International Journal of Scientific Research in Computer Science, Engineering and Information Technology
© 2020 IJSRCSEIT | Volume 6 | Issue 3 | ISSN : 2456-3307
DOI : https://doi.org/10.32628/CSEIT2063186

A Comparative Study on Applying Bio-Inspired Optimization Techniques for Designing an Effective Fuzzy Logic Controller

Thi-Mai-Phuong Dao
Department of Electrical Engineering Technology, Hanoi University of Industry, Hanoi, Vietnam

ABSTRACT

A fuzzy logic – based controller has been considered to be a feasible and effective control strategy for a numerous number of complex control problems. To design such an effective fuzzy logic controller, it is necessary to determine proper scaling factors which significantly affect the control quality of the system. This study concentrates on applying well-known bio-inspired optimization methods, i.e. PSO, GA and DE, to deal with this determination. A typical PD-type fuzzy logic architecture is chosen to be a traditionally intelligent controller. Then, the bio-inspired optimization methods will be applied for such a fuzzy logic controller to optimally determine its three scaling factors. The simulation results provided for the load – frequency control issue of a two-area interconnected hydropower system verifies the applicability of the proposed control strategy. Comparative simulations are also to decide which is the best choice of the bio-inspired optimization methods in the determination of significant scaling factors regarding the PD-type fuzzy logic controller.

Keywords: Bio-Inspired Optimization Techniques, PD-type fuzzy logic, PSO, GA, DE, LFC.

I. INTRODUCTION

A fuzzy logic technique -based control strategy is one of the most successful applications of fuzzy logic theory. The fuzzy logic-based control is highly suitable for designing effective controllers of complex control systems. It is clear a fuzzy logic – based control system may not require whole defined parameters, but it should be dependent on the knowledge of experts [1-4].

Theoretically, the following three issues need to be considered when designing a fuzzy logic – based controller [4]:

(i) Establishment of the suitable membership functions is implemented to change a set of crisp values into fuzzy logic domain;

(ii) It is necessary to decide a fuzzy logic rule base to process and evaluate control rules based on experiences of experts;

(iii) To convert a set of fuzzy logic values into the corresponding crisp set to make the control signal for the system, a defuzzification process is activated.

For a designed fuzzy logic architecture, one of the most significant implementations is the determination of the scaling factors which quite affects the control quality of the system. This is highly meaningful in a typical fuzzy logic-based controller such as PI- or PD-type fuzzy logic regulator in which there are theoretically three scaling factors: two for the inputs and one for the output. There also exist a number of methods to determine these scaling factors. One of the most efficient methods is to apply bio-inspired optimization technologies such as GA (genetic algorithm), PSO (particle swarm optimization) and DE (differential evolutionary). These methods have been testified to be much better than the other counterparts when solving control problems.

This paper presents a comparative study about the effectiveness of the above methods in determining scaling factors of a PD-type fuzzy logic controller. Specifically, the study results will be applied for a typical control problem example: the load-frequency control of a two-area interconnected hydropower system. It is a fact that the LFC against continuous load changes is one of the most vital control problem in power system operation and stability [5-8]. When applying the fuzzy logic-based control strategies, it is demonstrated that the results are much better than those of the other conventional control schemes, i.e. PI and PID regulators [8-9].

This study is structured as follows. Section II provides an overview of the PD-type fuzzy logic controller which needs to add three scaling factors as mentioned earlier. Section III then presents the procedure to apply bio-inspired optimization methods to determine such scaling factors. Next, Section IV provides simulation processes to verify the effectiveness of the proposed control strategies. The last section will consider conclusions and discussion raised from this study.

II. AN INTRODUCTION TO PD-BASED FUZZY LOGIC CONTROLLERS

It should be obvious that the PD – based fuzzy logic controller is one of the most popular intelligent control strategies which is able to obtain good control quality. The basic type of a PD – type fuzzy logic strategy applied to a control plant is presented in Figure 1. The output of the given controller u(t) is related to the control signal of the control plant by the proportional factor *Gu*. In most cases, each fuzzy logic controller is an input/output static nonlinear mapping, therefore the principle of such a fuzzy logic architecture could be indicated as follows [4]:

$$u(t) = G_u.g_u\left[G_e.g_e.e(\tau) + G_{ce}.g_{ce}.ce(\tau)\right] \quad (1)$$

Where g_e, g_{ce} and g_u are internal gains for the fuzzy logic inference. Meanwhile, G_e, G_{ce} and G_u are external gains, which can be tuned to design such an effective fuzzy logic controller. In Laplace domain, the equation (1) can be expressed as:

$$U(s) = (K_1 + K_2.s)E(s) \quad (2)$$

Where: $\begin{cases} K_1 = G_u.g_u G_e.g_e \\ K_2 = G_u.g_u G_{ce}.g_{ce} \end{cases}$

The above two factors, K_1 and K_2, correspond to the proportional and derivative gains of a traditional PD regulator. Similar to such a PD regulator, these two factors strongly affect control performances of a control system and therefore, they should be successfully tuned when designing an efficient PD-type fuzzy logic controller.

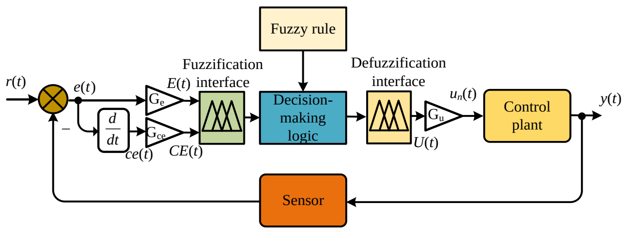


Figure 1: A PD-type fuzzy logic model – the typical principle diagram

The PD-type fuzzy logic controller used in this study has two inputs and one output. The typical configuration of such a fuzzy logic controller is depicted in Figure 2. It is noted that the two inputs include error signal ***e*** and the derivative of error ***ce***. The membership functions applied for inputs and output are presented in Figure 3. Here, triangular membership functions are employed because they are linear and popular in designing fuzzy logic-based controllers for control systems in practice. The 3D surface describing the corresponding fuzzy logic rule base is shown in Figure 4. The next section will present a procedure to determine three scaling factors, thereby further improve control quality of such a fuzzy logic controller.

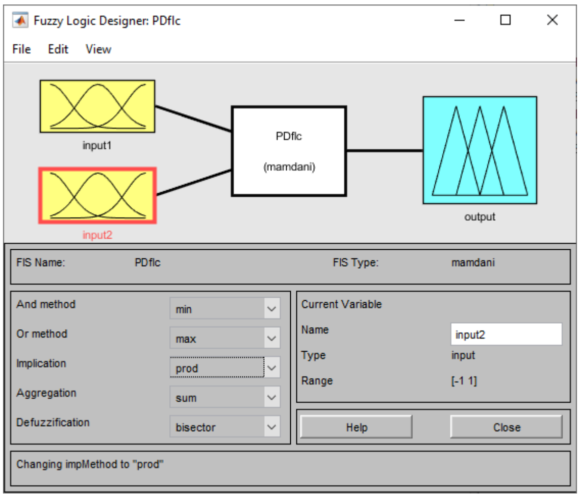


Figure 2: PD-type fuzzy logic model – the 2-input – 1-output configuration

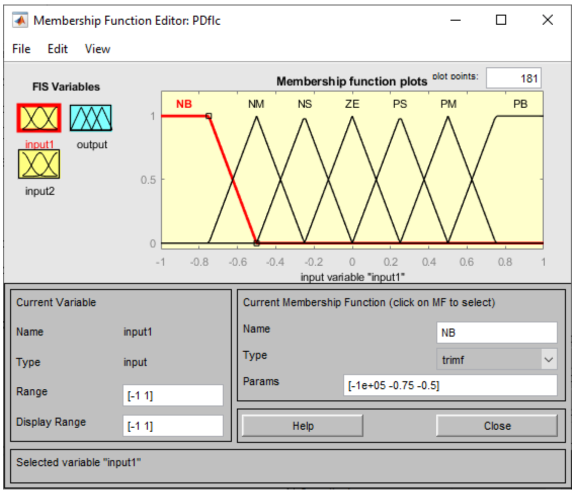


Figure 3: PD-type fuzzy logic model – membership functions

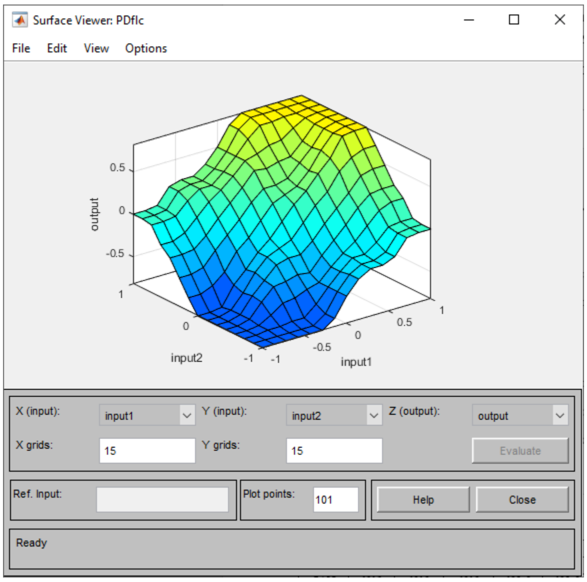


Figure 4: PD-type fuzzy logic model – a 3D surface

III.DESIGN OF BIO-INSPIRED OPTIMIZATION TECHNIQUES-BASED PD-TYPE FUZZY LOGIC CONTROLLER

The bio-inspired optimization techniques such as PSO, GA and DE have been widely applied for determining meaningful parameters of control systems [10-12]. From a huge number of existed reports, it is clearly found that these optimization techniques are effectively used to tune parameters which strongly affect control performances of a control system applying the bio-inspired optimization techniques – based control strategies. In this section, these optimization methods will be employed to optimize three scaling factors as mentioned in the previous section. It is noted that the PD-type fuzzy logic topology shown in Figure 1 will be employed as the core of the proposed control strategy.

The proposed block control diagram is depicted in Figure 5. Obviously, the bio-inspired optimization techniques with efficient mechanisms are able to successfully determine three updating factors, namely k_e, k_{ce} and k_u, thereby the three scaling factors of the PD-type fuzzy logic controller can be optimally derived. Typically, such three updating factors are multiplied by certain scaling factors of the PD-type fuzzy logic controller. Then, they are able to change the values of three scaling factors when calculating two coefficients of the PD-type fuzzy logic controller as indicated in (2).

According to the principle of the proposed control scheme as shown in Figure 5, the bio-inspired techniques will be applied to optimally determine the three updating factors. The most important point when applying the bio-inspired algorithms is to establish a suitable fitness or objective function. Such a candidate of objective functions can be selected as given below:

$$J = \int_0^T |e(t)|\,dt = \int_0^T |r(t) - y(t)|\,dt \to \min \qquad (3)$$

The effectiveness of the proposed control strategies when applying the objective function indicated in (3) will be testified in the next section.

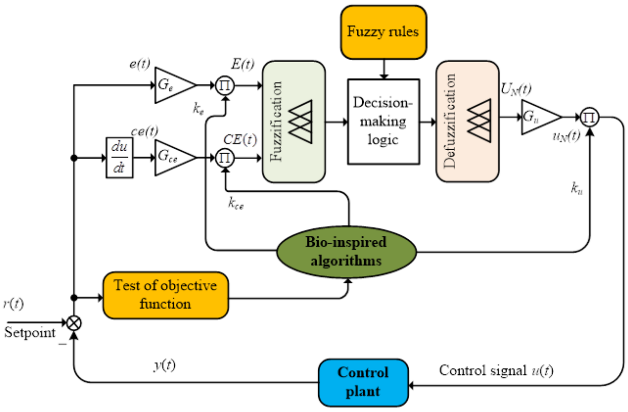


Figure 5 : The proposed bio-inspired-based PD – type fuzzy logic control strategy

IV. AN EVALUATION OF SIMULATION RESULTS

Consider an interconnected hydropower system consisting of two control-areas. In fact, each control-area is defined as a typical hydropower plant which is connected to the other one by a tie-line. Load-frequency control (LFC) is one of the most important control problems in power system operation and stability. In principle, the LFC strategy is mainly to maintain both the system frequency and tie-line power flow at desired values.

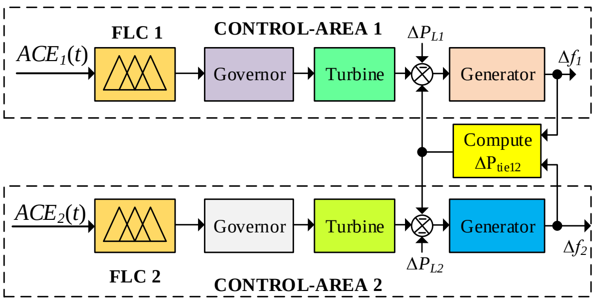


Figure 6: Block diagram of a two-area interconnected hydropower system

The diagram presenting the working principle of a LFC control system for a two-area interconnected hydroelectric power grid is shown in Figure 6. When loads continuously change in each area, it is clear the system frequency and tie-line power flow area are also deviated from their nominal values. The tie-line power flow change can be calculated from the frequency deviations as follows [5]:

$$\Delta P_{tie,1}(t) = \int_0^t 2\pi.T_{12}\left(\Delta f_1(\tau) - \Delta f_2(\tau)\right)d\tau \qquad (4)$$

Where T_{12} is a synchronizing factor of the power network. The control signal which is taken to each fuzzy logic controller is [5]:

$$ACE_k(t) = \Delta P_{tie,k}(t) + B_k.\Delta f_k(t), \quad k = 1,2 \qquad (5)$$

Using the above control signals as the inputs of the proposed fuzzy logic controller, it is clear the oscillations of both the frequency deviation and tie-line power change are able to be successfully eliminated. That is the technical control goal of the LFC strategy.

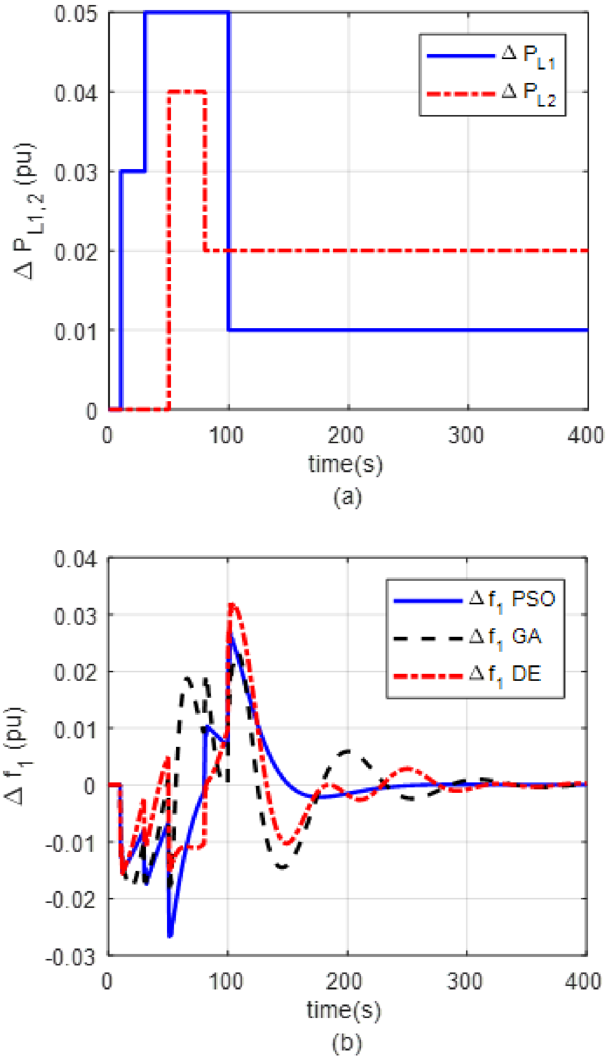
Now, consider a typical simulation case to testify the effectiveness of the proposed control scheme for the LFC problem of an interconnected hydropower system. In this scenario, a two – area interconnected hydropower network applying the PSO-based PD-like fuzzy logic controller applying different evolutionary optimization techniques, i.e. PSO, GA and DE.

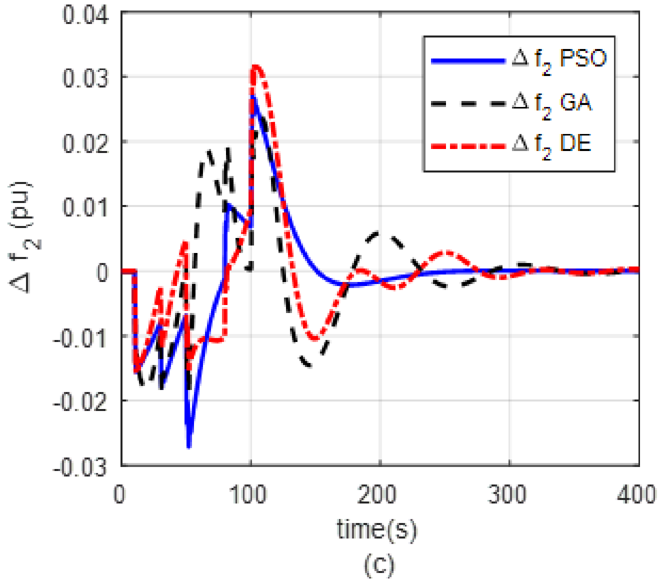
The simulation parameters are given in [6-8]. A candidate of the fitness functions selected for three optimization mechanisms is:

$$J = \int_0^\tau \left(|\Delta f_1(t)| + |\Delta f_2(t)| + |\Delta P_{tie,12}(t)|\right)dt \rightarrow \min \qquad (6)$$

where τ denotes the simulation time. In this section, τ is set to be 400 seconds.

The simulation results are shown in Figure 7 and Figure 8. It is clear from these figures two continuous load variation scenarios are embedded in the two-area power system (see Figure 7(a) and Figure 8(a)). Figures 7(b)-(d) describe the dynamic fluctuations of frequency deviations and tie-line power flow for each generation area. It should be obvious that three bio-inspired –based fuzzy logic controllers are able to eliminate these fluctuations, thereby they can bring the system back to the stability after the continuous load changes. To evaluate the different efficiency between them, Figure 8(b) shows the objective function given in (9) for these controllers. As shown in Figure 8(b), all objective functions are driven to be zero when time is increasing. Moreover, it is clear the PSO-based fuzzy logic controller obtained better control performance compared to the other two counterparts. Therefore, it should be the feasible control strategy for solving the LFC problem of an interconnected hydropower grid.





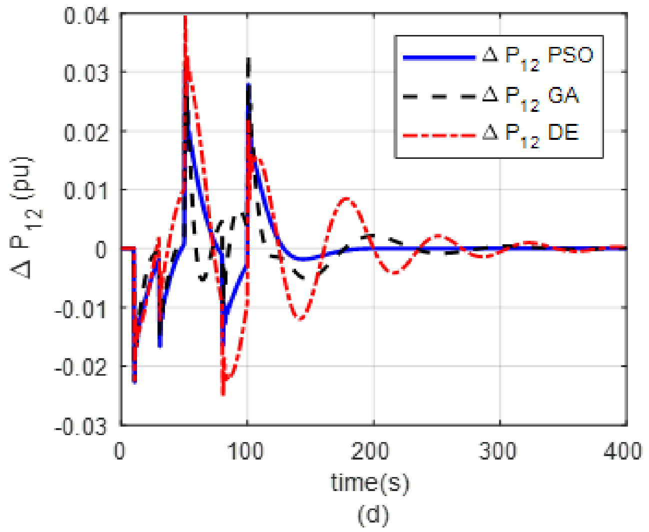


Figure 7. Dynamic responses of the two-area hydropower system in case of applying the proposed PD-like fuzzy logic controller

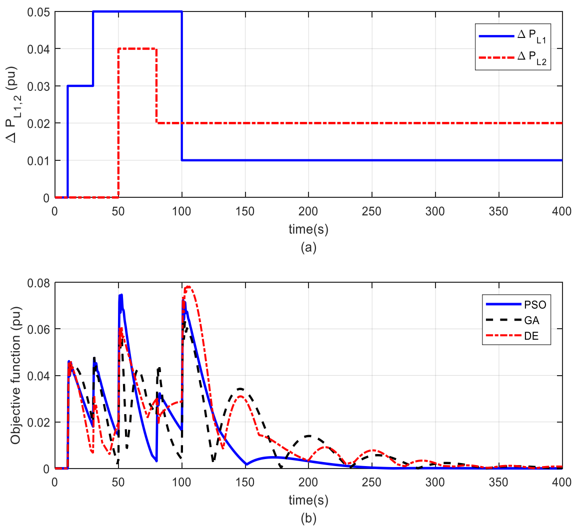


Figure 8. A comparison of the objective functions for three bio-inspired optimization techniques

V. CONCLUSION, DISCUSSION AND FUTURE WORK

This paper has fulfilled a comparative study on designing the PD-type fuzzy logic controller applying different bio-inspired optimization techniques, namely PSO, GA and DE. The designing procedure of these optimization mechanisms is to focus on the determination of three updating factors related to three scaling factors of such a PD-type fuzzy logic controller. Through control simulation results on a typical two-area hydropower system having the LFC, it is found that the PSO – based PD-type fuzzy logic controller obtained better control performances in comparison with the other two bio-inspired controllers. For future work, the PSO algorithm will also be applied to determine more parameters of the PD-type fuzzy logic controller, such as membership functions and rule base to design an optimal and robust controller in dealing with a nonlinear and complex control system.

VI. ACKNOWLEDGMENT

The author would like to thank **Dr. Khoat Nguyen** from Electric Power University in Hanoi, Vietnam for his significant discussions on the GA algorithms.

VII. REFERENCES

[1]. Fuller R., Giove S., Masulli F. Fuzzy logic and applications. 12th International Workshop, WILF 2018, Italy, September 2018.

[2]. Castillo O., Melin P. Hybrid intelligent systems in control, pattern recognition and medicine. Springer 2020.

[3]. Ying B., Hanqi Z., Dali W. Advanced fuzzy logic technologies in industrial applications. Springer, 2006.

[4]. Guanrong C., Trung T. P. Introduction to fuzzy sets, fuzzy logic, and fuzzy control systems. CRC Press, 2019.

[5]. Kundur P. Power system stability and control. New York, USA: McGraw-Hill, 1994.

[6]. Leonard L. Grigsby. Power system stability and control. 3rd edition, CRC Press, 2016.

[7]. Thi-Mai-Phuong D. Modelling and control of a hydropower plant in dealing with the speed control problem of synchronous generators. International Journal of Scientific Research in Computer Science, Engineering and Information Technology, 2020; 6(2): 258-264.

[8]. Nguyen N.K., Huang Q., Dao T.M.P. An investigation of intelligent controllers based on fuzzy logic and artificial neural network for power system frequency maintenance. Turkish Journal of Electrical Engineering and Computer Science. 2016; 24(4): 2909-2893.

[9]. Kocaarslan, I., Çam, E. Fuzzy logic controller in interconnected electrical power systems for load-frequency control. Int. J. Electr. Power Energy Syst. 2005, 27, 542-549.

[10]. Maude J. B., Panos M. P., Javier S. S. Computational intelligent and optimization methods for control engineering. Springer, 2019.

[11]. Gao X. Z. et al. Bio-inspired optimization methods of fuzzy logic controllers applied to linear plants. Soft Computing in Industrial Applications, AISC 75: 245 – 252.
[12]. Pelusi, D. Optimization of a fuzzy logic controller using genetic algorithms. Intelligent Human-Machine Systems and Cybernetics (IHMSC) International Conference, 2: 143-146.

Author Profile

Dao Thi Mai Phuong received Msc degree in *Automation and Control* at Hanoi University of Science and Technology, in 2010. She received the PhD degree in *Control Science and Engineering* at Hunan University, in 2017. She is working as a lecturer and researcher at Hanoi University of Industry in Hanoi, Vietnam. Her research interests include smart grids, intelligent control, advanced control theory and applications.

Cite this article as :

Thi-Mai-Phuong Dao, "A Comparative Study on Applying Bio-Inspired Optimization Techniques for Designing an Effective Fuzzy Logic Controller ", International Journal of Scientific Research in Computer Science, Engineering and Information Technology (IJSRCSEIT), ISSN : 2456-3307, Volume 6, Issue 3, pp. 749-755, May-June-2020. Available at doi : https://doi.org/10.32628/CSEIT2063186
Journal URL : http://ijsrcseit.com/CSEIT2063186