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Design of LFC and AVR for Single Area Power System with PID Controller Tuning By BFO and Ziegler Methods

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***Abstract*– This work presents two method for designing the parameters of PID controller, the first is Bacterial Foraging Optimization (BFO) algorithm, and the second is Ziegler method for tuning the parameters of PID controller of Load Frequency Control (LFC) and Automatic Voltage Regulator (AVR) for single area interconnected power system, The proposed controller is used to tune the LFC and AVR .The LFC loop controls real power &frequency and AVR loop controls reactive power & voltage. To maintain the system parameters of the given system at nominal value, PID tuning by BFO and Ziegler is proposed. This paper is proposed to show the interaction between the LFC and the AVR loops. The system with its control method is going to implement in MATLAB software. The interaction between frequency deviation and voltage deviation is analyzed in this paper. System performance has been evaluated at various loading disturbances. This paper describes the design, implementation and operation performance of PID controller as part of the combined loop of AGC & AVR for single area power system.**

***Index Terms*– Load Frequency Control (LFC), Automatic Voltage Regulator (AVR), BFO (Bacterial Foraging Optimization), Ziegler Method and (Integral of Square Error) ISE**

I. INTRODUCTION

ALL electrical products and processes are sensitive not only to the continuity of power supply but also on the quality of power supply such as voltage and frequency.

In power system, both active and reactive power demands are never steady they continuously change with the rising or falling trend. In brief, the changes in real power affect the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on changes in voltage magnitude. The quality of power supply must meet certain minimum standards with regard to constancy of voltage and frequency.

The voltage and frequency controller has gained importance with the growth of interconnected system and has made the operation of power system more reliable.

Many investigations in the area of LFC and AVR of an isolated power system have been reported and a number of Control schemes like Proportional and Integral (PI), Proportional, Integral and Derivative (PID) and optimal control have been proposed to achieve improved performance. Several new optimization techniques like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Simulated Annealing (SA) and Bacterial Foraging Optimization (BFO) [4], [7], [8].

Firstly the system studies have been carried with normal values of parameters, later the proportional plus integral strategy is implemented to obtain an improved response for the system. Also the effect of (+ 50%,-50%) variation in system parameters from their nominal values on the dynamic performance of the system has been studied by obtaining the response plots of frequency deviation of disturbed area. Finally, the techniques of optimal control theory are applied to develop an optimal feedback controller for enhancing the system dynamic performance of isolated power system. Numerical examples have been considered to demonstrate the effectiveness of optimal PID controller

The paper is organized as follows, section 2 describes the model of the plant including LFC and AVR, section 3 describes the tuning PID controller using (BFO) based multi objective functions and Ziegler Method, section 4 demonstrates the simulation results, tuning of BFO-PID and Ziegler-PID controllers, and conclusion is derived in section 5.

II. MAIN ASPECTS CONCERNING WITH SYSTEM MODELING

The first step in the analysis and design of a control system is mathematical modeling of the single area power system. Proper assumptions and approximations are made to linearize the mathematical equations describing the system, and a transfer function model is obtained for the component [8].The dynamic models in state-space variable form, obtained from the associated transfer function, is:

$$\dot{x} = Ax + Bu \qquad Y=CX \qquad (1)$$

Where *A*, *B*, *and C* are given in reference [13]

Also,

$$x = [\Delta F \quad \Delta P_t \quad \Delta P_g \quad \Delta P_{ref}]^T; \qquad u = [\Delta P_L]^T; \qquad (2)$$

$$y = [\Delta F] \qquad (3)$$

Are the state vector, the control vector and the output variables, respectively.

Where:

S: differential operator.
ΔP_g : the governor output change.
ΔP_{ref} : the mechanical power change.
ΔF: the frequency deviation.
ΔP_L : the load change.
ΔP_t : supplementary control action.
The structure of a PID controller is

$$G_C(S) = K_P + \frac{K_I}{S} + SK_D \tag{4}$$

Where K_P, K_I and K_D are proportional, integral and derivative gain constants.PID controller tuning by (BFO) and Ziegler methods for the LFC loop.

A simplified diagram of PID controller based combined loop of LFC and AVR is shown in Fig. 1:

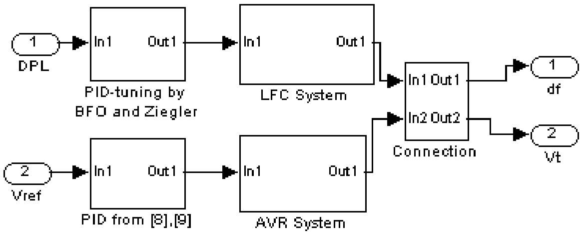

Fig. 1: simplified diagram of PID controller of LFC and AVR

Fig. 2 shows the simulink model of controller based combined loop of LFC and AVR.

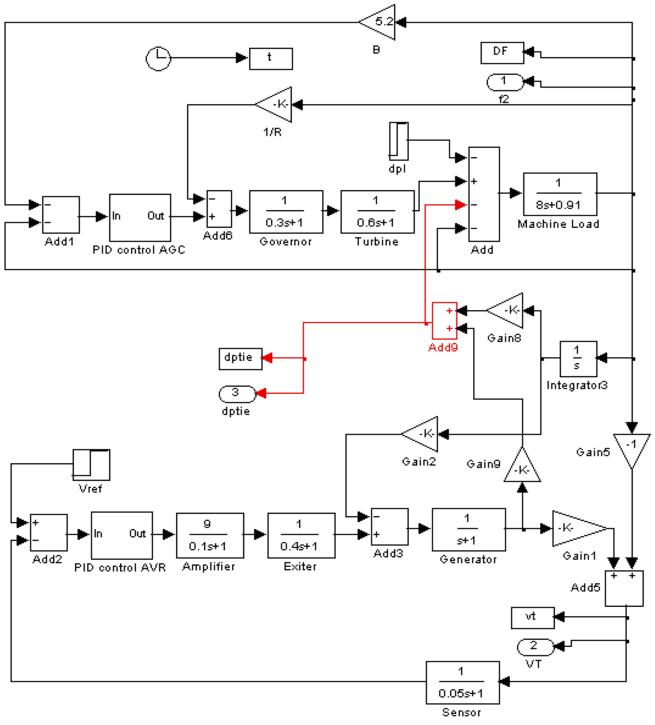

Fig. 2: Simulink model of PID controller tuning based AGC and AVR for a typical single area power system

III. TUNING PID CONTROLLER USING MULTI OBJECTIVE FUNCTIONS

A. *Bacterial Foraging Optimization Algorithm (BFOA)*

The algorithm to search optimal values of parameters is:

STEP1: Initialize parameters $n,N,N_c,N_s,N_{re},N_{ed},P_{ed}$,C (i) (i=1,2,…….N),$\theta^i$.

Where:
n: Dimension of the search space.
N : The number of bacteria in the population.
N_c: Chemotactic steps.
N_s: Maximum number of swim length.
N_{re}:The number of reproduction steps.
N_{ed} : The number of elimination and dispersal events.
P_{ed}: Elimination and dispersal with probability.
C (i): The size of step taken in the random direction specified by the tumble
$\theta^i(j,k,l)$: Position of the i^ih bacterium at j^th chemotactic, k^th reproductive and l^th elimination-dispersal step.
S: the total number of bacteria.
P: the number of parameters to be optimized that are present in each bacterium.

STEP 2: Eliminate dispersal loop: $l = l +1$;
STEP 3: Reproductive step: $k = k +1$;
STEP 4: Chemotaxis loop: $j = j +1$

For i =1,2... N, take a chemotactic step for bacterium as follows:
Compute fitness function, $J(i, j, k, l)$
Let

$$J(\theta^i, j, k, l) = j(i, j k, , l) + Jcc(\theta^i(j, k, l), P(j, k, l))$$

Where: (5)

$$Jcc(\theta^i(j,k,l)) = \sum_{i=1}^{S}[-d_{attractant}\exp(-wattractant\sum_{m=1}^{P}(\theta_m - \theta_m^i)2)]$$
$$+$$
$$\sum_{i=1}^{S}[h_{repellant}\exp(-w_{repellant}\sum_{m=1}^{P}(\theta_m - \theta_m^i)^2)] \tag{6}$$

Where
$d_{attractant}$, $w_{attractant}$, $h_{repellant}$, $w_{repellant}$ are different coefficients that should be properly chosen.
$\theta = [\theta_1, \theta_2 \ldots\ldots \theta_D]^T$ is a point in D-dimensional space.
Let $J_{last}=J(i ,j ,k\ l)$ to save this value since we may find a better cost via a run.
Tumble: generate a random vector $\Delta(i) \in R^n$ with each element Δ_m(i), m =1, 2 ...p, a random number on [-1, 1].

$$\theta(i+1, j, k) = \theta(i, j, k) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T}[\Delta(i)]^{0.5}} \tag{7}$$

Move: Let
This results in step size $C(i)$ for bacterium i.
Compute $J(i, j+1, k, l)$
Swim
Let m = 0 (counter for swim length)
While $m < N_s$ (if have not climbed down too long).
Let $m = m+1$;
If $J(i, j, k, l) < J_{last}$ (if doing better)
Let $J_{last}=J(i, j+1, k,l)$ and

$$\theta(i+1,j,k) = \theta(i+1,j,k) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^{T}}[\Delta(i)]^{0.5}}$$

Use this to calculate the new $J(i, j+1, k, l)$ as in (f):

Else if $m = Ns$. This is end of while statement.

Go to next bacterium (i +1) if i ^{1} N (i.e., go to (b))

STEP 5: If $j < N_c$, go to step 3. In this case, continue chemotaxis, since the life of bacteria is not over.

STEP 6: Reproduction:

For a given k and l, and for each i =1, 2....N, let $J^{i}_{health} = \sum_{j=1}^{N_c+1} J(i,j,k,j)$ is the health of bacteria. Sort bacteria and chemotactic parameters C (i) in ascending order of cost.

J_{health} (higher cost means lower health).

The Sr bacteria with highest J_{health} value die and the remaining Sr bacteria with the best value split.

STEP 7: If $k < N_{re}$, got to [STEP 3]. In this case, we have not reached the number of specified reproduction steps, so next generation of the chemotactic loop is started.

STEP 8: Elimination-Dispersal: For i =1, 2 ...N, with probability P_{ed}, *eliminate* and disperse each bacterium, and these results in keeping the number of bacteria constant. To do this, if a bacterium is eliminated, simply disperse one at a random location.

If $l < N_{ed}$, then go to [STEP 3]; otherwise end.

B. Ziegler–Nichols Method of Tuning PID

Another tuning method is formally known as the Ziegler Nichols method, by John G. Ziegler and Nathaniel B. Nichols in the 1944. In this method, the dynamic characteristic of the process are represented by the ultimate gain of a proportional controller and the ultimate period of oscillation of the loop. It usually determines the ultimate gain and period from the actual process by the following procedure [3]:

The integral and derivative modes of the feedback controllers are switched off so as to have a proportional controller.

In the automatic controller the proportional gain (or reduce the proportional band) is increased until the loop oscillates with constant amplitude.

With the help of a time recording of the controlled variable the period of oscillation is measured and recorded as T the ultimate period.

Table 1: Z-N tuning formula

Control Type	K_p	K_i	K_d
P	1/a	-	-
PI	0.9/a	3L	-
PID	1.2/a	2 L	L/2

Where **[**L = Time Delay**,** K = Process Gain**,** T = Ultimate Time Period**,** a = K*L/T].

C. Multi Objective Functions

The objective function considered is based on the error criterion. The performance of a controller has best evaluation in terms of error criterion. A number of such criteria are available. Now, problem should be written as an optimization problem and then be solved. Selecting objective function is the most important part of this optimization problem. Because, choosing different objective functions may completely change the ant's variation state. In optimization problem here, we use error signal. (Between the reference input r (t) and the controlled plant output y (t)).

$$\text{Error}=-(\text{DPref}+\text{BDF}+1/\text{R}*\text{DF}) \qquad (8)$$

In the proposed work, the performance of controllers is evaluated by the following various forms:

- Integral of square error (ISE) $F = \int_0^t e^2(t)dt$

Where, t is the simulation time in which objective function is calculated.

To obtain the PID tuning parameters one usually has to minimize a performance index F.

IV. SIMULATION RESULTS

For the (BFO) algorithm the following parameters [4]:
$s=99$; $P=0.25$; $N_c=4$; $N_{re}=6$; $Ned=2$; $N_s=3$;
$W_{datt}=0.05$; $W_{att}=0.02$; $h_{rep}=0.05$; $W_{rep}=0.05$;
For the (Ziegler) algorithm the following parameters:
$L=0.76$; $T=2.72$; $N=10$;

The best values of the PID parameters with BFO-PID algorithm are shows in Fig. 3.

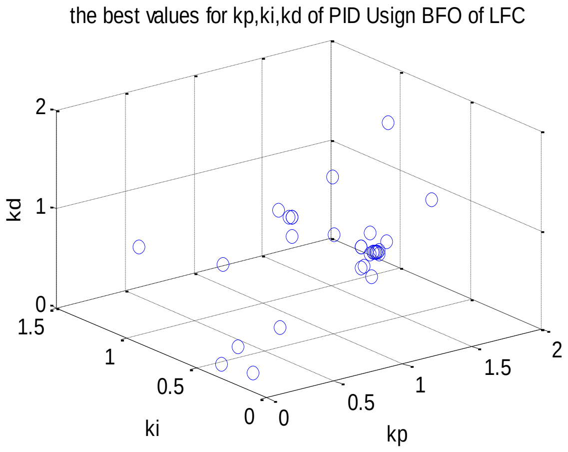

Fig. 3: Best Values for PID Parameters using BFO

Table 2 included the values of PID parameters with Ziegler-PID method, and the PID parameters with BFO.

Table 2: Parameters of PID controller for the LFC

Parameters of PID Type of Controller	Kp	Ki	Kd
LFC with BFO	1	0.8	1
LFC with Ziegler	1.75	1	1.2
AVR with BFO [9]	1	0.65	0.35
AVR with Ziegler [8]	1	0.65	0.35

Table 3: Parameters of AVR [8], [9]

Quantity	Gain	Time Constant
Exciter	1	0.4
Generator	1	1.0
Sensor	1	0.05
Amplifier	9	0.1

Table 4: Parameters of LFC [9]

ΔP_{ref}	K_D	R	H	T_g	T_T	ΔP_L
0	0.8	0.05	5	0.2	0.5	0.2

Case Studies

There are several parameters which affect the dynamic response of a system and they are Case 1: Governor Speed Regulation (R) Case 2: Integral Gain (B) Case 3: Load Disturbance (DPL) Different Case Studies have been carried by varying the above parameters. The variations are depicted by using MATLAB programming for an Isolated Power System with different controllers. The dynamic response for different cases is obtained with ± 50% changes in the parameter values.

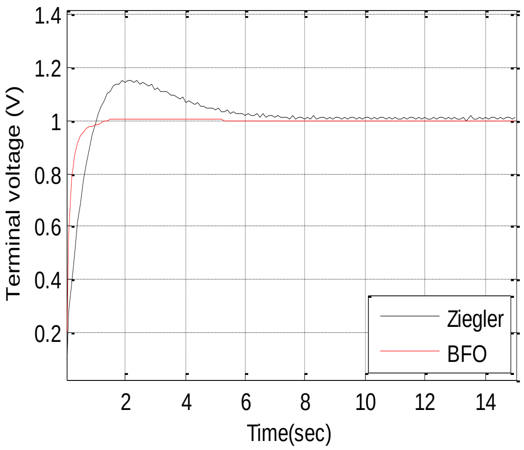

Fig. 4: AVR with BFO and Ziegler based PID controller

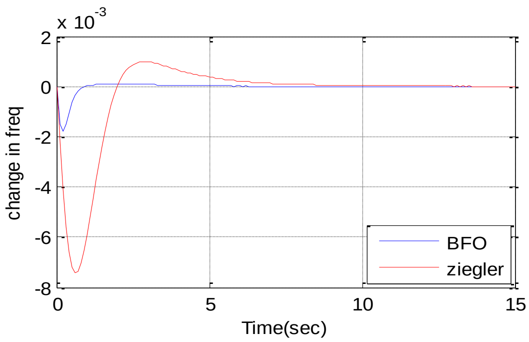

Fig. 5: Frequency response for single Area

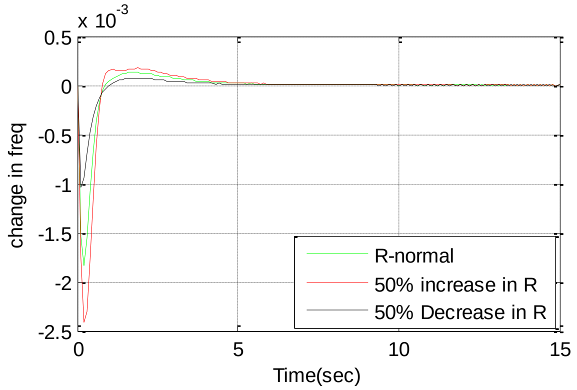

Fig. 6: Frequency response for single Area with variation in Speed Droop Characteristic with BFO

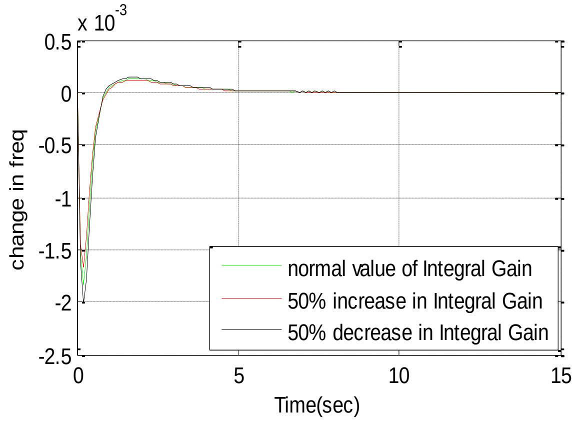

Fig. 7: Frequency response for single Area with BFO with variation in Integral Gain

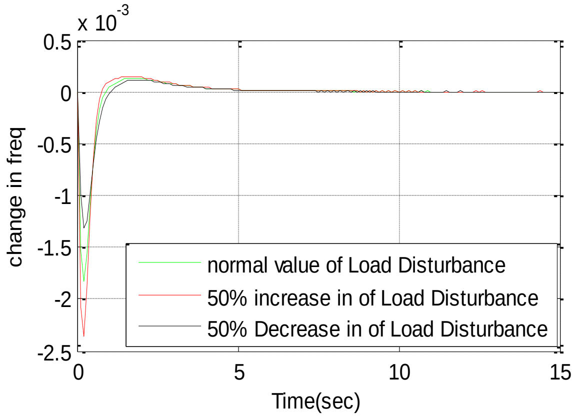

Fig. 8: Frequency response for single Area with BFO with variation in Load Disturbance

The analysis of the Fig. 6, Fig. 7 and Fig. 8 are shown in Table 5.

Table 5: Performance Analysis of BFO based PID Controller for LFC

parameter		**Load Disturbance**		**Integral Gain**		**Speed Regulation**	
		Ts	Mp	Ts	Mp	Ts	Mp
variation	Normal	3.95	1.8e-3	5	1.8e-3	5.2	1.5e-3
	+50%	4	2.3e-3	5.3	2e-3	5	2.5e-3
	-50%	3.94	1.2e-3	4.8	1.6e-3	5.4	1e-3

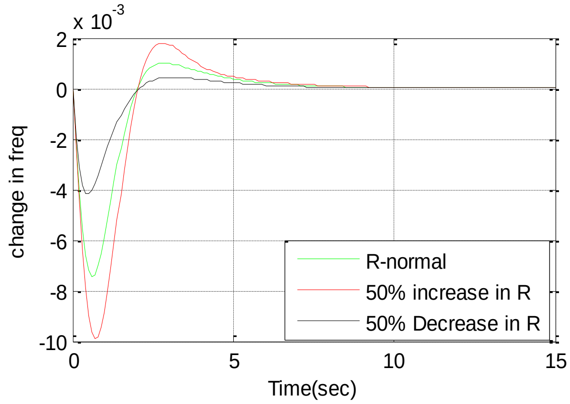

Fig. 9: Frequency response for single Area with Ziegler with variation in Speed Droop Characteristic

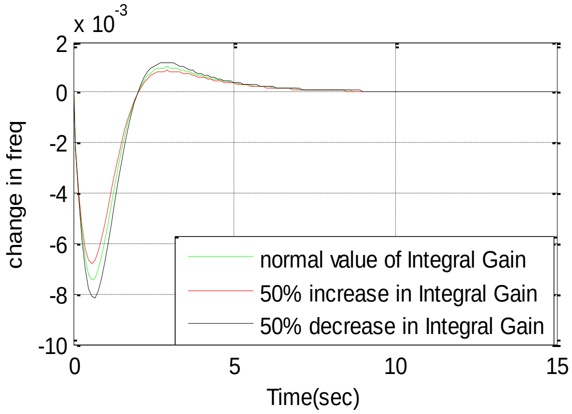

Fig. 10: Frequency response for single Area with Ziegler with variation in Integral Gain

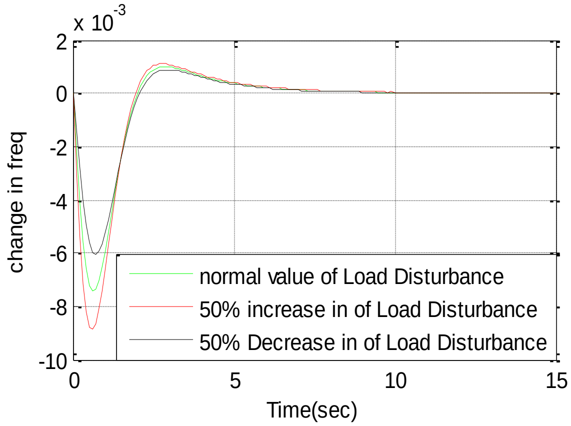

Fig. 11: Frequency response for single Area with Ziegler with variation in Load Disturbance

The analysis of the Fig. 9, Fig. 10 and Fig. 11 are shown in Table 6.

Table 6: Performance Analysis of Ziegler based PID Controller for AVR

parameter		**Load Disturbance**		**Integral Gain**		**Speed Regulation**	
		Ts	Mp	Ts	Mp	Ts	Mp
variation	Normal	7.5	7.5e-3	7.51	7.8e-3	7.5	7.5e-3
	+50%	6.5	10e-3	7.55	6.8e-3	7.51	9e-3
	-50%	7.8	4e-3	7.53	8.1e-3	7.57	6e-3

V. CONCLUSION

The terminal voltage response for a change in load of 0.2 p.u and regulation of 7 (sec) for Ziegler method, there is a high overshoot occurring at 2 seconds, while for (BFO) algorithm, the terminal voltage response regulation of 5 (sec) with very lowest value for overshoot at 2 seconds, see Fig. 4.

In Figure 5, for Ziegler the response for (DF) oscillates for a period of 4.8 seconds before settling down to zero deviation. There is high overshoot error occurring at 3.5 seconds, while for BFO the response for (DF) have low values for overshoot and settling time.

The response for 50% variation in speed regulation of governor for BFO–PID is shown in Fig. 6 from this figure, it can be observed that when R is increased the settling time decreases but frequency deviations increases and vice versa.

In Fig. 9 the response for 50% variation in speed regulation of governor for Ziegler-PID, the same observations for Fig. 6 are seen but the overshoot and settling time have higher values.

The response for 50% variation in Integral Gain is shown in Fig. 7. From this figure, it is clear that when Integral Gain is decreased the settling time decreases and frequency deviations decreases and vice versa.

In Fig. 10 the response for 50% variation in Integral Gain for Ziegler-PID, the same observations for Figure 5 are seen but the overshoot and settling time have higher values.

The response for 50% variation in Load disturbance is shown in Fig. 6. From this figure, it can be observed that when (DP) is increased the frequency deviation increases with no considerable change in settling time.

In Fig. 11 the response for 50% variation in Load disturbance for Ziegler-PID, the same observations for Fig. 8 are seen but the overshoot and settling time have higher values.

Finally, the tuning PID controller with BFO algorithm for LFC, AVR in a single area power system yields overall better performance regarding settling time and overshoot for the response in comparison to the tuning PID controller with Ziegler method.

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