduled value. The LFC parameters are tuned using PSO. This paper highlights the advantages of simple implantation and design of FLC approach. The PSO advantages as a powerful optimization technique were utilized. The simulation results showed the validity of the proposed Fuzzy-Swarm LF controller compared with an existing FLC in [9] and integral LF controller [1].

REFERENCES

[1] SAADAT, H., "Power System Analysis," *McGraw-Hill1*,1999.

[2] M. Albadi, A. Awladthani, B. Alomeiri and K. Ellithy,2002, "Comparative Study of Load Frequency Controller Designs for Interconnected Power Systems, "*SQU, Science and Technology*

[3] A. Al-Hinai and A. Feliachi, "Application of Intelligent Control Agents in Power Systems with Distributed Generators," *Proc. of IEEE Power Engineering Society's 2004 Power Systems Conference and Exposition (PSCE), NY, Oct*. 2004

[4] Maurice Clerc and James Kennedy, " The Particle Swarm Explosion, Stability, and Convergence in a Multidimensional Complex Space, *IEEE Transactions On Evolutionary Computation, 6(1),* 2002, 58 - 73

[5] O.I Elgerd, and C.E. Fosha, Optimum Megawatt-Frequency control of Multiarea Power Systems, " *IEEE Transactions on Power Apparatus Systems,* PAS-89, 1970, 556-563.

[6] J. Kennedy and R. C. Eberhart, "Particle swarm optimization," *in Proc.IEEE Int. Conf. Neural Networks, Perth, Australia,* Nov. 1995, pp.1942–1948.

[7] J.Wood and F.Wollenbreg , "Power Generation operation and Control" ,*John Wisly &sons*,inc,1996

[8] A. Al-Hinai and B.Omari, "Design of PID-Swarm Load Frequency Controller of Interconnected Power System ,"*international Conference on Communication, Computer & Power (ICCCP'07) Muscat*, February 19-21, 2007

[9] K. Ellithy and K.El-Matwaley. "Design of decentralized fuzzy logic controller for load frequency control including GRC effect, " *engineering journal of the university of Qatar* , vol.17,2004

[10] Q. P. Ha , "A fuzzy sliding mode controller for power system Load-frequency control, " *Second International Conference on Knowledge-Based Intelligent E l m n i c Systems,* 21-23 April 1998, Adelaide, Australia. Editors, LC. Jain and R.KJain

[11] Kevin M. Passino and Stephen Yurkovich"Fuzzy Control," *Addison-Wesley Longman, Inc*, 1998

TABLE IV

FUZZY-SWAM LF CONTROLLER OPTIMAL GAINS AS FOUND USING PSO

K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
19.0881	10.017	11.9993	1.7729	9.883	9.9822	24.4899	12.012	5.0028	0.0838	1.576	2.6081