Tuning of PID for LFC and AVR Systems

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Abstract- *Load Frequency Control (LFC) and Automatic Voltage Control (AVR) are one of the most important issues in electric power systems. Although Proportional–Integral (PI) controllers are commonly used for LFC and AVR systems in industry, they are unable to obtain good dynamic behavior in presence of various load changes and operating conditions because the PI controller parameters are usually tuned based on a classical error approaches. This paper present a new approach for tuning the suitable values for the proportional- integral –derivative (PID) controller parameters of load frequency control (LFC) and Automatic Voltage Regulator (AVR) systems using the imperialist competitive algorithm (ICA). This requires designing an accurate and fast controller to preserve the system parameters at nominal value. The basic purpose of system generation control is to balance the system generation against the load and losses in order to be preserved the desire frequency and power interchange between neighboring systems. The proposed method shows the application of ICA method to search optimal PID controller parameters of LFC and AVR systems. The proposed method had different capability like, easy implementation and good computational efficiency. The results were compared with other evolutional algorithm like SFL and PSO and the advantage of proposed method was revealed.*

Keywords: *Load Frequency Control (LFC), Automatic Voltage Control (AVR), Imperialist Competitive Algorithm (ICA), Shuffled Frog Leaping algorithms (SFL).*

I. INTRODUCTION

The issue of controlling the real power output of generating units in response to changes in system frequency and tie-line power inter-change within particular limits and also preserving the system voltage between specific limits are known as load frequency control (LFC) and automatic voltage control (AVR) [1]. AVR and LFC are very important factors in the operation of power systems. In power system, both active and reactive power demands are never steady they continuously change with the rising or falling trend. Steam input to turbo generators(or water input to hydro generators) must therefore, be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency, which may be highly undesirable. 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 function of excitation control is to regulate generator voltage and reactive power output. The desired real power outputs of the individual generating units are determined by the system generation control. 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 [2-4]. The conventional method exhibits relatively poor dynamic performance as evidenced by large overshoot and transient frequency oscillations.[5] These conventional fixed gain controllers based on classical control theories in literature are insufficient because of change in operating points during a daily cycle [6,7].

The main point here is to design and implement PID controller to search the optimal parameter for efficient control of frequency. In this paper a novel approach for tuning the proper values for the proportional-integral-derivative (PID) controller parameters of load frequency control (LFC) and automatic voltage control (AVR) systems of single area power system using the imperialist competitive algorithm (ICA) [8]. The results were compared with other evolutionary algorithms like SFL and PSO and the advantages of proposed Method was revealed. The paper is arranged as follows, Sec 2 express a brief introduction on AVR and LFC systems, Sec. 3 describes the models of the plant including LFC and AVR , Sec. 4 describes the proposed methods, Sec. 5 present the simulation results, the comparative analysis and conclusion are demonstrated in Sec 6 and 7,respectively.

II. An Introduction on AVR and LFC Systems

A. Automatic Voltage regulator (AVR)

to preserve the system voltage between limits by adjusting the excitation of the machines is the application of this control [**9**] . The automatic voltage regulator senses the difference between a rectified voltage derived from the stator voltage and a reference voltage. This error signal is amplified and fed to the excitation circuit. The change of excitation maintains the VAR balance in the network. This method is also referred as Megawatt Volt Amp Reactive (MVAR) control or Reactive-Voltage (QV) control. The simulink models of load frequency controller and automatic voltage as proposed by Hadi Sadaat.[**10**]. The Proportional, Integral and Derivative controller is included in LFC and AVR.

B. Load frequency Control (LFC)

to preserve real power balance in the system through control of system frequency is the application of this control is Whenever the real power demand changes, a frequency change occurs [**9**]. This frequency error is amplified, mixed and changed to a command signal which is sent to turbine governor. The governor operates to restore the balance between the input and output by changing the turbine (P-f) control [**11**]. The models of LFC and AVR with PID controller are shown in Fig.**2** and Fig.**3**, respectively.

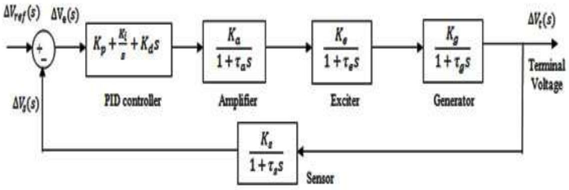

Figure 1. Simulink model of AVR with PID Controller.

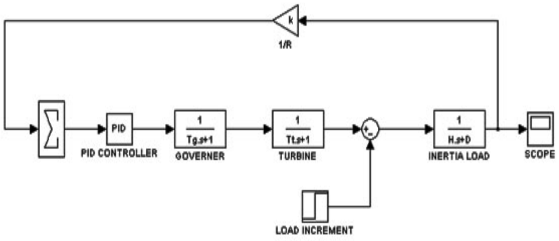

Figure 2. Simulink model of LFC with PID Controller.

III. PID Controller and AVR and LFC models

Today because of their simplicity, PID controllers are being widely used by industries. Its main point here is reduction/omitation of steady state error as well as an improvement in the dynamic response. Reduction/ omitation of steady state error is achieved by adding a pole at the origin with the help of integral controller, by increasing the system type by one. Transient response improvement might be achieved from the action of derivative controller which adds a finite zero to the open loop transfer function. As modeled in this paper, the transfer function of PID controller [12] is:

$$G(s) = K_p + \frac{K_i}{s} + K_d s \qquad (1)$$

IV. Heuristic Optimization Method

A. Imperialist Competitive Algorithm (ICA)

The proposed algorithm , like other evolutionary ones, starts with an initial population (countries in the world). Some of the best countries in the population are selected to be the imperialists and the rest form the colonies of these imperialists. All the colonies of initial population are divided among the mentioned imperialists based on their power. The power of an empire which is the counterpart of the fitness value in GA, is inversely proportional to its cost [**8**]. After dividing all colonies among imperialists, these colonies start moving toward their imperialist country. The total power of an empire depends on both the power of the imperialist country and the power of its colonies. We modeled this fact by defining the total power of an empire by the power of imperialist country plus a percentage of mean power of its colonies. Then the imperialistic competition begins among all the empires. Any empire that is not able to succeed in this competition and can't increase its power(or at least prevent decreasing its power) will be eliminated from the competition. The imperialistic competition will gradually result in an increase in the power of powerful empires and a decrease in the power of weaker ones. Weak empires will lose their power and ultimately they will collapse. The movement of colonies toward their relevant imperialists along with competition among empires and also the collapse mechanism will hopefully cause all the countries to converge to a state in which there exist just one empire in the world and all the other countries are colonies of that empire. In this ideal new world colonies, have the same position and power as the imperialist. The flow chart of the proposed method has been shown in Fig.**4**.

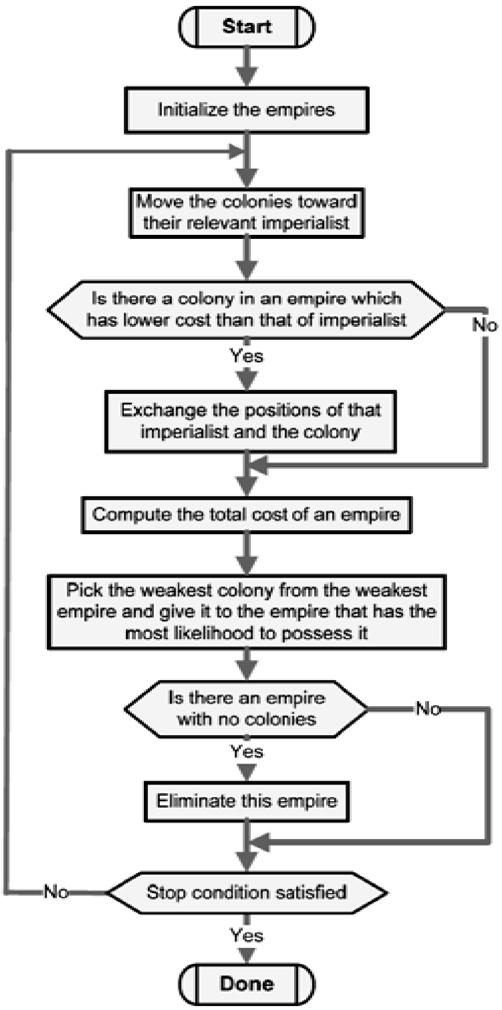

Figure 3. ICA flow chart.

B. Shuffled Frog Leaping Algorithm

*SFLA is a meta heuristic optimization method that mimics the memetic evolution of a group of frogs when seeking for the location having maximum amount of available food. The algorithm contains elements of local search and global information exchange [**13**]. The SFLA involves a population of possible solutions defined by a set of virtual frogs partitioned into subsets referred to as memeplexes. Within each memeplex, the individual frog holds ideas that can be influenced by the ideas of other frogs, and the ideas can evolve through a process of memetic evolution. using a particle swarm optimization like method The SFLA simultaneously performs an independent local search in each memeplex. To ensure global exploration, after a defined number of memeplex evolution steps (i.e. local search iterations), the virtual frogs are shuffled and reorganized into new memeplexes in a technique similar to that used in the shuffled complex evolution algorithm. In addition, to provide the opportunity for random generation of improved information, if the local search cannot find better solutions random virtual frogs are generated and substituted in the population. The local searches and the shuffling processes continue until defined convergence criteria are satisfied. The flowchart of the SFLA is illustrated in fig. **4**. The SFLA is described in details as follows. First, an initial population of N frogs* $P = \{X_1, X_2, \ldots, X_N\}$ *is created randomly. For S-dimensional problems (S variables), the position of a frog* i^{th} *in the search space is represented as* $X_i = [x_1, x_2, \ldots, x_{is}]^T$.

Afterwards, the frogs are sorted in a descending order according to their fitness. Then, the entire population is divided into m memeplexes, each containing n frogs (i.e. N=m× n), in such a way that the first frog goes to the first memeplex, the second frog goes to the second memeplex, the m^{th} *frog goes to the* m^{th} *memeplex, and the* $(m+1)^{th}$ *frog goes back to the first memeplex, etc. Let* M_k *is the set of frogs in the* k^{th} *memeplex, this dividing process can be described by the following expression:*

$$M_k = \{X_{k+m(l-1)} \in P \mid 1 \le k \le n\}, (1 \le k \le m). \quad (2)$$

Within each memeplex, the frogs with the best and the worst fitness are identified as X_b *and* X^w, *respectively. Also, the frog with the global best fitness is identified as* X^g. *During memeplex evolution, the worst frog* X^w *leaps toward the best frog* X_b. *According to the original frog leaping rule, the position of the worst frog is updated as follows:*

$$D = r.(X_b - X_w) \quad (3)$$

$$X_w(new) = X_w + D, (\|D\| < D_{max}), \quad (4)$$

*Where r is a random number between **0** and **1**; and* D_{max} *is the maximum allowed change of frog's position in one jump.*

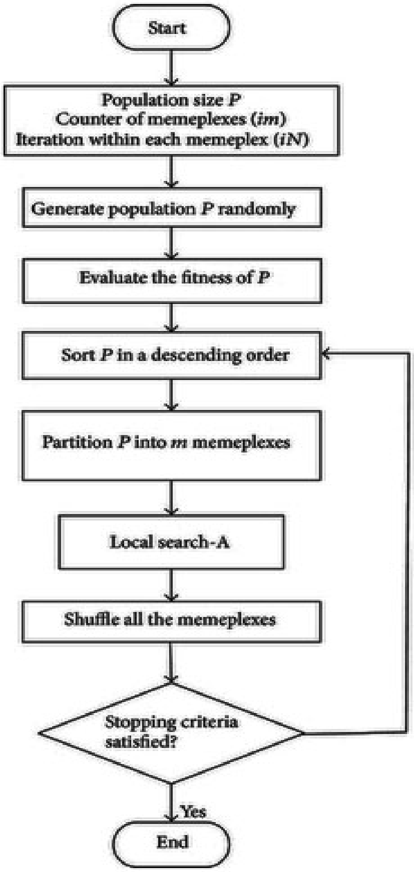

Figure 4. SFL flow chart.

V. Simulation Results

A. Simulation Parameters

*To verify the efficiency of proposed algorithms, The ICA and SFL algorithms are used to search an optimal parameter set containing K_p, K_i and K_d. The optimum values generated by the algorithms are stored in work space and shared with the LFC and AVR Simulink models. The parameters used for tuning the SFL and ICA algorithms and Simulink models are tabulated in table.**1**.*

TABLE.1. AVR & LFC SIMULATION PARAMETERS

	Simulation Parameters
LFC	Tg = ۰.۰۸,Tt = ۰.۵,H = ۱۰,D = ۱,R=۱۰,۲۰,Kg = ۱ ΔPL=۰.۱,۰.۲
AVR	Ke = ۱,Ka = ۱۰,Ks = ۱,Kg=۰.۷, Te = ۰.٤,Ta = ۰.۱,Ts = ۰.۰۱,

*The MATLAB-SIMULINK based block diagram of LFC and AVR system along with intelligent PID controller are shown in Fig **5&6**, respectively.*

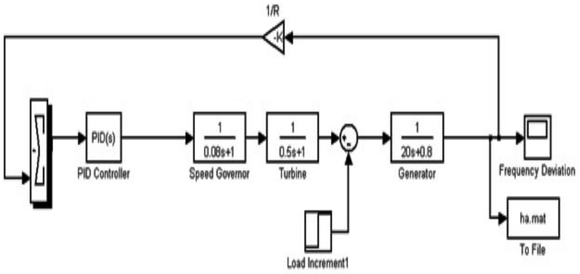

Figure 5. MATLAB-SIMULINK based block diagram of LFC system along with intelligent PID controller.

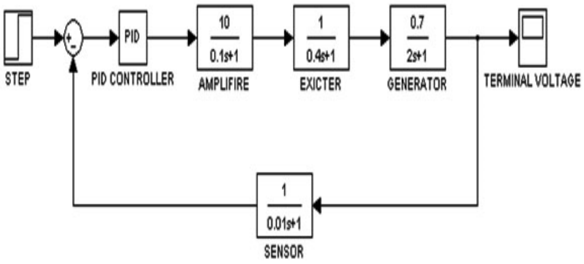

Figure 6. MATLAB-SIMULINK based block diagram of AVR system along with intelligent PID controller.

The ICA and SFL algorithm were simulated and tested by regulating the various parameters. The optimum parameter values that achieved better solution are reported in continuance.

B. Simulation Results

The simulations were done using the simulink package available in MATLAB 9. The LFC and AVR are simulated using SFL and ICA algorithms, for different values of load and regulation. The simulation time was set to 20 seconds for both, LFC and AVR in each case. The terminal voltage response for regulating PID parameters by using SFL and ICA are shown in Figs 7 & 8 and also the convergence profile of ICA and SFL are illustrate in Figs 9 & 10.

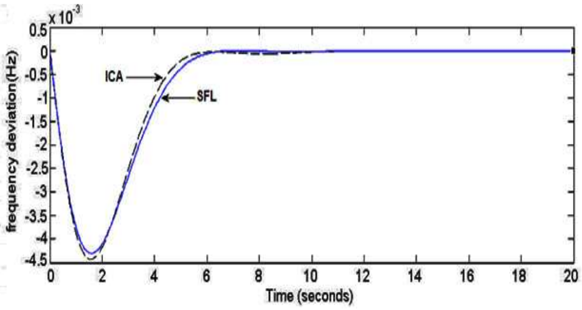

Figure 7. LFC with SFL and ICA for R=10 andΔ PL=0.1.

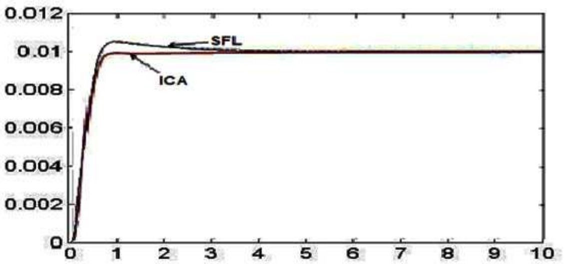

Figure 8. AVR with SFL and ICA for Kg=0.7and Tg=2.

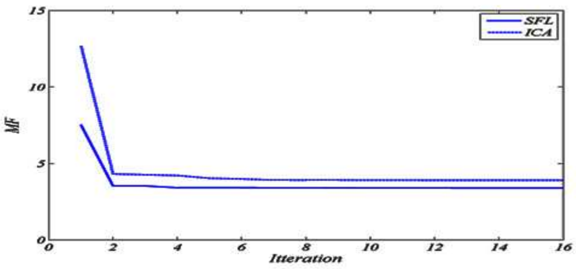

Figure 9. Convergence profile of SFL and ICA for AVR system.

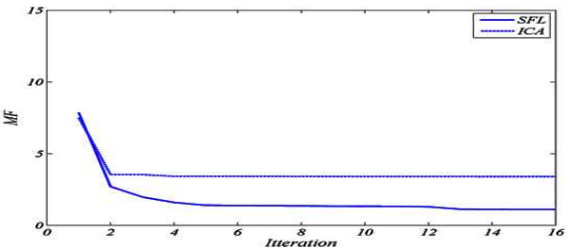

Figure 10. Convergence profile of SFL and ICA for LFC system.

It is observed that the settling time of AVR with ICA based PID controller is 1.89 and with SFL based PID controller is 3.6 seconds and there is no transient peak overshoot. As seen from the result, the ICA-PID controller could create very perfect step response of the terminal voltage in AVR system. Similarly the LFC model was simulated with different loads and regulations. It is inferred that the settling time of LFC with ICA based PID controller is 4.4878 seconds and with SFL based PID controller is 4.7701 seconds and there is no transient peak overshoot. These results clearly indicate that the proposed controller can search optimal PID controller parameters quickly and efficiently.

The speed governor system should be operated within the restricted control range of feedback gains due to the system instability. So, higher the value of load 'ΔPL' for a small 'R' value will introduce oscillations into the system. Hence ΔPL and R are selected as shown in Table 3 - 5 to obtain optimum results in terms of settling time, overshoot and oscillations. Increasing the load ΔPL into higher values will experience large overshoot and settling time.

TABLE .3. PERFORMANCE ANALYSIS OF ICA BASED PID CONTROLLER FOR LFC SYSTEM

Parameters	**R1=10**		**R1=20**	
	ΔPL=0.1	ΔPL=0.1	ΔPL=0.1	ΔPL=0.1
Settling Time(sec)	4.4878	4.5714	6.1231	6.2241
Overshoot(Hz)	0.0000	0.001	0.0000	0.0021
Oscillation(Hz)	0 to0.1	0 to0.001	0 to0.1	0 to 0.0021

TABLE .4. PERFORMANCE ANALYSIS OF SFL BASED PID CONTROLLER FOR LFC SYSTEM

Parameters	**R1=10**		**R1=20**	
	ΔPL=0.1	ΔPL=0.1	ΔPL=0.1	ΔPL=0.1
Settling Time(sec)	4.77	4.93	6.96	7.14
Overshoot(Hz)	0.0000	0.0035	0.0001	0.005
Oscillation(Hz)	0 to0.1	0 to 0.0035	0 to0.1	0 to 0.005

TABLE .5. PERFORMANCE ANALYSIS OF SFL BASED PID CONTROLLER FOR AVR SYSTEM

K_g	τ_g	*Algorithm*	o_{sh}	t_{st}	*Max_dv*
0.7	**1**	**ICA**	**0.0000**	**0.87**	**0.0163**
		SFL	**0.0000**	**1.33**	**0.013**
	1.4	**ICA**	**0.0000**	**1.9**	**0.0175**
		SFL	**0.0002**	**0.5547**	**0.017**
	2	**ICA**	**0.0001**	**1.89**	**0.0047**
		SFL	**0.0002**	**3.6**	**0.01**
1	**1**	**ICA**	**0.0001**	**0.92**	**0.0225**
		SFL	**0.0001**	**0.888**	**0.0196**
	1.4	**ICA**	**0.0000**	**0.9938**	**0.0205**
		SFL	**0.0001**	**0.68**	**0.019**
	2	**ICA**	**0.0001**	**1.2**	**0.0142**
		SFL	**0.0005**	**1.38**	**0.013**

VI. Comparative Analysis

A comparison on dynamic performances between various controllers for LFC and AVR are represented in table 6 & 7. The settling time, oscillations and overshoot are compared for a load change of 0.10 and regulation of 10. It is observed from the table that the designed ICA-PID controller exhibits relatively good performance with very less settling time, overshoot and transient oscillations [9].

TABLE. 6. PERFORMANCE COMPARISON OF ICA BASED AVR WITH DIFFERENT METHOD

Fixed Parameters: Ka=10 , Ta=0.1 , Ke=1, Te=0.1, kg=1 ,Tg =1, Kr=1 , Tr=0.05			
Methods	**Setting time(sec)**	**Overshot(Hz)**	**Oscillation(Hz)**
PSO	8.82	0	0 to 0.1
SFL	4.34	0	0 to 0.1
ICA	2.37	0	0 to 0.1

TABLE. 7. PERFORMANCE COMPARISON OF ICA BASED LFC WITH DIFFERENT METHOD

Fixed Parameters: $T_g=0.2$, $T_T=0.5$, $k_g=1$, $H=5$, $D=0.8$			
Methods	**Setting time(sec)**	**Overshot(Hz)**	**Oscillation(Hz)**
PSO	8.2	0.0014	0 to 0.0014
SFL	5.79	0	0 to 0.1
ICA	4.94	0	0 to 0.1

The bar chart in the Fig.11 shows the comparative analysis made between different controllers like PSO, SFL and ICA. Comparison has been made with respect to settling time, oscillations and overshoot. When an electrical load change occurs, the turbine-generator rotor accelerates or decelerates, and frequency undergoes a transient disturbance. The controller should not allow transient oscillations or overshoot, which in-turn trips the under-frequency relay connected in the system. Oscillations, settling time and overshoot are all related: change in one will cause a change in others. Hence, it is important that the designed controller must be efficient in selecting the optimum gains in order to achieve better results.

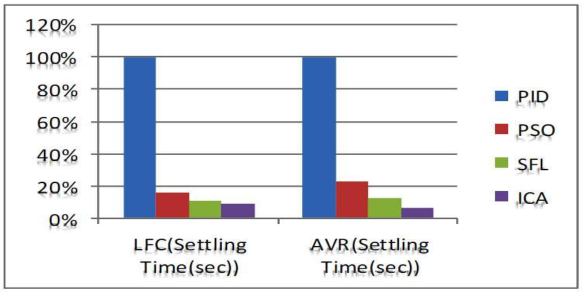

Fig.11 Comparative Analysis of Different controllers with ICA based controller for LFC and AVR

VII. Conclusion

The quality of the power supply is determined by the constancy of frequency and voltage. Minimum frequency deviation and good terminal voltage response are the characteristics of a reliable power supply. The conventional controllers used for this problem have large settling time, overshoot and oscillations. Hence, when evolutionary algorithms are applied to control system problems, their typical characteristics show a faster and smoother response. An intelligent technique has been proposed for combined voltage and frequency control in an isolated power system. The proposed ICA-PID controller provides a satisfactory stability between frequency overshoot and transient oscillations with zero steady state error. The simulation results illustrate the effectiveness of the proposed controller under changing loads and regulations.

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