IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331,
PP 105-111
www.iosrjournals.org

PSO Optimized FLC For The Design Of Load Frequency Control

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Abstract: *Load frequency control problem is considered as one of the mostimportant issues in the design &operation of power systems. Due to lack of goodefficiency in parameters variation conditions, working conditions of system andnon-linear factors, a simple PI controller is not suitable in industrial applications.Instead, fuzzy controllers can be used in order to enhance the performances of thesystems. In this paper, the use of the optimized type-1 fuzzy logic controller usingParticle Swarm Optimization (PSO) algorithm is proposed to solve the loadfrequencycontrol problem. To the best of our knowledge, the PSO optimization offuzzy type-1 controller in order to solve load-frequency control problem, has notbeen investigated so far. The proposed controller has good performance and iscapable to solve the load-frequency control problem in conditions of widevariations of system parameters and nonlinear factors such as generation rateconstraint. Simulation results show that the optimized fuzzy controller proposed inthis paper exhibits better performance compared to PI controller in damping ofsystem deviations.*

Key words: *power system, load frequency control, type-1 fuzzy logiccontroller, PSO algorithm.*

I. INTRODUCTION

The main aim of power systems is to provide the required power supplyto customers with a given voltage and frequency. Considering the growingenergy demand of the customers, the stability and reliability of power systems are important. The load-frequency control problem in a power system dealswith sudden disturbances that disrupt normal conditions of system operationand occur due to outage and connection of loads on different hours in power system. Any change in active power demand in a point of a power system isreflected throughout the system as a frequency change (Panda, 1998).

The problem of output active power control of a power system inresponse to power system frequency changes and between regional powers ofsystem lines in a specified range is known as the load-frequency controlproblem. For optimal performance and optimal operation of power systems, thefrequency changes must be maintained within certain limits. Many processcontrol systems, such as computers, are sensitive to changes in the frequencyand their operation is impaired. For such systems, their frequency must beregulated and controlled (Chaturvediet al., 1999; Moon et al., 2002). Therefore,an adequate supplementary controller to regulate and prevent frequencydeviations must be used in the main control center.

The purpose of load frequency control problem is to maintain a uniformfrequency and to adjust and control converted power between areas of thepower system in a planned value. In other words, we can say that the aim ofload-frequency control problem is keeping the steady-state error of the systemon zero. In previous studies on solving the load-frequency control problem,various methods have been used. In the proposed methods, the PI controller ismost widely used in industry. The PI controller has a fixed gain that is designedin rated operating conditions and its utilization is simple, but frequencyoscillations can also appear in this case. This means that the PI controllerindicates a poor dynamic performance against of system parameters variationand non-linear conditions such as generation rate constraint (Hameedet al.,2010; Chang & Fu, 1997). Different types of fixed gain controllers are designedin rated operating conditions while they are unable to achieve performance inpractice under many changes in the operating conditions of the system.

In order to solve the load frequency control problem and to minimizepower system deviations, operating conditions and system parameters variationsmust be considered; genetic algorithms and other intelligent methods are used toimprove the PI controller performance and to optimize controller coefficients.As for the non-linearity of the power system and inability to extract its precisemathematical model, in recent years the use of the fuzzy method in design ofcontroller was proposed (Ying, 2000; Mendel, 2000; Hidalgo et al., 2009;Panda et al., 2009; Ying, 2006). In some studies, fuzzy logic is used to adjustthe PI controller parameters.

In this paper the type-1 fuzzy logic controller optimized using ParticleSwarm Optimization (PSO) algorithm is used to damp oscillations of frequencyin a single area power system. In designing the proposed controller, the nonlinearfactor of generationrate constraint is considered and the results of theoptimized type-1 fuzzy logic controller using PSO algorithm are compared tothat of a classical PI controller.

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II. THE SINGLE AREA POWER SYSTEM

The load frequency model of the studied single area power system isshown in Fig. 1. In solving the load-frequency control problem of the studiedsystem, the generation rate constraint is considered. The non-linear turbinemodel considering the generation rate constraint is shown in Fig. 2.

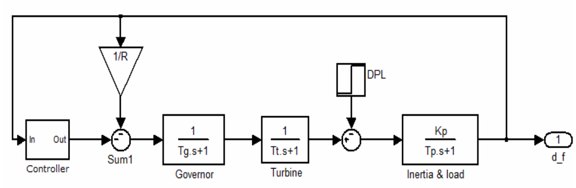

Fig. 1: Studied single area power system.

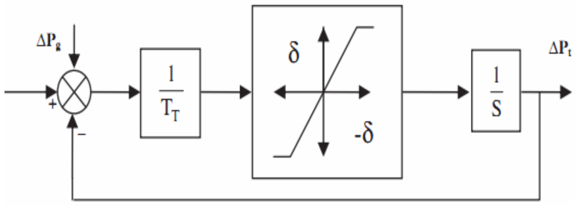

Fig. 2 : Non-linear turbine model considering the generation rate constraint.

The studied single area power system parameters are defined with theadding limiter to the turbine that are listed in Table 1. In the studied powersystem, the area control error (ACE) and its variation (ΔACE) are consideredas fuzzy controller inputs.

Table 1
Studied Single Area Power System Parameters

Parameter	Value
Tg	0.08
Tt	0.3
Tp	20
Kp	120
R	2.4
DPL	0.01

III. PI AND TYPE-1 (T1) FUZZY LOGIC CONTROLLERS

The PI controller block-diagram and its parameters are illustrated inFig. 3. The fuzzy controller uses fuzzy logic rules in control applications. Fuzzyrules have been established based on control laws. Fuzzy logic systems are notdesigned based on mathematical models. Fuzzy controllers implement thehuman logic using fuzzy logic based on membership functions, fuzzy rules and
membership rules.

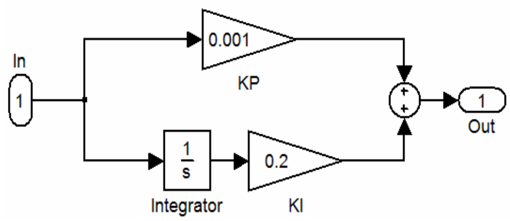

Fig. 3: The Proposed PI controller.

A fuzzy system is described by a set of IF-THEN rules and uses diversemembership functions. To solve the load-frequency control problem in fuzzycontroller, controller inputs, ΔACE, ACE, and its output are considered as thecontrol signal. The fuzzy type-1 controller structure is shown in Fig. 4.

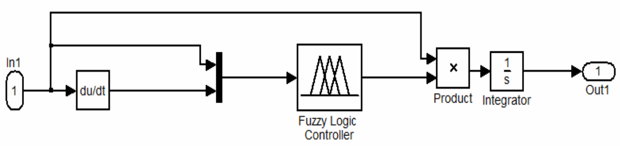

Fig. 4 : The Proposed fuzzy type-1 controller.

The design of the type-1 fuzzy controller has 4 steps that are presentedas follows:

Step 1: The first step should be to determine the system dynamicbehavior and characteristics. At this stage, the controller input and outputvariables and their variations range should be determined. In addition, suitableinput signals should be determined for load-frequency control problem. Inputsignals are considered to create the base rules as the IF part and the outputsignal of the fuzzy controller are considered as the THEN part.

Step 2: At this stage, the appropriate fuzzy sets and membershipfunctions are determined. At this stage, the degree of fuzzy membershipfunctions associated with each variable or input, output signals are determinedand the process of fuzzification is completed.The membership functions of fuzzy type-1 controller are illustrated in Fig. 5.

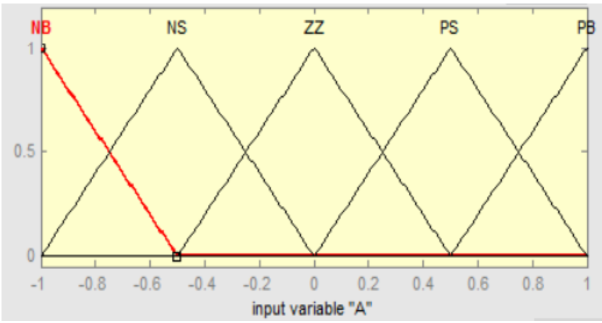

Fig. 5 The membership functions of proposed fuzzy type-1 controller.

Step 3: The inference engine is described. In this step, fuzzy rules areformed by the control rules that system performance is based on that rules.

Step 4: At this stage, the defuzzification process is performed. Fuzzyrules are combined and the defuzzification process is performed on the outputand the output of the fuzzy inference engine becomes crisp.

In this paper, inputs and outputs membership functions are the same andthe 5-segments triangular membership functions are used. Since each input hasfive membership functions, the number of base fuzzy rules is 25 that arepresented in Table 2.

Table 2

Fuzzy Rules of the Proposed Fuzzy Type-1 Controller

ec / e	**NB**	**NS**	**ZZ**	**PS**	**PB**
NB	S	S	M	M	B
S	S	M	M	B	VB
ZZ	M	M	B	VB	VB
PS	M	M	VB	VB	VVB
PB	B	VB	VB	VVB	VVB

IV. OPTIMIZED TYPE-1 FUZZY LOGIC CONTROLLER USING PSO ALGORITHM

In this paper, to design the self-tuning adaptive and fuzzy loadfrequencycontrol system and to achieve a better performance of type-1 fuzzycontroller, the PSO algorithm is used to optimize the membership functions parameters with the aim of minimizing system frequency deviations. In thestudied system, ACE and ΔACE are considered as the input signals and as forthe input signals, the output signals are used to change the set points in the loadfrequencycontrol problem.

4.1. PSO Algorithm

In this paper, a PSO algorithm is applied to optimize the membershipfunctions of fuzzy type-1 controller. The optimization problem is defined as follows:

minf (x)

subject to$x_i \in X_i$, i=1,2,3,... N → (1)

In (1), f(x) is the objective function and x is the collection of thedecision variablesx_i. The set $X_i$is the collection of possible range of variable$x_i$and N is the number of variables. The PSO optimization algorithm (Taher,2008; Kennedy &Eberhart, 1995) is one of the latest and strongestmetaheuristic methods of optimization and has been used in solving complexproblems up to now.

The PSO algorithm starts to work with a random population (i.e.particles) and then searches the optimal solution (particle) of the problem witheach updated generation. Particle i is defined by its spatial position $S_i$and itsvelocity V_i. At each stage of population movement, each particle is updated bytracking the two best positions.

The first one is the local best position, in terms of competency, which isobtained separately for each particle up to now. This value is P_{best}. The second one is the global best position, obtained by the all of the particles among the

population, up to now. This value is G_{best}. After finding the values of the $P_{best}$and G_{best}, each particle updates its new velocity and position based on thefollowing equations:

$$V_i^{k+1} = W V_i^k + C_1 r_1 (P_{best_i} - S_i^k) + C_2 r_2 (G_{best_i} - S_i^k) \rightarrow (2)$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \rightarrow (3)$$

The problem convergence is dependent on the PSO algorithmparameters such as W, C_1 and C_2 .W is the updating factor of the particlesvelocity. C_1 and C_2 are the acceleration factors, which are the same and are inthe range of [0, 2]. r_1 and r_2 are two random variables uniformly distributed inthe range of [0, 1]. W is the inertia weight and is constant in the PSO algorithm.In modified PSO, to strengthen the PSO algorithm performance and solve itsdisadvantages with updating W, for obtaining the best reply in terms of theconvergence velocity and accuracy in the optimization problem, the followingequation is used:

$$W^k = W_{\max} + k\left(\left(W_{\min} - W_{\max}\right) / iterMax\right) \rightarrow (4)$$

In (4), Wmin and Wmax are the minimum and maximum values of theinertia weight, the iterMaxis the maximum number of the algorithm iterations,and k is the current iteration of the algorithm. The inertia weight is varied by (4)and causes the convergence, which is defined as a variable in the range of [0.2 0.9]. Because of updating the inertia weight with updating the particles velocity,the PSO algorithm has a perfect performance. In solving the optimizationproblem, the number of algorithm iterations has been reduced and theconvergence power has been increased under the conditions of increasedcommunity members. Finally the optimization algorithm is ended by theparticles convergence to a certain extent. The optimal parameters of PSOalgorithm used in this study are presented in Table 3.

Table 3
The Optimal Parameters of PSO Algorithm Used in Optimization Problem

Swarm Size	C_1	C_2	W	iterMax
20	2	2	0.4-0.9	100

4.2. Implementation of the Proposed Method

In the proposed fuzzy typ-1 controller for better performance, theprocessor parts of controller (K_1, K_2 and K_3) are optimized in a specifiedrange. The fuzzy type-1 controller consists of processor Parts is shown in Fig. 6.

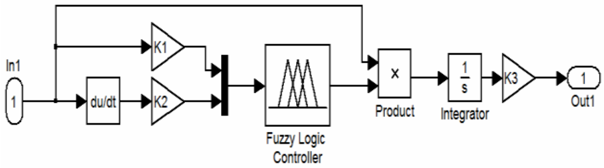

Fig. 6 – The fuzzy type-1 controller with processor parts.

In proposed fuzzy type-1 controller, the parameters K_1, K_2 and K_3 areused to tune the controller for better performance in damping system frequencydeviations.

The optimal and accurate performance of the fuzzy controller isdetermined by the membership functions. That means that if the bestmembership functions are selected for controller then the best performance of the controller is achieved. Thus, the PSO algorithm is used to determine theparameters of K_1, K_2 and K_3 considering the objective function of optimizationproblem in Fig. 7.

The objective function is chosen as the Integral of Time multiplied bySquared Error (ITSE) as follow:

$$f_{ITSE} = 1000\int_0^\infty t(|ACE^2(t)|)dt \quad \rightarrow (5)$$

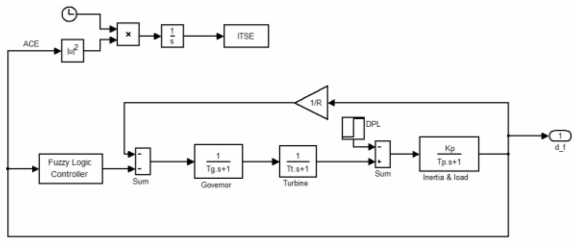

Fig. 7: Application of PSO algorithm considering objective functionfor optimization of proposed fuzzy type-1 controller.

V. SIMULATION RESULTS

Using PSO algorithm the optimal parameters of K_1, K_2 and K_3aredetermined as Table 4. The curve of PSO algorithm convergence is presented ifFig. 8.

Table 4
The Value of Parameters of K_1, K_2 and K_3

	K_1	K_2	K_3
T1FLC	0.889	2.01	0.60

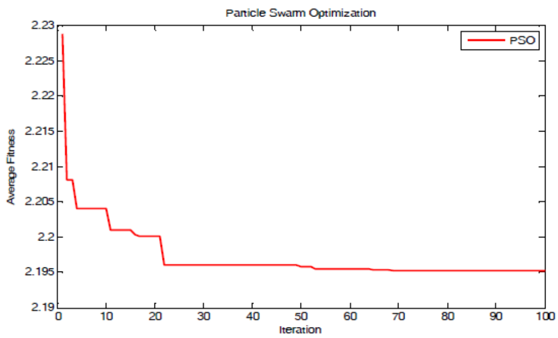

Fig. 8: curve of PSO algorithm convergence.

After determination of parameters of K_1, K_2 and $K_3$the single areapower system is simulated using PI and optimized fuzzy type-1 controllers andthe result of simulation is shown in Fig. 9.

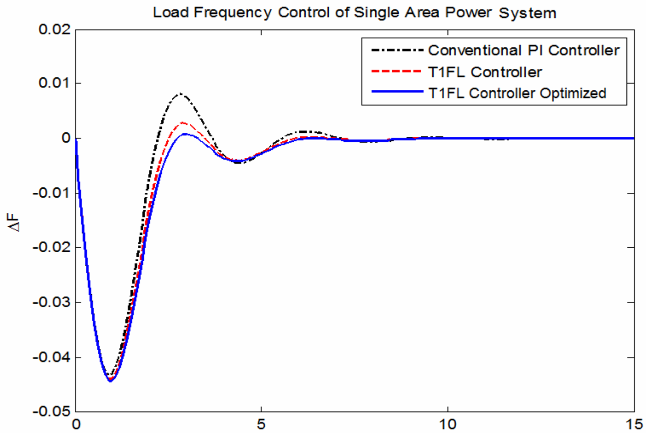

Fig. 9: Load frequency control of single area power system using PI andoptimized fuzzy

Fig. 9 shows that the frequency deviations of the single area powersystem are damped by using the proposed optimized fuzzy type-1 controller inless settling time and maximum overshoot versus the PI controller. So theproposed fuzzy controller shows better performance in load frequency controlof a single area power system.

VI. CONCLUSIONS

1. In this paper, the optimized type-1 fuzzy logic controller was proposedto solve the load frequency control problem of single area power system.

2. Using PSO algorithm the parameters of the membership function oftype 1 fuzzy controller were optimized.

3. Simulation results show that the proposed type-1 fuzzy controller indamping of frequency deviations of power system has a better performance thanthe PI controller.

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